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Crossing Disciplinary, Institutional and Role Boundaries in an Interdisciplinary Consortium

Abstract

To illuminate barriers to collaboration, this study examines who participates in crossboundary scholarly collaboration most often and which types of boundary crossing (disciplinary, institutional, role) are engaged in most often. The data from this study came from an interdisciplinary consortium with five partner institutions, including one Historically Black College and University (HBCU). The core disciplines involved in the consortium are life sciences, computer science and math and engineering. Through statistical analysis, we determined that members of the consortium engaged more in interdisciplinary research than interinstitutional research. Participation in all boundary crossing collaborations was greater at the HBCU and students and postdocs were less likely than academics to cross institutional boundaries.

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Study purpose

Scientific expertise is spread across institutions and disciplines, which sometimes requires collaboration across boundaries in order to advance knowledge. Funding agencies such as the National Science Foundation (NSF) and National Institutes of Health (NIH) recognise this, and seek to support forms of boundary-crossing work that extend across disciplines, institutions and roles. This study examines who participates in cross-boundary scholarly collaboration and which types of boundary crossing (disciplinary, institutional, role) are engaged in most often.

The existence of discrete disciplines is not contrary to the advancement of knowledge. Rather, the tension between disciplines sparks new ideas. As Simsek and Louis (1994) found in their study of organisational change, continued adherence to a successful course of action does not result in continued success; rather, occasional introduction of new paradigms is necessary for advancement. Explaining one's own perspective to someone else lets one see it in a new light as well as helping someone else see the world differently; as a result, coconstruction of knowledge is more likely to take place (Vygotsky, 1986).

Disciplines have ideological systems for looking at the world, which become norms over time (Hora, Millar, & Ramaley, 2010). In translating across disciplines and across generations of scientists, these norms cannot be taken for granted the way they sometimes are between long established practitioners of a discipline. The norms must be made explicit and therefore come under scrutiny. A similar process holds for differences in institution, especially when thinking about research expectations, priorities and support. Based on geographic region and organisation type, institutions have different cultures. Holley's (2009) research revealed interdisciplinary initiatives cannot be accomplished without shifts in institutional culture. Academics become

enculturated in the values of the institution they are affiliated with over time and contact with scientists outside that culture can challenge assumptions.

Lattuca (2001) offered the perspective that “scholarship must cross paradigms, as well as disciplines, in order to be interdisciplinary” (p. 245). Similarly, Klein (2010) asserted that interdisciplinary studies “integrate content, data, methods, tools, concepts and theories from two or more disciplines or bodies of specialised knowledge in order to advance fundamental understanding, answer complex questions, and solve problems that are too broad or complex for a single approach” (p. 181). The National Science Foundation, the National Institutes for Health, and other funders believe in the promise of work facilitated by crossinstitutional and cross-departmental enterprises. While these calls speak to interdisciplinary research, without qualitative analysis, it is not possible to determine the extent to which reported output actually meets the definitions of interdisciplinarity as described by Lattuca (2001), Creamer (2005), or Klein (2010), among others. Whether or not it is authentically interdisciplinary in terms of changing mindsets, the scholarship actively promoted by funding agencies, especially in Science, Technology, Engineering, and Mathematics, typically emphasises work done by more than one person (Sonnenwald, 2007). With this qualification in mind, we wanted to understand how collaborative work unfolds by looking for collaboration patterns within an interdisciplinary, interinstitutional consortium whose goal is to ‘promote the transfer of discoveries from biology into computer science and engineering design’ (BEACON, 2010). This study examines how discipline, institutional mission and academic role predict a scientist’s likelihood to participate in interdisciplinary, inter-institutional and cross role collaborations.

Review of Literature on Scholarly Collaboration

Over the past decade, there has been a strong belief among policymakers, scientists and influential foundations that scientific collaboration has a positive impact on research productivity and scientific discovery (Hessels & Van Lente, 2008; Lee & Bozeman, 2005). Scholarship in this area has garnered attention in recent years and is especially important considering the rise of science centers built to promote collaboration (Perkmann, et al., 2013). While progress has been made in examining the relation between collaboration and scientific productivity (Lee & Bozeman, 2005; Van Rijnsoever & Hessels, 2011), little research examines how well science centers promote interinstitutional and interdisciplinary collaboration.

As scholars are increasingly involved in collaborations between scholars from different departments and institutions, research has focused on barriers to such collaboration (Bouwma-Gearhart & Adumat, 2011). Some identified barriers to successful interdisciplinary collaboration include the role of discipline and department professional identities, professional advancement, and philosophical and cultural differences (Levine, 1994; Holley, 2009; Hora & Millar, 2012). Recent research identifies elements of successful collaborations, such as recognising the value of others’ expertise, recognising partners are on different paths in their career trajectories, the important role of brokers, ability of successful brokers to frame research and theory in accessible ways, and ability of interdisciplinary teams to catalyze institutional change (Bouwma-Gearhart, Perry, & Presley, 2014).

Interdisciplinary research collaborations can change how people think about research problems, and there are other benefits (Amey & Brown, 2004; Bakhtin, 1981; 1986). One such benefit of collaboration is its use to combat academic isolation. For example, research conducted by Melin (2000) found researchers working with colleagues reported feeling excited to be working with colleagues on complex programs and expressed satisfaction engaging with one another more so than those who worked alone. Collaboration is also important because such partnerships have been identified as a major factor in the dissemination of scientific work (Bozeman & Corley, 2004). A study by Lee and Bozeman (2005) suggests those who collaborate produce more publications than those who do not.

Bozeman and Corley's (2004) findings revealed those who pursue mentor collaboration are more likely to obtain tenure and collaborate with women. In addition, those with larger grants are more likely to have more collaborators, and female scientists are more likely to collaborate with other females than males (Bozeman & Corley, 2004). Significant differences were noted according to rank, as 84 per cent of non-tenure track female collaborations were with other women (Bozeman & Corley, 2004). Researchers tend to collaborate most frequently with those in their geographic area and are most likely to collaborate with those in their own work group (Bozeman & Corley, 2004). This serves as a foundation to pursue additional questions regarding the role of science centers and the identification of predictors of successful collaboration.

Scientific collaborations have been defined as interactions that take place within a social context between two or more people that facilitate the completion of tasks required to achieve a mutually shared goal (Owen-Smith, Riccaboni, Pammolli, & Powell, 2002). Previous research indicates collaborations typically emerge from social networks, and research examining collaborative networks has used social network analysis to examine the ways in which scientific productivity is hindered or enhanced by social networks (Sonnenwald, 2007). One such study by Abbasi and Altmann (2011) used co-authorship data to map the collaboration network of researchers. The results of their analysis indicate research productivity is positively correlated with weighted degree centrality (centrality to the social network) and efficiency (Abbasi & Altmann, 2011). This means scholars with many ties (i.e., multiple coauthorships) have better research performance than those with fewer ties (i.e., single coauthorships) and scholars who maintain many ties to one co-author publish more than scholars with relationships to many co-authors. Our project sought to extend the use of social network analysis through the use of sociograms to evaluate scholar collaborations within a science and technology center.

Conceptual framework

To understand collaborative knowledge production, we use Akkerman and Bakker's (2011) theory of boundary crossing that draws on Bakhtin (1986) and Vygotsky (1978, 1986). Akkerman and Bakker identify (1) institutional affiliation, (2) expertise levels and (3) disciplinary differences as examples of boundaries that, when bridged, may result in new understanding. In addition, they rely on Vygotsky's (1978, 1986) conceptualisation of decision making, which supports the notion that researchers view the world through disciplinary lenses and the characteristics of their disciplines impact how they work.

Vygotsky (1987, 1986) believed what people learn is shaped by their objectives, the tools they use, communities they are part of, hierarchies of the systems they are in and rules they are subjected to. Some salient aspects of his research focused on the role of social factors such as guided learning, meaning making and his understanding that cognitive functions are impacted by individual beliefs, values and cultural adaptation. Two of Vygotsky's learning concepts are: the More Knowledgeable Other (MKO), referring to someone with better understanding than the learner about a particular task, process, or concept; and Zone of Proximal Development (ZPD), which initially measured the difference between what children learn independently and what can be achieved with guidance from a skilled partner (Vygotsky, 1987), but has now been used in numerous studies of adult learning (Bonk & Kim, 1998; Huang, 2002). Using this conceptual lens as the foundation for the current study allows us to explore how to facilitate the advancement of knowledge by encouraging scholarly boundary crossing.

Bakhtin (1981, 1986) argues that understanding ourselves and our own culture is only possible in relation to other people and other cultures. His philosophy asserts that moments when we break with conventional structures of our thoughts are when we can best grasp the truth. This view reveals the need for interaction between colleagues from different disciplinary and institutional backgrounds. Bakhtin wrote, 'The merging of all trends into one and only one would be fatal to science (if science were mortal). The more demarcation, the better, but benevolent demarcation. Without border disputes. Cooperation.' (1986, p. 136-7). In other words, science advances through consideration and reconciling of different perspectives.

Methods/Data Sources

This case study was conducted using data from a National Science Foundation Science and Technology Center. The Center is a consortium of five primary institutions including three Carnegie classified Highest Research and two Higher Research universities (Carnegie Foundation for the Advancement for Teaching, 2016), one of which is a Historically Black College and University (HBCU), North Carolina Agricultural and Technical State University. The other institutions are Michigan State University, the University of Washington, the University of Texas at Austin, and the University of Idaho. Their respective Carnegie classifications mean these institutions are in the top two categories for their level of research output. The Center has a stated mission to promote cross-boundary activity, including forms of cross-institutional and cross-disciplinary scholarship. As of January 2016, when data was collected, the Center included 834 members in roles that include academics (241), postdocs (91), graduate students (320), staff (54) and undergraduate students (99). Approval for the research in this paper was obtained from the Michigan State University Institutional Review Board.

Our study used data from a database created by the Center for members to record their annual outputs and demographic data for accountability to its grant funder, the National Science Foundation. The database includes members' institution, department, academic/administrative role, race, gender and citizenship. Since the database is updated through member self-reporting, some attributes were incomplete. We filled in as much as possible through web searching for demographic data on Center members, but this remains a limitation of the database. Members are also responsible for updating the database to show their annual outputs related to the Center, so it may not be an exhaustive list of all Center outputs. We recognise this as a limitation of using a

secondary data set. Because disciplines and institutions vary in the outputs they value, the database includes grants, publications, presentations, teaching and outreach activities. We studied 1,214 outputs from the first six years of the Center. This included 329 journal articles, 134 grants, 355 conference presentations and 141 outreach activities. Future research may disaggregate collaboration trends by type (presentations, publications, grants, and outreach) rather than considering them together. The average number of coauthors from the Center on these outputs was 3.35.

We classified the 58 department affiliations of Center members into one of seven major disciplines identified by the National Science Foundation: arts and humanities (20 members), life sciences (498 members), computer science and mathematics (137 members), engineering (92 members), environmental sciences (3 members), social sciences (22 members), or physical sciences (13 members) (NSF, 2016). This classification scheme resulted in a conservative estimate of interdisciplinary collaborations because members also consider collaboration between individual departments within these disciplines (e.g., Zoology and Biology within Life Sciences) to be interdisciplinary. A few of our classifications are not perfect as some departments (e.g., bioengineering, bioinformatics) could fit in more than one discipline.

Because collaborations often come from or continue because of social networks (Sonnenwald, 2007), we used Social Network Analysis techniques to identify factors correlated with co-authorship. We define social networks as the interaction between two or more people. Social Network Analysis can show how members of an organisation are connected to one another, where ties are lacking and which members are the most connected to others in the organisation (Cheong & Corbitt, 2009; Kadushin, 2011). Schlattmann (2017) found that network analysis is a useful method to analyze research collaboration. We used NetDraw to create sociograms detailing the co-authorship ties in the Center, and a statistical analysis program, SPSS, to identify which member attributes (discipline, institution, and role) were correlated with collaboration. We employed chi-squared tests to determine whether statistically significant differences existed between the expected frequencies of values in various categories of research and the observed frequencies. We were also able to supplement these results with corresponding data from a longitudinal study that includes surveys of member perceptions of Center effectiveness and 15 interviews with faculty members of the Center. These included members representing each of the five institutions and each of the three disciplines.

Results

The results from the Network Analysis and data analyses provide insight into who participates in cross-boundary work over six years of this five university collaboration. First, we examine cross-boundary work as a whole, and then by institution, discipline and academic role.

Cross-Boundary Work

Individuals tend to collaborate with researchers from their own institutions much more than they do with those from other institutions (compare the clumping of institutions in Figure 1 to the intermingling of disciplines in Figure 2). Interdisciplinary coauthored work is over twice as frequent as inter-institutional coauthored work. Of Center outputs, 35.3 per cent involve

interdisciplinary collaboration, 17.2 per cent involve inter-institutional collaboration and 11.6 per cent involve both. Cummings and Kiesler (2005) found projects with more disciplines involved reported as many positive outcomes (such as leading to new research, tools, positions, or partnerships) as projects with fewer disciplines, but projects with more institutions were not as successful as projects with fewer institutions.

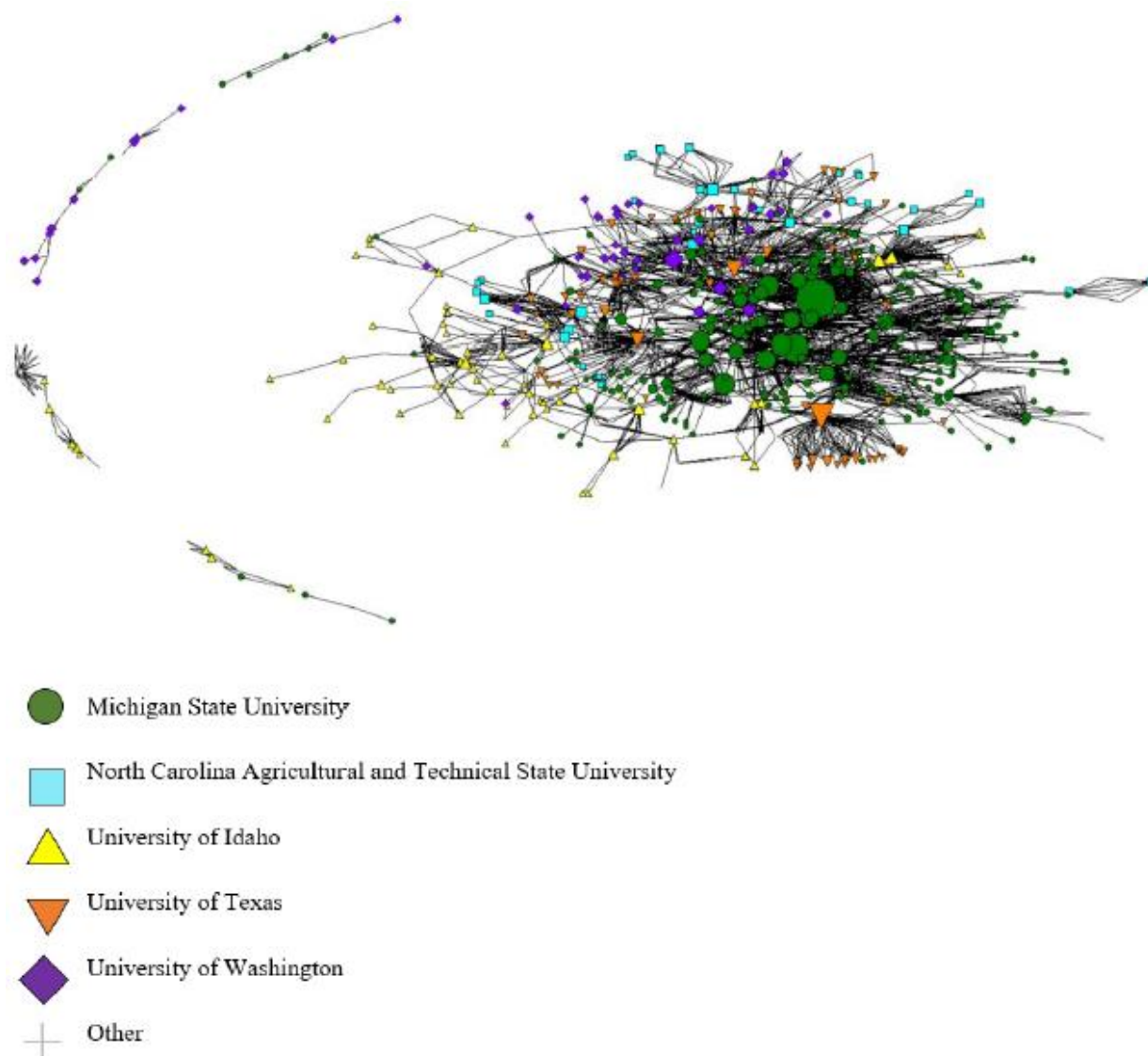


Figure 1. This sociogram shows co-authorship ties between Center members who collaborate within the Center. Shapes stand for members while lines stand for coauthorship between them. Shapes delineate institutional affiliations as displayed in the key. The size of the shape representing each member is based on the number of collaborative outputs they produced. Centrality in the diagram indicates a well-connected individual. Periphery in the diagram indicates few connections.

This sociogram illustrates the way institutions tend to collaborate mostly within their own organisation, as displayed through close clustering of like shapes. The most notable exception to this trend are the squares representing North Carolina Agricultural and Technical State University, which intermingle with the other shapes representing other institutions. Another way to view these data is by disciplinary association which is displayed in the following figure.

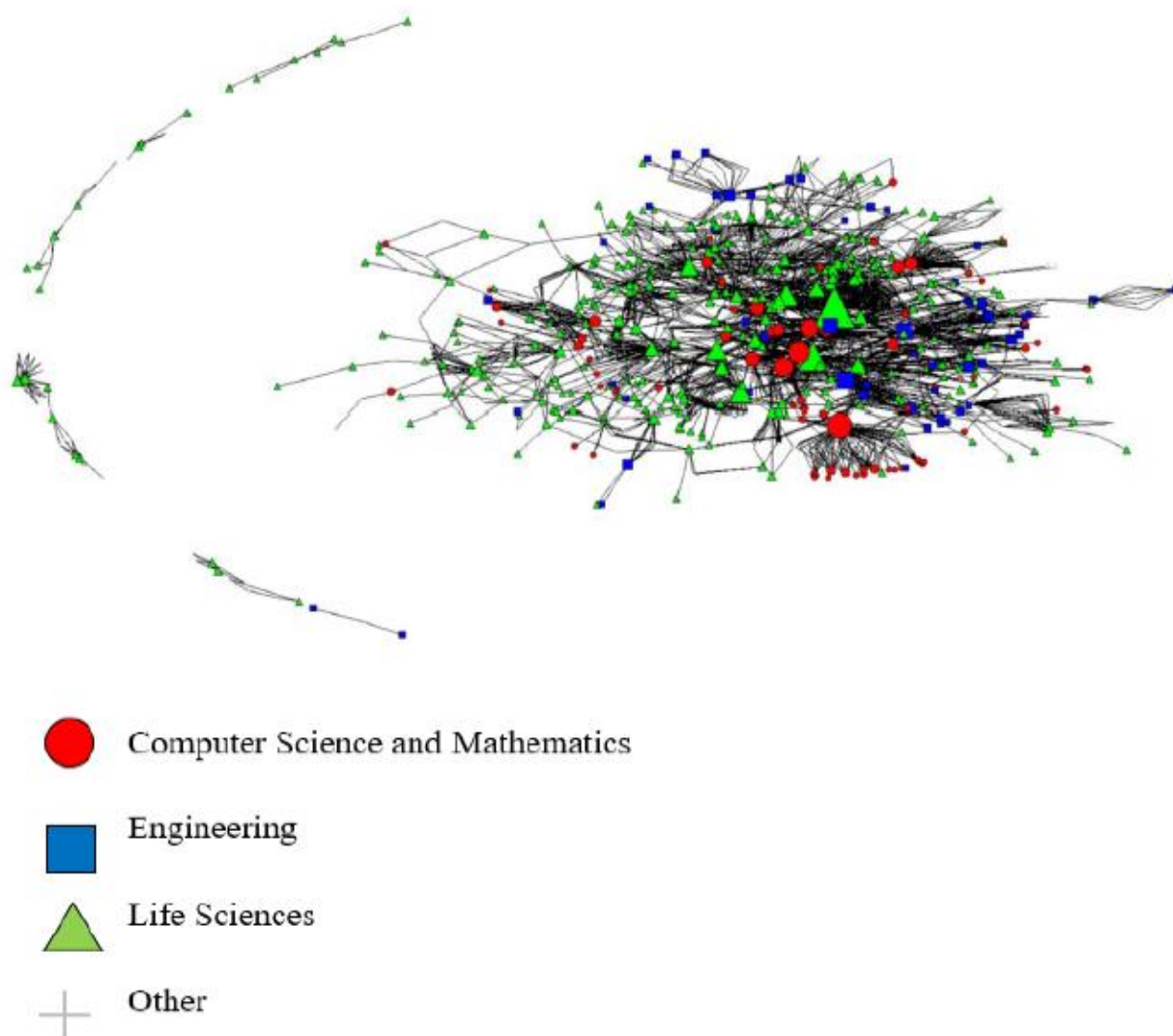


Figure 2. In this sociogram, shapes delineate disciplinary affiliations as displayed in the key. Again, the size of the shape representing each member is based on the number of collaborative outputs they produced. The largest triangle in this image represents the same individual as the largest circle in the last image, a prolific collaborative scholar who studies the life sciences at Michigan State University.

In contrast to the clustering by institution in Figure 1, members do not cluster by discipline, but form close collaboration ties incorporating different disciplines, as depicted by the intermingling between different shapes in this sociogram. Also evident in this sociogram is a collaborative relationship between a faculty member in computer science at the University of Texas and his graduate students, represented by the cluster of circles in the lower right section of the sociogram. As illustrated by the position of graduate students on the periphery of the image, as opposed to the more central position of the faculty member, represented by the larger circle, these graduate students rarely collaborate outside their institution.

Based on the results of this study and considering Vygotsky's (1986) concepts of the More Knowledgeable Other and the Zone of Proximal Development, it is pragmatic for scholars to seek expertise within their own institution, as they are able to identify and enlist the help of experts more easily and often, compared with trying to make similar connections across institutions. We received feedback from Center members through our qualitative research, which was collected during the same time period as the recorded outputs. Our qualitative research revealed institutions and departments placed different value on boundary crossing work. For instance, one participant worried "whether there will be adequate within-department rewards for faculty working primarily across departments". When working on interdisciplinary research, individuals and groups may lack congruence because the research is impacted by factors such as beliefs, values, and culture that stem from foundational disciplinary differences; however, scientists may willingly overcome these hurdles in order to find the disciplinary expertise they need to solve their research problems.

Interdisciplinary co-authorship is growing at the Center, while the frequency of interinstitutional research has reached a plateau. Individuals who cross disciplinary boundaries are more likely to cross institutional boundaries, and vice versa. Most (67.5 per cent) interinstitutional work is also interdisciplinary, but most (67.1 per cent) interdisciplinary work involves only one institution. While incentives of funding and opportunities for interdisciplinary research available to Center members are often enough to overcome the disciplinary barriers, there are not as many incentives or opportunities to overcome the barriers of distance for inter-institutional research, even with support of telecommuting technologies. Inter-institutionality may be less fruitful in producing original ideas than interdisciplinarity, since scientists studying the same specialty at different institutions may have similar mindsets because they have had similar education. Those who collaborate interdisciplinarily are 37.9 per cent more likely to collaborate interinstitutionally than their peers who do not collaborate interdisciplinarily. Those who collaborate interinstitutionally are 39.6 per cent more likely to collaborate interdisciplinarily than their peers who do not collaborate interinstitutionally. This may be because those with the best interdisciplinary networks are also those with the best interinstitutional networks, since an established reputation in interdisciplinary research is likely to correlate with a geographically widespread reputation.

Institution Mission and Cross Boundary Work

The Center we examined includes four institutions with similar missions and one HBCU, North Carolina Agricultural and Technical State University. The HBCU's mission statement focuses on the provision of educational opportunities and its historical focus on educating black students, while the missions of the other four institutions also include teaching, but place more emphasis on the research goals of their institutions (NCA&TU, 2018; MSU, 2018; UW, 2018; UTA, 2018; UI, 2018). Though we found that the mission of the institutions seems to matter, the institutional rankings (according to the "Best Colleges" national rankings) of the universities by *Forbes* and *U.S. News and World Report* does not correlate with the members' likelihood to collaborate interdisciplinarily, inter-institutionally, or in general.

One way in which the mission made a difference was that scholars at the HBCU involved in the Center were least likely to collaborate among all the Center institutions as only 42.4 per

cent of HBCU members collaborated with other Center members. This might be because these scholars are more focused on teaching than research in accordance with their institutional mission, consider single-authored works to have more value for them, or have fewer people willing or available to collaborate with them in fields represented in the Center. Perhaps there is not as robust an environment supporting research at the HBCU compared to a highest intensity research institution. The educational focus of the academics at the HBCU was exemplified in an interview in which a participant was asked what he would like the Center to do to help his career; he answered, “One of the big things is just resources and opportunities to create opportunities for students.” This is juxtaposed against the values expressed by researchers at the Highest Research Universities, such as one academic who said the Center “has spurred new collaborations, taking my research into areas that I would not have explored otherwise”.

While the scholars at the HBCU are least likely to collaborate overall, at only 42.4 per cent, scholars at the HBCU who collaborate are the most likely to engage in *inter-institutional* collaboration with other Center members, at 79.5 per cent. A chi-square test of independence showed an association between institution and inter-institutional collaboration as statistically significant, $X^2(5, N = 485) = 16.41, p = .006$ (see Table 1). The HBCU’s collaboration stood out, while the rest of the institutions looked alike. This inter-institutional work at the HBCU may reflect a greater need for collaboration to produce scholarship. Only 11 per cent of Center members were affiliated with the HBCU, so they had fewer collaborators available to them at their home institution than researchers at the other four institutions.

Table 1.

Results of Chi-square Test and Descriptive Statistics for Institution and Inter-institutional Collaboration

Institution	Inter-Institutional Collaboration		Total Collaborating Members
	True	False	
U. of Idaho	25 (38%)	41 (62%)	66
Michigan State U.	103 (43%)	138 (57%)	241
North Carolina A & T State U.	20 (51%)	19 (49%)	39
U. of Texas - Austin	26 (37%)	45 (63%)	71
U. of Washington	21 (40%)	31(60%)	52
Other	12 (92%)	1(8%)	13

Members at the HBCU are also the most likely to engage in *interdisciplinary* collaboration, which may be a result of being the only institution in the Center with nearly equal distribution of members from all three of the center’s core disciplines: Life Sciences, Computer Science and Engineering. A chi-square test of independence showed an association between institution and participation in interdisciplinary collaboration as statistically significant $X^2(5, N = 485) = 32.18, p < .000$ (see Table 2). Members at the HBCU are the most likely to be involved in collaboration between multiple academics, which reflects the fact that they do not have any Center postdocs and also makes sense since they do more interdisciplinary and inter-institutional work than the other institutions, which often incorporates multiple academics. They have the

highest rate of collaborations between graduate students and academics, which fits well with their teaching mission.

Table 2.

Results of Chi-square Test and Descriptive Statistics for Institution and Interdisciplinary Collaboration

Institution	Interdisciplinary Collaboration		Total Collaborating Members
	True	False	
U. of Idaho	25 (38%)	41 (62%)	66
Michigan State U.	162 (67%)	79 (%)	241
North Carolina A & T State U.	31 (79%)	8 (%)	39
U. of Texas - Austin	42 (59%)	29 (41%)	71
U. of Washington	25 (48%)	28 (54%)	52
Other	5 (38%)	8 (62%)	13

Disciplinary Cross Boundary Work

Members of all three core disciplines (Computer Science and Mathematics, Engineering and Life Sciences) participate in collaboration and inter-institutional collaboration fairly equally. A chi-square test of independence found no significant differences for the amount of institutional boundary crossing by disciplines. However, there is a difference in disciplinary boundary crossing by discipline. Life Sciences members collaborate interdisciplinarily at a lower rate than computer science and mathematics or engineering members. A chi-square test of independence showed an association between discipline and participation in interdisciplinary collaboration as statistically significant $\chi^2(3, N = 485) = 20.320, p < .000$ (see Table 3). This might be explained by the fact that evolution is traditionally a part of the study of Life Sciences, while it is a new object of study for engineers, mathematicians and computer scientists. It may therefore be difficult for scholars in computer science or engineering to produce evolution work without collaboration with a life scientist. Previous scholarship on interdisciplinarity (Becher, 1989) claimed that applied fields tend to collaborate more than pure disciplines. In the case of an interdisciplinary collaboration, disciplines such as mathematics that are normally viewed as pure, become applied to a common object of study (in this case evolutionary biology). Perhaps this interdisciplinary work is leading to a new field.

Table 3.

Results of Chi-square Test and Descriptive Statistics for Discipline and Interdisciplinary Collaboration

Discipline	Interdisciplinary Collaboration		Total Collaborating Members
	True	False	
Life Sciences	166 (53%)	149 (47%)	315
Engineering	42 (68%)	20 (32%)	62
Computer Science & Mathematics	57 (74%)	20 (26%)	77
Other	25 (81%)	6 (19%)	31

Academic Role Cross-Boundary Work

Overall, 38 per cent of collaboration involves multiple academics (the rest primarily involves a single academic collaborating with students and/or postdocs). However, the majority (62 per cent) of *interdisciplinary* collaborations and the majority (65 per cent) of *inter-institutional* collaborations involve multiple academics. Involvement of multiple academics correlates with more boundary crossing. This may be because they have more developed networks than students or postdocs. It makes sense that scholars would seek the expertise of experienced academics as collaborators, rather than aspiring academics.

As might be expected, a greater proportion of graduate students and postdocs collaborate compared with academics. Publishing with others may be more feasible at this level rather than striving for single authored publications, or may be a function of working relationships with academics due to assistantships, lab assignments and traditional local mentoring relationships. Only 6 per cent of collaborations occurred without the participation of an academic, and these collaborations were primarily outreach activities, such as giving science presentations at K12 schools, rather than high profile outputs such as journal publications. Of collaborations, 54 per cent involved at least one graduate student and at least one academic. Center members learn through social interactions with their expert senior colleagues with whom they are in close proximity as Vygotsky (1986) noted among younger learners.

Though a greater proportion of graduate students and postdocs collaborate than academics, a smaller proportion of graduate students and postdocs collaborate interinstitutionally. A chi-square test for independence showed a statistically significant difference between role and inter-institutional collaboration, $\chi^2(5, N = 485) = 38.059, p < .00$ (see Table 4). Graduate students and postdocs may have less developed networks at other institutions than academics, being newer to academia with fewer opportunities to cultivate relationships needed to work across institutions with others to whom they do not directly report. Academics accumulate networks over time (Fitzgerald, 2018). Academics may not always include students in work that is inter-institutional which requires external funding and extra coordination.

Table 4.
Results of Chi-square Test and Descriptive Statistics for Role and Inter-institutional Collaboration

Institution	Inter-Institutional Collaboration		Total Collaborating Members
	True	False	
Academics	82 (59%)	58 (41%)	140
Postdocs	28 (43%)	37 (57%)	65
Graduate Students	65 (32%)	139 (68%)	204
Undergraduate Students	24 (60%)	16 (40%)	40
Staff	3 (13%)	21 (88%)	24
Other	5 (42%)	7 (58%)	12

Graduate students and postdocs in this study do not have trouble getting interdisciplinary collaborators within their own institution. Although one might suspect that interdisciplinary work would be more challenging for students still learning their disciplines, a chi-square test for independence showed no statistically significant relation between role and interdisciplinary collaboration. Perhaps this is because the Center incentivises interdisciplinarity and offers courses to cross-train students in disciplines represented in the center. In 2013, postdocs and doctoral students were asked if participation in the Center has increased their networks outside their discipline, and 52.4 per cent of postdocs and 56.7 per cent of doctoral students indicated *a great deal*.

Those in Center leadership positions (primarily well-established senior scholars around whose work the original Center proposal was founded) account for much of the interinstitutional and interdisciplinary work. While Center leadership makes up only 6.6 per cent of members, they account for 13.3 per cent of inter-institutionality and 10.3 per cent of interdisciplinary work. They may have the best networks and the most freedom to collaborate with whomever they choose.

Discussion

With Bakhtin's (1986) idea of the value of breaking conventions to the advancement of knowledge in mind, the lower levels of interinstitutional collaboration may be attributed to researchers feeling bound in their interactions by the formality of long distance communication; it may be easier for those who are together physically to develop the necessary personal relationships leading to boundary spanning and meaningful collaboration. The Center communicates across institutions using a video conference platform. Many survey respondents expressed the idea that it is "difficult to feel connected with the video conference platform". It is important to respond to the social needs of researchers to encourage their best work. To work effectively together, scientists need pathways to communicate informally with one another. A consortium such as the one we studied can help scientists hurdle the barriers of distance. The advancement of science depends on acknowledging communication challenges between scientists at all levels due to location, career status, values, disciplinary culture, reward structure, and other social norms (Vygotsky, 1986). Opportunities to develop informal relationships are not just morale boosters; they are catalysts for scientific creativity (Lattuca, 2001). This was born out by comments from our participants, many of whom said in various ways that the part of the Center which appealed to them most was "having faculty members and graduate students experience deep, prolonged interdisciplinary thinking about research problems".

Reconnecting our research to Vygotsky's (1986, 1987) learning concepts, learners come to understand the knowledge of the expert (More Knowledgeable Other) through interactions with the expert. Each person in a collaboration brings different expertise to the project. However, as noted above, barriers such as distance, values and disciplinary culture can also inhibit the dissemination of knowledge, which is why more interdisciplinary research than inter-institutional research occurs. One challenge of developing a department is whether to hire like-minded academics to develop depth in a specialty or to hire a diverse group to promote multiple ways of knowing at your own institution.

To promote boundary crossing, it is important for departments to reward scholars for their efforts in disciplines other than their own. This can sometimes be difficult because disciplines have varying ideas of which outputs and outlets have the most value. Another way to promote boundary crossing is to create an environment with fairly equal representations of different disciplines. Based on our findings, a balanced representation from disciplines involved in a consortium could help facilitate interdisciplinary collaboration. Students who mature in an environment that blends perspectives may gain awareness of their respective strengths and weaknesses and what different viewpoints have to contribute.

Considering Bakhtin's (1986) assertion that the advancement of knowledge comes from the reconciliation of different perspectives, perhaps the amount of inter-institutional co-authorship in the Center we studied is not limited due to insurmountable differences between the institutions, but a result of all the similarities they share. The more teaching-focused HBCU may do the best job of interinstitutional co-authorship because it has the greatest differences from the other institutions and therefore, more need and opportunity to cross boundaries. Scientists, including those at the other institutions, have less to learn from those similar to themselves and much to learn from those who are distinctive. Those developing collaborative initiatives in higher education should consider inviting institutions with differing missions who may have the most to contribute to one another.

In collaborative scholarship, scholars depend on one another to bring different contributions to the research. The pressure to produce and limited experience for early scholars can inhibit collaboration that takes place more freely among established scholars no longer worried about tenure and promotion. Co-authorship between experienced scholars and new scholars is a form of teaching and mentoring. Maher, Timmerman, Feldon and Strickland (2013) argue that co-authorship with academics is essential for doctoral students to learn the norms of scientific writing. New scholars depend on those more experienced to produce scholarship and advance their careers, but every collaborator needs an incentive. Tenure and promotion evaluations could give credit to academics for co-authorship with students, new scholars, or scholars at minority serving institutions.

Implications of our findings include: (1) funding agencies need to consider the definition of cross-boundary work (disciplinary, institutional and role) when creating Requests For Proposals and what data will be considered valid for their definition of crossboundary work if funding is to result in more authentic collaborations; and (2) universities need to support crossboundary work through allocating resources and emphasising crossboundary research in tenure and review processes. Since its inception, the Center in our study has made numerous efforts to improve crossboundary collaboration e.g., increasing technology support, changing funding criteria for proposals, adding mentoring opportunities. Still, we found uneven patterns of participation among members with much of the output coming from a smaller group of 'heavy hitters' who also maintained significant output unrelated to Center efforts. This could mean that part of the challenge is breaking into networks that already exist rather than looking to launch new groups for cross-boundary work. However, more research is needed into the encouragement of cross-boundary work.

If we want to move beyond co-authorship as a proxy for scientific collaboration, we need also to move beyond quantitative analysis of output and the type of reports provided to funders as evidence of change. Further interviews with scientists could shed light on how and why they choose to participate in cross-boundary work, what strategies are used to overcome challenges, and what are seen as benefits and costs of doing so. Future research could investigate the long term impact of Centers on the future collaboration habits of scholars involved in them.

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