Synergistic Interactions of K-16 Partnership Work, Research, and Teaching in Higher Education Science Faculty Members

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Abstract

Work between higher education faculty and K-12 schools and teachers is fairly common, sometimes initiated by schools, sometimes designed by science professors under the aegis of *broader impact* as mandated by the National Science Foundation's research grant solicitations and most recently mandated by their Math Science Partnership (MSP) solicitations. While most such work is focused on K-12 impact, this series of case studies examines the bidirectional, or "push-back" effects of such work on the professors' teaching and on their scientific research. The study is informed by and contributes to Ernest Boyer's (1990) discussion of scholarship in academia. Five of the subjects of this study were engaged in an MSP project and one professor's work evolved from outreach as part of other research grants. All subjects formed partnerships characterized by mutual commitment, growth, respect and trust. The findings variously and powerfully illustrate interactions between: partnership work and the professors' teaching, partnership work and research, and teaching and research. It also uncovers factors impacting these interactions.

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The study examines interactions between a triad of components of professors' academic work: teaching, research and *application,* described by Boyer (1990) as that particular kind of service that focuses on the use of knowledge for the public good. The paper focuses on a series of case studies of four professors and one non-academic scientist-educator all of whom were active in secondary science outreach work through a Math Science Partnership (MSP) program funded through a National Science Foundation (NSF) grant. In addition, the study includes a fifth professor who does a great deal of secondary school partnership work in conjunction with many research grants, none of which are MSPs.

The hypothesis driving this study is that K-16 partnerships involving rigorous scholarly work fall within the definition of application in Boyer's model and may have palpable transformative effects on professors' teaching, and perhaps either directly or indirectly on their disciplinary knowledge and ultimately their research. The research questions are: *Are there interactive effects of partnership work on professors' academic lives? If so, how are they manifested and what factors contribute to, constrain or otherwise shape them? In addition, could such work be described as rigorous and scholarly?* To answer this, a series of case studies was undertaken to examine possible bidirectional impacts between K-16 partnership work and teaching, K-16 partnership work and research, and teaching and research.

This study focuses on the impact of such partnerships on the professors themselves, and while not a primary focus of the study, in some cases, impact on the professors' institutions is implied. While most K-16 partnerships are formed to benefit K-12 schooling, this study explores neither the impact of these partnerships on K-12 students, teachers and schools nor the public

perception of academia. Rather, its focus is solely on the interactions of partnership work within the scholarly lives of the professors who engage in it.

Background

The goal of the NSF's MSP program is increased K-12 student achievement in challenging mathematics and science courses. To this end, NSF charged the MSP programs to focus on the development of an enlarged current and future pool of highly qualified and diverse mathematics and science teachers. To achieve this teacher workforce, MSP programs are designed to enlist professors who are experts in their science, technology, engineering and/or mathematics (STEM) disciplines to work in a variety of ways with practicing and pre-service K-12 teachers. NSFs theory of action is that the professors act as "change agents" (Zhang et al, 2009) for K-12 schools and teachers.

While never specifically articulated, NSF program officers have described (personal communication) their hopes that by working directly with K-12 teachers, STEM faculty from institutions of higher education (IHEs) might, in turn, gain insights that would be valuable to the professors' home institutions. This effect might increase the quality of teaching in disciplinary courses attended by pre-service STEM teachers, while at the same time improving general undergraduate STEM instruction. The NSF, its program evaluators, Westat (Zhang et al, 2009), and researchers in MSPs (Pomeroy et al, 2009) have begun to amass evidence of such bidirectional impacts. While the NSF's MSP programs are not alone in providing exemplars of synergistic interactions of K-16 educational partnerships, research, and teaching in IHE STEM faculty (Pomeroy & Rui, 2009), the MSP program design sets up contexts that maximize the potential to develop and nurture such interactions. This study also includes a non-MSP STEM

professor who, on his own initiative for over 20 years, formed his own partnerships with secondary teachers and students through the *broader impact* mandate of numerous research grants he has designed and received.

All NSF research grants require proposals to address *broader implications.* NSF defines *broader implications* as *"To promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and for other purposes"* (NSF Act of 1950). The broader impacts criterion can be addressed by any of the following questions:

- How well does the activity advance discovery and understanding while promoting teaching, training and learning?
- How well does the proposed activity broaden the participation of underrepresented groups (e.g., gender, ethnicity, disability, geographic, etc.)?
- To what extent will it enhance the infrastructure for research and education, such as facilities, instrumentation, networks and partnerships?
- Will the results be disseminated broadly to enhance scientific and technological understanding?
- What may be the benefits of the proposed activity to society? (NSF, 2007)

Many research grantees use outreach in K-12 schools as fulfillment of this obligation. In its MSP solicitations, however, NSF made partnership between K-12 schools and institutions of higher education (IHEs) the distinguishing element.

While there are many examples of higher education faculty working in K-12 schools or with teachers that fall under the aegis of *service*, few can really be called *partnerships* that fulfill the academic role of application as envisioned by Boyer. *Service* simply demands that one party performs an act for the benefit of the other; examples might be lectures, internships, conducting

courses, or even developing materials. The salient factor in categorizing any of these as *service* would be that the professor is perceived as the expert and agent of change; it is a one-way transaction (Gibbons, 1999). Some of these very activities might be categorized as partnerships, however, but only if both parties are committed to substantial learning and growing. While the word *partnership* can describe a wide spectrum of activities involving two or more parties, the particular MSP which is the focus of this study believed that true partnerships demand and result in substantial bidirectional transformations. Early activities in the five-year MSP project conducted workshops with participating professors to help them form partnerships that require the kind of mutual commitment, growth, respect and trust that can only be established by hard work often involving the restructuring of beliefs and ideas. The non-MSP professor, who expressed very strong similar convictions in relation to his partnership work, was included in this study to explore what this kind of transformative partnership might look like in a non-MSP setting.

The notion of *bidirectionality,* or mutual transformation, in this sense draws from two bodies of scholarship: one very new area is computer science, and the other is social contracts. The contribution in the first area can be drawn from the Grace Report (Czarnecki et al., 2008) which describes a conference of computer programmers from a variety of sub-disciplines in programming. This community addressed bidirectional transformations in programming in terms of operations, data and metaviews. Taking these out of the programming context for the purpose of this study, *operations* becomes the ways in which A works with B and B works with A, and operations can be transformed through bidirectional interactions. *Data* becomes the actual knowledge exchange between A and B, and this, too can become transformed as a result of new knowledge. And, finally, the *metaview* becomes the schema, or organization of ideas and

constructs both about the different contexts within which A and B work and about the structure of the disciplines of knowledge which are the focus of their interactions. Like operations and data, metaviews are also subject to bidirectional transformation through engaging interactions.

Another aspect of *bidirectionality* is informed by Gibbons' (1999) argument for the need of transparent and participative interaction between science and society. Gibbons states that it was "assumed that the most important communication was from science to society," however new and much more robust knowledge can and must develop from the social contextualizing of scientific knowledge and methodologies. Because of this, the traditional way of looking at professors' work in K-12 schooling is to examine the impact on components of the K-12 system. This study examines such work in terms of the impact on the professors. Gibbons describes evolving societal demands on scientists in terms of knowledge creation. Likewise, this study illustrates that the value of the role of professors in schooling both to the schools and to the professors depends on their willingness and ability to undergo transformation.

A Westat study group (Zhang et al, 2009) recently published a report of eight case studies of high engagement MSP projects on the effect the STEM faculty engagement on their own teaching and on their institutions. The Westat study confirmed positive impacts on the professors' teaching; however, the study did not explore possible effects on the professors' research. In another study, Pomeroy, Wolff and Rui (2010) analyzed a survey of 605 higher education faculty members engaged in MSPs across the country. The open-ended questions asked them to describe the impact of their MSP engagement on their teaching and research. Of the 237 professors who both teach STEM courses and do STEM research, 12.7% described an impact on their own disciplinary knowledge and/or research and 48.9% percent described a positive impact on their own teaching practices. In beginning to explore whether such impacts

are unique to MSPs, Pomeroy and Rui (2009) also compared the impacts of educational outreach work as reported by a sample of non-MSP NSF science grant awardees and MSP STEM faculty members. This study confirmed that both groups of respondents reported positive impacts on their teaching and on their research. Because of the survey nature of that investigation, however, it leaves unanswered questions about what these impacts actually look like and how they occurred. This current study builds on this growing body of work in that it explores in more depth the impact of educational partnership work in both MSP and non-MSP professors, and it explores impacts on research and disciplinary knowledge as well as teaching.

One of the most significant drawbacks to this kind of demanding partnership work is its lack of value as seen by STEM departments and IHEs in terms of faculty reward structures including tenure and promotion (Braxton et al. 2002; Hora & Milar 2008; Zhang et al., 2009). For this reason, this study focuses explicitly on examining MSP impacts in terms of the context of the professoriate and the academy, specifically on the very definition of *scholarship*. Under Ernest Boyer's leadership, the Carnegie Foundation for the Advancement of Teaching began to identify the features of scholarship that contribute to the academy, especially at the undergraduate level (Boyer, 1990). Boyer argued that there is a disconnect between what is espoused in official institutional tenure and promotion policies (e.g., that teaching is paramount) and what is practiced. This was more recently confirmed in a study by Braxton, Luckey, and Helland (2002). This current study is informed most significantly by Boyer (1990) in three ways. While many in academia consider research, teaching and service to be the three lynchpins upon which scholarship is valued and awarded, Boyer argued for recognition of four aspects of scholarly life. The components of his model are: *discovery* which aligns most closely with research in that it supports the creation of knowledge, *integration* which binds together

knowledge between the disciplines, *application* which, as stated above, focuses on the use of knowledge for the public good, and finally, the most critical of all, *teaching*. For the purpose of this study, the kind of service which can be described as citizenship either within the university or the community at large is not considered. K-16 partnerships, on the other hand, are considered within the Boyer's view of *application* since they entail professors applying their disciplinary expertise to the many challenges of building foundational disciplinary expertise in K-12 teachers and, ultimately, in their students. While application is generally considered least important in academia (Boyer, 1990; Braxton et al., 2002), its low prestige is especially confounding since, as Boyer (1990) explains, "[It] is serious, demanding work, requiring rigor– and the accountability–traditionally associated with research activities" (p. 22).

The second way that Boyer's work informs this study is his proposal that "Knowledge is acquired through research, through synthesis, through practice and through teaching" (p. 24). Critical to the argument in support of all of these activities being valued as scholarly work is the proposition that knowledge generation occurs not only through research, but also through teaching, application and cross-disciplinary synthesis. If this proposition can be verified by empirical and case study methodologies, then there is compelling evidence for valuing this work for faculty rewards, in particular, and for the benefit of the disciplines, in general.

The third way that Boyer's work informs this study is his description of scholarly work. The term *partnership work* is used to differentiate the professors' work in this study from typical educational outreach, such as presentations for teachers and/or students, since that work does not challenge the professors' knowledge and belief structures and hence does not to fit into the domain of application. To facilitate the consideration of this work in Boyer's true sense of being demanding and requiring rigor, for this study *rigorous scholarly work* is defined as:

- reflecting on and analyzing ideas and observations, especially in terms of academic literature;
- testing of hypotheses according to the standards of the discipline;
- engaging in critical analysis of findings with a community of peers; and
- disseminating findings to a scholarly audience.

This study looked for evidence of these characteristics of the professors' K-16 partnership work.

An interesting aspect of the particular MSP which was the focus of this study is its clearly articulated belief in the value of providing different ways for faculty and schools to engage in the partnership work. The MSP provided opportunities for STEM faculty engagement including:

- training and presentations for the STEM faculty;
- co-facilitating summer institutes for teachers in content and pedagogy;
- co-facilitating professional development, ranging from individual sessions to year-long initiatives such as curriculum development with teachers;
- leading initiatives at their home universities, such as developing teaching and learning communities;
- conducting pedagogical research;
- participating in MSP-sponsored professional learning communities; and
- taking leadership roles in the MSP.

Participating faculty were bought out for course releases during the semesters in which they worked on the project. It became apparent in the early stages of the project that every faculty member had unique interests, abilities and time constraints that rendered uniform engagement impractical. While all the MSP subjects of this study engaged in partnership work over several years, the range of types of engagement and intensity of commitment provided them with a

flexibility that met their interests and needs while at the same time providing the MSP with valuable resources.

Although the leadership of the MSP in this study initially hoped for positive impacts on the professors' pedagogical practices, there was no attention paid to the possibility of impact on the professors' disciplinary knowledge and/or their research, and in fact, the null hypothesis – that there would be no impact on professors' disciplinary knowledge and/or research – was assumed. The idea for this study arose from the author's observations of such impacts occurring in participating STEM professors with whom she worked.

Methodology

Sampling

Volunteers were solicited from the most actively participating science faculty in the MSP and from scientists known to the researcher as experiencing bidirectional impacts along any of the three dimensions. Of those who volunteered and were interviewed for this study, six subjects were selected as exemplars. This method of selection falls under the rubric of purposeful sampling, used when an "investigator wants to discover, understand, and gain insight and therefore must select a sample from which the most can be learned" (Merriam, 1998, p. 61).

Data Collection

These case studies were developed principally through interviews, though some data was also gleaned from observations. The observations were designed to generate a shared experience, so that the observer and the subjects could have a focal point of discussion about the subjects' pedagogical decisions, their beliefs, and the contextual factors within which they teach. In some cases, pre- and post-observation interviews were conducted; in most cases, due to

subjects' time constraints, the pre- and post-interview protocols were combined into a single post observation interview. All interviews were digitally recorded, transcribed by a graduate assistant and proofread. In cases in which technical language was used or there was a question about what was said, the segments in question were sent to the subject for correction or clarification. The methodology was designed to be sensitive to capturing the depth and breadth of impacts that partnership work could generate given the very diverse range of activities in which the professors engaged.

Because the researcher was active in the same MSP as the subjects and the non-MSP subject was a former colleague, some of the knowledge and description of them is gleaned from participant observation. While such information helped flesh out the context within which the subjects were working, the interviews and/or observations were the sole sources of the contents of the write-up and analysis of the case studies.

Analysis

Each case was initially written as a *story* of the subjects' engagement in partnerships and resulting self-report of impacts and issues of this engagement. While normally a case study would not be reviewed by its subject, after each *story* was written, but before any analysis or interpretation was included, the text was sent to the subject for verification of correct representation of facts.

Each case study was developed separately and analysis was conducted in which examples or issues of scholarly work as defined above were identified across each of the three dimensions identified in the early stages of the research:

a. partnership work and teaching

b. partnership work and research

c. research and teaching

In addition to identifying instances of these impacts, the cases were analyzed to uncover factors that may have contributed to, constrained or otherwise shaped the bidirectional impacts among these three aspects of academic life.

At the completion of analysis of all case studies, a cross-case analysis of each of the above factors was performed. This was accomplished by looking for emerging themes among the coded sections and synthesizing them into a collection of findings.

The Subjects

Each subject, referred to by pseudonym, is introduced below with a very brief summary of his various partnership engagements and impacts. It should be noted that these summaries only begin to illustrate the depth and breadth of their partnership activities and capture a sense of the robust scholarly work in which they were engaged. More specific descriptions and quotes appear in the *Findings*.

Andre, an early to mid-career physical chemist, participated in MSP professional development and, as a result, transformed his classroom practice. His MSP experiences led him to totally redesign his university chemistry courses from traditional lecture to guided inquiry. This culminated in Andre's conducting a research project on the effect of his new course design on student attitudes toward science. Through the power of his example, he convinced another chemistry professor to reconsider and redesign his courses as well. Additionally, in a year-long project, Andre was part of a team of IHE STEM faculty and high school teachers designing an integrated science course for one of the MSP's partner high schools. His work with a high school physics teacher in this project led him to challenge an existing theory about molecular

motion. His discovery has the potential for significant impacts in applied and theoretical chemistry.

Adam, an early career biostatistician, was recruited and supported by the PI of his university to attend the MSP seminar series on formative assessment. Afterward, he decided to conduct an action research project with a colleague on formative assessment in their classes. The MSP funded his initiative in the form of a one-course buyout, so that he could design his interventions and work with a middle school teacher who was already implementing some of the same strategies in her classes. He has been conducting controlled studies on the effect of his assessment interventions. These studies have led him into new areas of professional collaborations and leadership. When Adam indicated an even deeper interest, the MSP helped him put together a proposal for another MSP to utilize these formative assessments and test their efficacy in a randomized control study with forty-four high schools. The MSP also brought Adam into its Research and Evaluation Professional Learning Community (PLC), drew on his expertise and provided him with new opportunities to explore and apply his research methodologies. Perhaps most interesting is that MSP work has led him to consider applications of his biomedical specialty in statistics to the field of educational research.

Tom, a senior faculty member who is an ecologist, was provided the opportunity to extend and apply some of the practices he had already begun in his teaching and research. This enabled him to further refine his classroom practices and deepen his view of "research as curriculum." The MSP encouraged him to test a hypothesis he had concerning the effect of his students working in high school classrooms. This ultimately resulted in his writing an additional MSP grant proposal.

Jeremy, an early career molecular biologist, participated in various MSP activities, but clearly the most valuable, intense and sustained for him was the integrated curriculum development project (see also *Andre*, above). The design of that project required deep and intense discussions which led Jeremy to reflect on big ideas in his discipline. This work impacted both his own course designs and his research. In addition, Jeremy's engagement with the MSP led him to make significant changes in his teaching so as to more actively engage students in learning.

Relatively early in the MSP project, *Ted*, a mid-career geologist, left his academic position at one of the MSP partner universities and became the director of professional development at a regional educational science center. He is committed to inquiry instruction and to facilitating field-based workshops and institutes in geology. His MSP work provided him with opportunities to pursue these interests in relation to his discipline in ways that he indicated he otherwise would not have had. In the course of preparing for an inquiry-based science activity with teachers he discovered a new geologic feature that contributes significantly to the understanding of the historical geologic record in his locale. While he is not currently in academia, his story does contribute to an appreciation of the impact of partnership work on disciplinary knowledge.

Jim, a mycologist and the most senior of the subjects, has been teaching in higher education for 35 years and conducting research for 32 years. When he talks about his work he can scarcely contain his excitement. He is bursting with new ideas, enthusiasm and, as he describes it, "almost missionary zeal." His entire affect suggests wonderment and love for what he is doing and the impact it has had on him, on his students, on teachers with whom he has worked, on the community, his university and on his field of research. Though not involved in a

MSP program, Jim has been engaged in partnerships far longer than any of the MSP professors in this study. A unique aspect of his career track is that he started his career as a high school teacher and then moved into higher education. In addition, during a phase of his university career, he adjusted his load so that he could go back to teaching in high school as well. During this period of dual teaching, he received the Presidential Award of Excellence in High School Science Teaching. This aspect of Jim's professional life is important in understanding him as an academic because it speaks to his comfort with high school students and in the value of their teachers. The issues and challenges faced by teachers and students are part of his lexicon, and he is as comfortable in talking about and experimenting with teaching methods and reflectively examining his pedagogical practice as he is in doing his research.

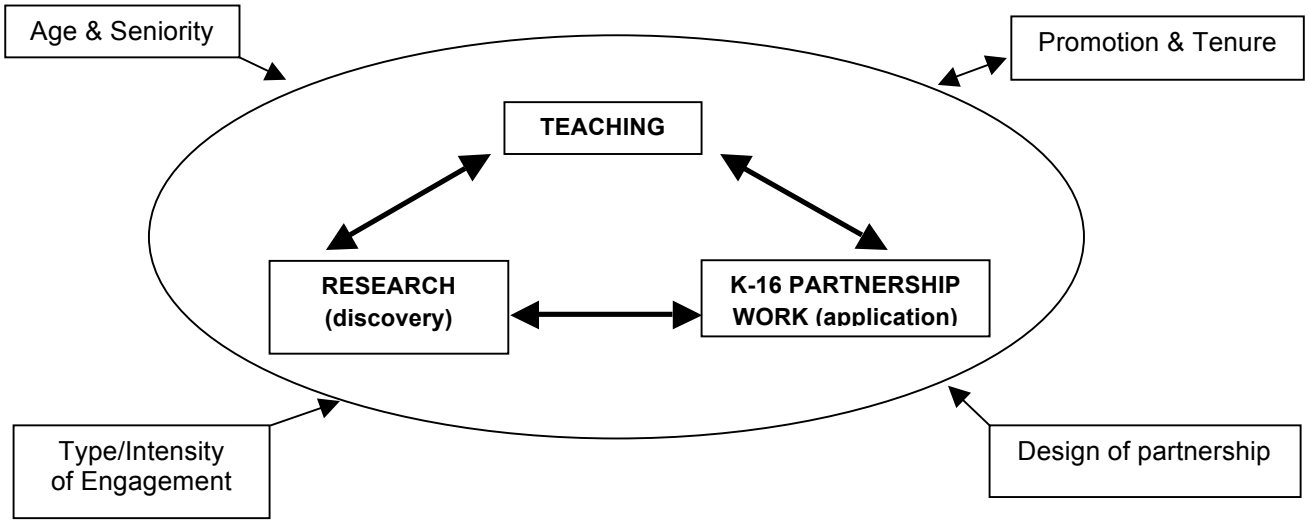
Results

Based on the findings of this study, although other external factors may impact the focal interactions illustrated below, four emerged as impacts on those interactions:

1. the role of tenure and promotion
2. age and seniority
3. type of engagement in K-16 partnership work
4. the actual design of the outreach engagement as it relates to IHE faculty engagement.

In some cases these factors facilitated interactions; in other cases they inhibited them. The discussion below will focus first on the three key bidirectional interactions and then on the external factors.

Figure 1.



These cases reveal instances in which the professors' partnership work positively impacted their teaching and/or their disciplinary research. In some cases the work also led the professors to conduct research on their own teaching practices. Among many findings, the following are the most significant that emerged from analysis of the bidirectional impact among each dimension among the three components of academic life examined in this study.

Bidirectional Impact of K-16 Partnership Work and Teaching

This aspect of analysis focuses on the impact of partnership work on the professors' own teaching and, conversely, the impact of the professors' teaching on their partnership work. The findings below reveal that the subjects' attitudes toward teaching had significant impacts on their partnership work, but analysis did not uncover any identifiable impacts of their own teaching practices on their MSP work. In the cases of the MSP professors, their teaching was greatly impacted by their MSP work.

Finding 1: Perhaps the biggest factor in the interaction of the partnership with teaching was the professors' willingness, and often eagerness, to engage in serious scholarly examination of their own teaching practices.

Jeremy, Andre, and Adam all engaged in examination, modification, and testing ideas about their pedagogical practices. Through his attendance at a series of workshops in formative assessment with teachers, Adam, for instance, found that the process of defining learning objectives made him realize he had been assessing students on learning outcomes unrelated to the course material in his class. He quipped:

> I look back at some of my old exams and there were some fun questions in there that assessed them on something totally unrelated to what we've done in this class! … [I]t's almost an embarrassment, but I think that's normal. And so whether or not we find results from the data … [significant], I find that my experience of going through that process of defining learning objectives has been really helpful for my teaching.

Jeremy explained that he is dedicated to providing his students with as many opportunities to connect with scientific research as possible in his classes, because he is trying to make it accessible to them. "The way that I try to engage the students is different." Through both workshops and one-on-one work with teachers, Jeremy's teaching evolved as he became convinced of the importance of students engaging more deeply with scientists and research to build real life connections to the concepts he is teaching. He also developed an emphasis on students' ability to communicate effectively.

> I make sure that they're in tune with what I'm saying and they're able to not just spit it back at me, but formulate more complex answers in scientific terms based on what we've

> been talking about. So I've made [my classroom teaching] much more a conversation than it originally was.

And from an introductory Process-Oriented Guided Inquiry Learning (POGIL) workshop with teachers and other professors, Andre became hooked on this strategy as a way to truly engage his students and eventually rewrote all his course materials using a modification of this strategy. All of these professors considered their teaching as work in progress--a dynamic rather than static aspect of their professional lives.

Finding 2: *Reciprocal learning relationships developed between professors and school teachers as they worked together to understand each other's expectations of their students.*

As one strategy, the MSP provided STEM faculty with opportunities to improve K-12 instruction by having them work with teachers to craft explicit statements about intended learning objectives. These were then used to ensure alignment between instruction and assessment. As a result of Adam's engagement with teachers on this task, he began to consider his own expectations of students, and he totally changed the way he assesses students, saying, "What has changed a lot for me is my appreciating the need to understand whether the students understood what it is that I think I taught them." He realized:

> If I'm doing as good a job as I think I can with teaching, but my students aren't learning, [then] I'm not being effective. . . . [I have found that] more time preparing for my teaching, specifically defining the learning objectives, was incredibly helpful for me to think about what I want the students to get out of the class. It was also incredibly helpful for me in designing assessment tools [such as] writing quizzes for the students. Rather

> than saying, "We covered Chapter 3, let's have a quiz on that," I said, "Here's the four learning objectives … that we're going to cover on this exam."

Providing evidence of the scholarly nature of this work, Adam is now disseminating his work in his disciplinary professional community and has co-authored a new NSF proposal to expand the work in formative assessment to several school districts and IHEs and study the impact.

After co-facilitating a two-day workshop with middle school science teachers, Andre explained:

> This approach to learning these concepts is very interesting and different from the normal approach. As disciplinary faculty we learned how to add to the knowledge base within our fields, but we never had a chance to learn about how to teach.

Finding 3: Work in the partnership reinforces professors' interest in pedagogy, provides them with a pool of like-minded colleagues, inspires research that supports their convictions, supports them in trying new practices, and provides a peer community for reflective practice and pedagogical research.

All the MSP subjects in this study, with the exception of Adam, were very active in the project's Science PLC which included project staff in science, research and science teachers from partner high schools. These monthly meetings spanning several years, were very focused and animated. They provided opportunities for participants to bring their own issues and interests to the table as well as work on project-wide issues. Adam participated in the project's Math PLC. In addition most of the subjects also both presented at and participated in the project's Research and Evaluation PLC which was formed specifically to support staff, teachers and professors in conducting research. Most, especially the more junior faculty members,

indicated the value of these PLCs in providing peer support, exemplars and critical friends to each other in their engagement with pedagogical issues, strategies and research.

These subjects had a direct impact on their immediate MSP colleagues, and sometimes on their institutional colleagues. Several subjects indicated their intention to continue to regularly incorporate action research into their teaching, and some contributed new pedagogical knowledge, skills and ideas back to the MSP and their own institutions as they became proficient in their new teaching strategies. The following, written for the MSP's annual report by Andre's university's sub-award principal investigator, illustrates the new found value of pedagogical research:

> [Andre] ventured into the field of educational action research with MSP support in order to become a more effective instructor, and found the endeavor to be beneficial. . . . [T]he most valuable part is his excitement. He was initially resistant to doing this research and felt it was a waste of his time and effort. [Andre, however] found this to be a useful endeavor. He hopes to be able to sustain the activity as a regular part of his teaching. He has already been thinking of changes he will make in the surveys to enable him to gain further insight into his students' beliefs in order to inform his teaching.

As mentioned elsewhere, Andre also convinced a more senior, and very traditional, colleague in his department to develop and utilize the same guided inquiry methods in his classes.

Bidirectional Impact of K-16 Partnership Work on Knowledge and Research

This aspect of the analysis focused on the hypothesis that K-16 partnerships involving rigorous scholarly work may have either direct or indirect transformative effects on professors'

disciplinary knowledge, and ultimately their research. As detailed below, the findings revealed that MSP partnership work as described in this study resulted in new discoveries, new understandings, and new applications of prior knowledge.

Finding 4: This study confirms the hypothesis that the robust scholarly aspects of K-16 partnership work could lead to new discoveries in the disciplines.

In the MSP, both Ted and Andre discovered new researchable phenomena in their disciplines as a direct result of working on inquiry instruction with teachers. While neither of these discoveries has yet resulted in more formal exploration and publication, each of these scientists displayed real excitement and engagement with their discoveries. Ted tells the following story about discovering a previously unknown aspect of his region's geology while preparing for a field trip for teachers:

> I walked in on a trail and found an incredible teaching outcrop. The main outcrop was the gneiss, but at the base of the outcrop and all around it in the soil were blocks of sandstone and conglomerate. This rock is the beach deposit formed as the ocean flooded over this area 550 million years ago. On top of that I found outcrops of the jasper, so I could show the teachers this classic sequence. … This is very exciting to me as a researcher because there is the chance to identify the orientation of the fault, if this is indeed the case.

Ted indicated that most people think of geology as an unchanging science, so it was exciting for him to be able to illustrate by his personal example the growth of our deeper understanding of the Earth's geologic history, and use his own process of discovery as an example of the Nature of Science at work.

The following series of events were actually observed by the author who was facilitating a group of STEM faculty members and high school teachers on developing an inquiry-based integrated science course for 9th graders in one of the project's partner school districts. For three months Andre had been working quite intensely with the physics teacher. At one point, when he was trying to help the physics teacher design an inquiry activity demonstrating that some energy is always lost to heat in energy transfers, he became confused with inconsistencies between the results he obtained and expected in rolling a marble down a chute. Two weeks later at the next session, he admitted that he had been grappling with this surprise result, and he was still confused. The high school physics teacher suggested that the marble might have gained enough rotational energy to possibly explain the discrepancy. Andre, having been away from physics for a long time, laughed at himself for forgetting this, but the intense churning about the problem for two weeks had made him think about how a marble or ball bearing falls through liquid in traditional measurements of viscosity. His thinking led him to pursue the potential of a new solution to a problem in fluid dynamics. He then built two pieces of apparatus, 1) a rolling ball viscosimeter, and 2) a rolling ball cantilever and made some measurements with the help of two enthusiastic Physical Chemistry students who volunteered to participate in this inquiry. As Andre later explained of his investigation, even if new instruments do not show a new way to look at molecular motion, "I will [still] have created a nice Physical Chemistry experiment which I can add to my modernization of the curriculum initiative. If the latter works [demonstrating a new phenomenon], I will have partially solved a long-standing problem for the [chemical] coating industry." The following reflection exemplifies the level of rigor and engagement that Andre brought to this work:

> So what appears to be a simple, innocent little experiment with a bearing rolling down a tube filled with a liquid can easily turn into a research project that requires expertise well beyond my own, or that of a single research group, to develop new experimental and theoretical methods. My goal at this point is to see if I can improve the empirical model, and if I can quantify the difference on the dynamics (still to be measured) made by coating the bearing. If indeed I can accomplish both goals, then I may get back in touch with theoretical and experimental groups around the country and share my findings with them.

While Ted's and Andre's partnership work led to new discoveries, just as significantly it provided them with an unexpected level of personal intellectual excitement that was especially engaging, fulfilling and contagious to all participants. This same phenomenon takes a different shape, but is none the less evident in Jim's case.

Most of the partnership work that Jim designs involves students and teachers doing original research. Annually he runs a science symposium in which the students present their papers for review. This involves mentoring high school students and their teachers in authentic scientific research all the way from observation, through identifying researchable questions to publication in the form of symposia and, in some cases, refereed journals.

> In the last 10 years I've seen 7 of our kids publish papers in refereed scientific journals. Which is just outstanding -- even high school kids -- all of these resulted from outreach activities.

This is perhaps the most compelling, and certainly the most observable evidence of partnership work impacting research and knowledge in the disciplines.

Finding 5: Through the MSP K-16 partnership work, some of the STEM faculty reported discovering new applications of their knowledge.

Adam, for instance, has been drawn into sessions with evaluation and research teams that provide him opportunities to either apply strategies with which he is very familiar or explore new bridges between the biostatistical approaches with which he is most familiar and the educational applications he is just starting to learn. He is now thinking about doing applied educational research that comes "from classroom experiences in terms of educational models and statistics education models as well." This interest has prompted him to pursue studies of some of the methodologies especially applied to educational research. He is also interested in "looking for the gaps that exist in methodology, so that I can make a natural bridge into that research, into that theoretical research from the applied research that I'm doing."

Bidirectional Interaction of Research and Teaching

Though not directly related to MSP work, this aspect of the analysis explored interactions between teaching and research in the subjects' work. As mentioned in the Introduction, while partnership work does not come into play directly in this dyad, if there is a bidirectional relationship here, and if partnerships impact either teaching or research, then partnership work may indirectly impact the other member of the dyad or the teaching-research interaction itself. All subjects reported interactions between teaching and research ranging from a relatively superficial level (e.g. using their research as examples of phenomena or methods for their students) to a relatively deep level (e.g. designing curriculum around research).

Finding 6: The most common impact of research on teaching lies in the professors' abilities to bring their research into their classrooms through the utilization of examples of phenomena or the applications of research techniques.

The most powerful examples of this finding were in observed classes. In almost every aspect of Jeremy's and Tom's classes, key ideas were introduced and discussed through the presentation of research--and in some cases their own research. The recurring theme Tom espouses and practices is "research as curriculum." Adam provided this explanation of his use of research in his teaching:

> I find that when I teach from my own research, I can give a much richer picture for the students about what's going on, [for example] what were some of the issues with this variable that we're looking at. … [I] can respond much better to students … when they ask very intelligent questions … I have to give a theoretical answer if it's someone else's research, [but] if it's my research, often I've thought about that already, so I can give a much better answer.

However, like several other subjects, Adam explained that his use of research in the undergraduate classroom is at a very basic level. However, his graduate students are much more actively engaged with his research designs and methodologies, in some cases almost in a workshop style. While Jeremy, Adam, Tom, and Jim all talked about the use of their research in their teaching, it was evident that they had all done this prior to the partnership work. What appeared to change for them was the degree to which they did it and the level of intentionality with which they did this as a pedagogical strategy.

Finding 7: Several of the subjects in this study indicated that teaching positively impacts their disciplinary knowledge, skills and/or research.

Tom and Jeremy indicated, for example, that the act of organizing their disciplinary knowledge for teaching positively impacts their research. Tom described teaching as a way to organize knowledge; furthermore, he has his students do original research, and this sometimes provides him with new things to think about and questions to pursue. Jeremy indicated that, while he is not experiencing the generation of new knowledge through his teaching, he finds that the broader requirements of his teaching provide a valuable perspective to his research. He explained:

> When you're doing research and not teaching, you can think more narrowly. And you have your specialty and you look into things on the periphery [only] as much as you need to, to get an experiment done as much as you need to [and] to write a paper. But, when [as a teacher] you have to go from beginning to end through a whole topic or through a whole textbook . . .you get a much greater appreciation for the big picture. And you see the connections more. . . . [I]n discussions that I have in the lab where I work, I'll go in . . . [and] they'll be talking about something, and they'll think they're talking about a topic, but I know from the lecture I gave three days ago that they're really blind to this. And I can go and say "Well here, go home tonight and read this chapter and it [may] change your thinking." So, by having to teach things that I don't necessarily do research on, it informs the things [on which] I do . . . [conduct] research.

In another twist on this finding, Tom also explained that he has teams of students working on certain problems. He described one team that was working on why frogs are disappearing worldwide.

> And they're doing some really interesting neat work there that is being published and is being trickled out. And all the student's names are in the publications. And all my students actually end up on my publications too. [There are only a few whom] I've had in the last five or six years [whose] names aren't tucked in there. [On] some of them I make them senior authors. And every time I do to a conference I go with at least two or three students. And they present papers, so you know they're steeped in the process of doing science and not just talking about it.

In a similar vein, Jim gave a very clear illustration of one mechanism by which teaching impacts his knowledge and his research in his comment, "I love it when students ask questions that I cannot answer." The following is one of several examples he provided to show how students' questions led to new discoveries in his field explaining that on field trips his students became very curious about the wide range of colors of *Amanita muscaria*, a rather common mushroom,

> and we were rather intrigued by the fact that we had so [much] … color variance here. And so when I would teach my general mycology courses in the summertime, … I kept seeing this variation on a theme and people kept asking me… "What's this species, what's that species?" If it's a different color, are they different species?

He explained that his initial response was the commonly held belief among mycologists that these are all variants of the same species. But eventually

> that led me to ask the question, are they really different? And so looking at the macro and the micro morphological features, it didn't seem that they were. But then I linked in with

> a molecular biologist and we did the genetics of these things,… we began to see that things that we were calling one thing were not really those things at all; they were entirely different. … So here is a simple case where a very common fungus was looked at as a result of people asking me questions over the years and my taking it to the next step in my research programming, involving post-docs and other faculty and finding in fact [that] we just opened this Pandora's Box. And that's really exciting. …We've published four papers on this and on the genus Agaricus."

Another mechanism for Jim's own growth comes through his preparation for classes. Jim explained that he is very attentive to different learning modalities, and he tries to teach to many different ways of learning. He is continually trying new ways to present materials and help students understand concepts. Teaching also requires him to stay up to date on developments within the fields he is teaching.

> I think that as one teaches you always search for more and new information, particularly newer information, and trying to stay current with literature. So I find that as I teach, my teaching changes as the function of the sense I have students want newer information, so I keep myself abreast of the literature.

When probed for why keeping abreast of the literature for preparation for classes would be any different than for his research, he explained:

> If I were working exclusively in research, the literature searching and the information gain would be very narrow and more specific related just to the research endeavor. But in teaching, it's much broader. So I find that I look at a broader literature list and that I keep myself abreast of broader concept[s], within the broader context.

Furthermore, he explained that this has a positive impact both on his own general disciplinary knowledge and on his research in that he can place his work in the broader context

of scientific pursuit. When asked if he believes there is any relationship between the way he teaches and the impact of inquiry teaching on his own learning and research, Jim explained that it takes more time to develop experimental processes that engage students. But he has found that when he engages in inquiry with students even at the introductory level, he finds they want more and more specific courses. These lead him to develop more courses at higher levels with more inquiry that in some cases puts the students into the molecular biology research laboratories. So the process becomes one of increasing circles of mutual challenge and learning.

Finding 8: To at least some degree, all the MSP subjects use their own teaching as a subject of research.

As these professors become more adept at conducting pedagogical inquiry, the scope of research lives broadened to include teaching. As mentioned above, Andre conducted a research project on the impact of his newly designed course. While Jeremy and Jim did not conduct formal research on their courses, they both indicated that they were very thoughtfully reflecting on their practices and making adjustments as indicated. Utilizing pre-post tests, Tom conducted research on the impact of having his students teach some of his course concepts. Adam's case is unusual, in that he is using statistics to evaluate the effect of the formative assessment strategies that he is implementing in his statistics classes. The lines between his teaching and research become incredibly blurred. He explained:

> Knowing that education is something very important to me, I've actually gotten fairly involved in not only the education research that I'm doing here but [also] the statistics education world. I've been nominated to be chair of the Statistics Education section of the Mathematical Association of America.

External Factors

As mentioned in the Introduction, it became apparent that four factors: tenure and promotion, age and seniority, type of engagement in K-16 partnerships and partnership design -- emerged as shaping, enhancing or constraining the interactions of teaching, research and service in these subjects. While the last two factors are clearly different, they are combined into one discussion.

Tenure and Promotion

Finding 9: The subjects' tenure status, rank, aspirations and the culture of their institutions determined whether or not tenure and promotion were significant factors.

In cases of the tenured full professors, needless to say, tenure and promotion have absolutely no impact on professors' K-16 partnership work; conversely, their partnership work has no impact on their tenure and promotion. In the case of junior or mid-career faculty, it became very clear that a careful balance must be maintained between the demands of tenure and/or promotion and MSP work which is generally not valued as much as research in their disciplinary fields. In some cases, the subjects reported both positive and negative impacts of their MSP work on their status and rank. Jim described his

> mentoring of young faculty, who in turn, learn how they can reach out, mentor others [high school teachers and HS students] and not feel overwhelmed or misguided from their tenure and promotion tract.

Age and Seniority

Finding 10: While subject selection was not designed to investigate the impacts of age and seniority, this set of cases nonetheless illustrates the value of a diverse cohort of STEM faculty who represent a range of ages and levels of seniority.

The limited findings of this study suggest that age and seniority do in some cases impact the relative weight of faculty influence on leadership and activities, school teachers, fellow STEM professors, their home institutions, and the discipline at large. One factor in the relationship between rank and partnership activity was very clear in that senior faculty in partnerships can play significant roles as mentors to more junior faculty. What was evident in this study was the degree to which mentoring of junior faculty by senior faculty was valued by both mentors and mentees.

In terms of other impact, as department chair, Tom is clearly in a position to impact both his department and university. And Jim, as the most senior of the subjects of this study, is in a position where he can, in fact, speak up and be listened to since he is a senior faculty member with an in international reputation and prolific publication record who has brought in many grants to the university. His outreach efforts are both bringing students into the university and generating a lot of community interest and support. He talked about impacting the university culture.

> [I]t's all about selling yourself [and] your programming, and demonstrating that the programming can benefit those who participate in your outreach programming toward their promotion and tenure process. … [O]n this campus, I've gotten the higher administration to buy into what it is I'm doing and through my outreach they recognize when they see other faculty coming through for promotion and tenure acknowledging

> their input, their efforts, in contributing to these various programs. Participating faculty are provided greater visibility and therefore credibility in all that they do.

Jim explained that up until fairly recently, in STEM departments at his university there was very little emphasis on outreach in the tenure and promotion process.

> And so a lot of faculty just say, "I just can't afford to be involved in that because I don't get anything for it." [The issue is] the time expenditure. But [I try to do it in] such a way that … I convince the … higher up administration that what … we're doing is effective not only for the community, but effective for the university, and it connects community with the university, which justifies and legitimizes [service/outreach] at the legislative level by giving it further meaning. And I report to all of our legislators the outcomes of our outreach programming, and they too buy in and see how the university is fulfilling one of its missions: … to connect and … shrink the … [gap] that exists between the general community and the university community.

Type of Engagement in K-16 Partnership Work

Finding 11: Diversity of type and intensity of engagement and commitment to true partnerships suggest the effectiveness of a program design which values and provides different ways for faculty and schools to engage in the partnership work.

As described in the Background section, this MSP provided many different ways for STEM faculty to engage in partnership work. The findings above illustrate the fact that transformative and/or bidirectional interactions occurred in many different kinds of activities, ranging from planning for professional development to working intensely with teachers, or even conducting their own pedagogical research.

In the MSP data analyzed in this study, two levels of K-16 partnership work emerged:

a. Establishing relationships--absolutely critical and often best mediated and facilitated by staff who are deeply connected with each community (schools and higher education)
b. Intellectual engagement resulting in robust scholarly work.

These faculty all engaged in a variety of first-level partnership work involving collaborative activities in which faculty at both institutional levels worked toward finding common ground, establishing mutual trust, and beginning to discover and understand the disciplinary areas and issues they have in common, as well as the institutional contexts and constraints that they do not. Though not directly asked about this aspect of the work, all subjects in this study made references to the value of establishing such relationships in terms of laying the groundwork for the second level, which is the true intellectual engagement resulting in robust scholarly work.

In Jim's case, he designed his own outreach/partnership work to maximize both his own and the participants' engagement and sense of fulfillment. Having found a successful program of partnership engagement, he writes that into every grant proposal he prepares regardless of whether or not such outreach is required by the funder.

Limitations

Clearly, there are limitations to this study that must be accounted for. The limited generalizability of case studies is one factor to consider. However, since the purpose of this research was to explore instances of bidirectional impacts on the professors and tease out factors contributing to them, case study methodology was appropriate. That methodology was, however, limited by the demographics of the subject pool in several ways. For one, because they

were all volunteers, it is possible that the study missed possible differences between those who volunteered and those who declined. Another limitation arises out of the use of purposeful selection of only those who are exemplars of the phenomena studied. If the study had included non-exemplars of significant bidirectional interaction between the teaching, research and K-16 educational partnership components of academic life, it might have been possible to explore factors that contribute to these interactions, versus those impeding them. A further limitation is that all the subjects are men; furthermore, they are all White. There were STEM faculty women and non-White men who participated quite actively in many of the MSP activities; however, they did not volunteer, despite several attempts to schedule interviews with them. It is impossible to know if any of the factors and issues discussed above might have been informed differently by a more diverse pool of subjects.

The researcher's acquaintance with the subjects must also be considered, thus:

a. Did the relationships with these subjects affect the studies, and if so, how?
b. Did personal knowledge about their MSP work and, in some cases, non-MSP work outside the scope of the research design, in some way affect the studies?

In spite of every effort to be as objective as possible, there is always an element of subjectivity. For this reason, the only material that was used for this study was that which was gathered directly through the interview and observation methodology described. That said, however, personal knowledge of the subjects and/or the nature and impact of their work--gained from participation in meetings with them or from ex-parte communications helped the author contextualize the subjects and their work.

Other questions emerge from the consideration that all the MSP subjects come from only one project:

a. How would the findings be different in a comparison study which included subjects in other MSPs with different types of engagement?
b. Was there some other aspect of this MSP that either promoted or detracted from the interactive effects among MSP work, teaching and research?

While these questions do suggest the limited generalizability of this study, the strength of the findings suggests the value of further studies to expand our understanding of the dynamics of such partnership work on academics' professional lives.

A final limitation to consider is the chosen analytical methodology. The use of an observation protocol such as the Reformed Teaching Observation Protocol (RTOP) (Piburn, et al., 2000) was originally considered to guide and inform the classroom observations in relation to standards of best practices. As the study unfolded, however, it became apparent that the real value of the observations was in providing a shared experience around which we could focus the interview; hence, the use of such a protocol became moot. During the analysis phase of this project, it became evident that another research and analytical tool that could have been used is social network analysis (Piburn, et al., 2000). Such an analysis might have unpacked in even more detail the breadth and depth of collegial relationships within the subjects' IHEs, among their MSP colleagues, and across IHEs. While the use of the RTOP and social networking were beyond the scope of this particular project, in future studies they might help further our understandings of IHE faculty involvement and impact.

Discussion

Despite its limitations, this study clearly uncovers a number of findings that confirm reciprocal interactions among all three components of academic work: teaching, research and

service in the form of robust partnerships. These findings increase our understanding of the impact and dynamics of these interactions, as well as factors that contribute to them. While not specifically analyzed for instances of the operations, data and metaview levels of bidirectionality, all three can be seen in the results.

The driving theory of action behind the MSP program was that STEM faculty could have a positive impact on K-12 teachers, and thus on their students' performance. That proposition was not the focus of this paper. Other studies have revealed that the positive impact on the pedagogical practices of STEM faculty is a fortuitous secondary effect of their MSP or similar work (Fedock, Zambo, and Cobern, 1996; Haug and Marion, 1996; Pomeroy et al., 2010; Zhang et al., 2009). The value of this positive impact on pedagogy at the IHE level is that better pedagogy in mathematics and science could possibly lead to more students wanting to major in mathematics and science, and their improved learning experiences in their discipline-based courses might encourage them to think about teaching as a career and better prepare them to become excellent educators. As evidenced by limited classroom observations and self-report by the professors, this paper confirms that activity in the MSP can result in improved pedagogy. Other studies are currently in process to explore whether student interest in teaching and student achievement in the STEM disciplines are impacted by the resulting improved pedagogical practices. Linking these studies would be a critical step in examining potential causal relationships.

The possibilities that MSP-type partnership work could have a positive impact on the STEM professors' knowledge, skills, and/or research were implied by Boyer (1990), but untested. While the evidence of such a limited series of case studies is not overwhelming, the results of this study confirm that the positive impact of such partnership work on professors'

research and disciplinary knowledge and skills is, in fact, a robust proposition and warrants further study.

The experience of the MSP's more junior faculty suggests that initiatives directed at increasing the value of K-16 educational partnerships in academic culture and policy could benefit individuals engaging in such initiatives, their institutions, and their disciplines. Furthermore, studies to explore the impact of age and seniority in these partnership such as this could be valuable in that they may help inform NSF in the strategic deployment of faculty in activities that would maximize their bidirectional interaction and, hence, value.

Finally, the activities of the professors described in this paper illustrate the kind of robust scholarly work that Boyer describes. In most cases, engagement with the work was not focused on the professors' own needs or interests, but true partnership work with teachers inspired the professors' questions about their own practices and ideas. This led them to examine their practices, and the beliefs underlying them, at the same time that they were engaging K-12 teachers in similar examinations. Such critical analysis of ideas and practices is part of the true work of an academic and, as evidenced in these studies, has great transformative potential not only in terms of pedagogical practice, but also in terms of disciplinary knowledge, and even institutional impact.

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