Leveraging Social Network Data to Support Faculty Mentoring: Best Practices from NJIT Advance

Nancy Steffen-Fluhr, Regina Collins, Anatoliy Gruzd, Mingzhu Zhu, Brook Wu, Katia Passerini
NJ Institute of Technology (NJIT)/Dalhousie University/NJIT/NJIT/NJIT

"The Old Boys Network" used to be a metaphor, signaling hidden inequalities. Now it is a map—a web-like highway on which we can track the flow of social capital from one human node to another. At the NJIT Advance Project, funded by a grant from the National Science Foundation, we are learning how to read that map and to transfer our navigational ability to young faculty and university change agents. In broad terms, the goal of NJIT Advance is to demonstrate that social network analysis can be used to affect institutional transformation, ensuring the full participation of women in academic science and engineering. Our specific objective is to develop predictive models of faculty career success as part of a novel, network data-driven approach to faculty mentoring. In this paper, we discuss the methodology we have used to collect and analyze faculty network data over the past decade (2000-2010) and demonstrate how we are making that data available to faculty mentors and mentees through two new mapping tools: the Research Interests Map and the Faculty Connections Visualizer.

The roots of this project go back to 2005 when research for our Status of Women Faculty Report made it clear that at NJIT, as at other similar institutions, women felt isolated, outside the information loop. In our initial grant, we addressed this issue by stimulating greater interconnectivity among researchers and, simultaneously, studying existing patterns of interconnectivity. The good news, seven years later, is that many of the gender differences suggested by our preliminary data seem to have diminished. Our most recent analysis (presented in greater detail below) shows that there are no statistically significant differences between female and male retention. Men and women are promoted at essentially the same rate as well. These local results are consistent with national data. A 2010 study published by the National Academies Press, Gender Differences at Critical Transitions in the Careers of Science, Engineering, and Mathematics Faculty, concluded that, "For the most part, men and women faculty in science, engineering, and mathematics have enjoyed comparable opportunities within the university, and gender does not appear to have been a factor in a number of important career transitions and outcomes" (p. 23). A more recent longitudinal study of 2966 science and engineering faculty from 14 universities drew much the same conclusion: "Overall, men and women are retained and promoted at the same rate" (Kaminski and Geisler, 2012, p. 864).

This good news tends to obscure some very troubling data, however. Despite apparent progress in equity, the gender composition of the academic STEM workforce is still profoundly different from the human population it serves. And likely to remain so. Despite slightly improved hiring rates for women (up from 25% to 27%, according to Geisler), retention failures for both men and women are so frequent, especially at the assistant professor level where the 11 year attrition rate is 50%, that "it may take 100 years before women are 50% of the faculty in STEM departments" (Kaminski and Geisler, p. 866). At NJIT, where the 2001-2010 hiring rate for female STEM faculty was only 17.8%, it may take forever!

When the results of the Kaminski/Geisler study were announced in The Chronicle of Higher Education, readers inundated the E-journal with cynical comments, the gist of which was "So what?" The notion of equality is a lot easier to sell than the notion of parity. And yet parity is profoundly important. For one thing, trying to solve important problems using only half of the
collective human brain is not smart. This is more than rhetoric. A recent study sponsored by the National Science Foundation demonstrated that the collective intelligence of a group (a measurable capacity dubbed the “c factor”) is positively correlated with the proportion of females in the group (Wooley et. al., 2010). That is, the problem-solving ability of a group diminishes as the number of women decreases.

There are other, more obvious costs as well. Academic hiring is expensive, especially in STEM where start-up packages are necessarily large. Promotion and tenure failures are increasingly damaging to institutions who have to husband scarce dollars as never before. All of which means that, the 2010 NAS report notwithstanding, faculty retention is still a critical issue for women in STEM. "Few women want to go to places where few women are" (Steffen, 2010). To break this negative feedback loop, we need to work smarter as well as harder, giving women STEM faculty not merely the same chance at advancement as the men but a better chance: a network advantage.

**Data Collection Methods:** NJIT Advance is essentially a proof-of-concept grant. The concept at issue is whether or not supporting collaboration supports women STEM faculty--at NJIT and, potentially, at other, similar institutions as well. To answer this question, we needed to know more about the relationship among four broad variables: collaboration, productivity, retention, and advancement in rank. To make our work useful to others, we also needed to choose a methodology that could be sustained at NJIT and replicated elsewhere on a large scale.

Social network analysis (SNA) has been around since the 1930's when Jacob Moreno first introduced "sociometry"; but the need to collect data in time-consuming face-to-face interviews limited its use. In the last decade, however, advances in computing and the availability of large data sets have made SNA increasingly attractive, especially for longitudinal analysis. A powerful combination of theory and tools, SNA allows researchers to open the cover of the human hive and track the complex choreography inside. SNA demonstrates in precise, mathematical terms what we know intuitively--that the hierarchies on the organization chart often have very little to do with the way work really gets done and who really has power. The X-ray vision that SNA provides is especially important for institutional change projects, vulnerable as they often are to the deceptions of tokenism.

Although we experimented with several forms of social network data collection, including surveys and interviews, fairly early on in our project we settled on bibliometric data-mining as our primary method. The advantages of this approach are fairly obvious: faculty publication data are free, verifiable, and can be scraped off of individuals without their active participation. Moreover, publications are invariably time-stamped. This means that when bibliometric data is combined with Human Resources data (hire dates, rank, tenure status, etc.) and with Research Office data (grant proposals submitted and funded), we can track the evolution of the faculty network over time, noting when and how new nodes (people), new ties, and new resources are added to the system (Barabasi, 2001).

Co-authorship is only one dimension of collaboration,\(^1\) of course, but it is increasingly central to faculty life, driven, in part, by greater specialization, lower communication costs, and increased pressure to publish. A large body of social science literature attests to both the importance of collaboration in contemporary academic science and engineering and to the appropriateness of using co-author networks as proxies for collaboration.\(^2\) Although the frequency of co-authorship obviously varies by discipline, it is now the norm in STEM fields, even in mathematics where it used to be rare (Mali, 2012; Grossman, 1995). Moreover, unlike citation networks, co-authorship captures real social ties (Mali, 2012).
In order for co-authorship network mapping to be a sustainable, scalable practice in mentoring and institutional transformation, data collection needs to be automated and accurate. We used a three-stage approach to achieve this goal. We began by searching Google Scholar. Human Resources provided us with a spreadsheet containing the names of all NJIT faculty from 2000-2010. We wrote a program that crawled Google Scholar looking for publications by people with these names. Using raw data from the initial results, a parser program followed each title link to the source database and extracted the relevant bibliographic information. In the initial run, our meta search returned 63,937 raw hits from more than 2,500 separate source databases. Predictably, the raw data contained a great deal of "noise"--e.g., duplicates, different versions of the same work, etc. The inevitable "common name problem" was especially troublesome--i.e., distinguishing the work of an NJIT faculty member from the work of non-NJIT authors who have the exact same name. Although we were able to clean the data successfully, we became concerned about the sustainability of our method because the information display patterns unique to each source database meant that we would need to create hundreds, perhaps thousands of separate parser programs--and to update them periodically in response to format changes in the source DBs. In consequence, we switched to Elsevier’s large database (Scopus) as our primary source. After our NJIT Advance grant ends, our database will be periodically updated by feeds from Digital Measures (DM), a commercial software system adopted by the university in 2009 through which faculty are required to submit their annual reports. By mining Scopus, we were able to construct a database that contains 8395 NJIT faculty publications, 3608 of which were co-authored by NJIT faculty during the period 2000-2010. (These co-authored publications are our "network.") We were also able to identify a subset of publications in which one of the collaborators was a faculty member from another university and another subset of publications in which NJIT graduate students were one or more of the co-authors. We combined the publication counts with personnel data obtained from HR to create an attribute spreadsheet that contains the names of the 514 faculty members who worked at NJIT from 2000-2010, their department, gender, rank progression, tenure status, hire date, separation date (if any), retention status (left/stayed), years at NJIT, and years in the study. We performed standard statistical tests on this data using SAS and ANOVA. To analyze the structure of the faculty co-authorship network and calculate centrality measures, we used the Organizational Risk Analyzer (ORA) software package and UCINET, a social network analysis program distributed by Analytic Technologies.

Collaboration, Productivity, Retention, and Advancement: Many decades ago, faculty were tenured or not tenured at NJIT depending on whether they were perceived to be "collegial" by their senior colleagues. (Following the rules of homophily, men passed the test more often than women.) Today, at NJIT and across academia, promotion and tenure (P&T) is largely a numbers game. Although good teaching (as evidenced by student evaluations) and good citizenship (as evidenced by committee service) are necessary, they are never sufficient for advancement. In STEM fields, the basic "productivity" formula is number of papers published in journals and conference proceedings + the impact factor of these journals/conference proceedings + the h-index (which purports to measure publication quality, defined as the number of citations, as well as quantity) + number of grant proposals submitted + dollar amount of funding received. We are tracking all of these dimensions in our project; in the data analysis we report in this paper, however, simple publication count is used to measure productivity.

We began by making sure that we could prove the obvious: that at NJIT from 2000-2010, faculty productivity, as defined by publication count, was positively correlated with both
retention and promotion, especially the movement from untenured assistant professor to tenured associate professor. We generated a series of hypotheses and tested them against our data in a number of different ways. NJIT consists of five schools/colleges: the Newark College of Engineering (NCE), the College of Computing Sciences (CCS), the College of Science and Liberal Arts (CSLA), the School of Management (SOM), and the College of Architecture and Design (COAD). In some instances, we looked at faculty data across all disciplines and included in our analysis non-tenure track Research Professors because they often co-author; however, the results presented below generally focus on STEM faculty (i.e. from the five departments of NCE, CCS, and four of the seven units in CSLA: Physics, Mathematical Sciences, Biological Sciences, Chemistry and Environmental Science). Apart from the Research Professors, our data set contains only tenure track faculty. When we tested hypotheses involving rank change, we removed the Research Professors, who cannot be promoted. We were also careful to control for the uneven gender distribution in the sample (77 females, 437 males).

H1. STEM faculty who publish more are more successful in terms of rank increase. Initially, we tested this hypothesis on all of the tenured/tenure track STEM faculty in the sample (n=327–38 female; 289 male). The hypothesis was supported: 0.3898, p < .0001, ANOVA F=31.96, p < .0001 (df = 2). Because we were especially interested in the impact of publication on the rank change associated with tenure, we also tested this hypothesis on a cohort composed of STEM faculty who were hired at the rank of assistant professor from 2000-2003: 6 Again, the hypothesis was strongly supported: 0.64695, p < .0001; ANOVA F=27.35, p < .0001 (df = 1). However, we were concerned that our analysis might be skewed because our dataset does not count publications of people who left NJIT during the study period, and it is to be expected that somebody who left will have fewer publications. To correct for this problem, we redid the assistant professor cohort study a slightly different way: dividing the total number of publications by the number of years in our study. Once again, the hypothesis was strongly supported. Those who did not move up in rank had an average (mean) publication rate of 5.73 publications per year (SD=3.36). Those who were promoted from assistant to associate had an average (mean) publication rate of 8.67 publications per year (SD=0.91). A t-test shows that this difference is statistically significant (t=3.60, p=.0009). The correlation for rank change and publication rate was 0.505, p=.0009, which is quite strong. There was a weaker but nevertheless positive correlation (0.220, p=0.0122) between publication rate and rank change for all STEM faculty who had an initial rank of Assistant Professor during our study.

We also investigated another, closely related hypothesis: H2 STEM faculty who left the university during the study period had fewer total publications than faculty who were retained. We tested this hypothesis on the data for the assistant professor cohort hired between 2000-2003, dividing the total number of publications by the number of years each was in the study. Those who stayed had an average (mean) publication rate of 8.78 publications per year (SD=0.94). Those who left had an average (mean) publication rate of 3.46 publications per year (SD=2.33). A t-test confirmed that this difference is statistically significant (t=10.35, p<.0001). The correlation for negative retention and publication rate was -0.859, p<.0001, which is very strong. An ANOVA test for negative retention and publication rate also produced significant results: F=107.22, p<.0001 (df=1).

Productivity and Gender: We tested a number of hypotheses that predicted differential career outcomes for female and male faculty and found no statistically significant support for any of them. However, we did find some support for the widely held, though much contested belief that women faculty publish less than their male counterparts. (Lee & Bozeman, 2005, p. 679).
Reviewing relevant studies conducted over the last 20 years, Lariviere et al. (2011) conclude that "women publish between 70% and 80% as many articles as men" and that these differences are consistent across disciplines and national boundaries. When we looked at tenured tenure track STEM faculty publication rates by dividing the total number of publications by the number of years in our study, our results, too, suggested a gender gap. From 2000 to 2010, the mean publication rate for women was 12.08 (SD=8.83). In contrast, the mean publication rate for men was 19.19 (SD=13.34). That is, the NJIT female STEM faculty publication rate was only 63% of the male rate. (T-test: t=3.28, p=0.0011 (df=345). ANOVA: F=10.75, p=0.0011, df=1.) Even though our other hypothesis tests suggest that gender is no longer an overt factor in career advancement at NJIT, this data raises a red flag, spurring us to re-examine our earlier studies and obtain additional quantitative and qualitative data.

**The Relationship Between Collaboration & Productivity:** After establishing to our satisfaction that faculty productivity, as defined by publication count, is positively correlated with both retention and promotion, we turned next to a more complex question directly related to the goals of our project: What is the relationship between collaboration and productivity? The literature is somewhat divided on the matter. There is general agreement that although faculty collaboration is still infrequent in some disciplines (e.g., history), it is the now the norm in STEM. Beginning with Price and Beaver in 1966, social scientists have often used co-authorship as a direct measure of faculty collaboration (He et. al., 2005, p. 308). Although there are some doubters, the majority of these studies agree with Lee and Bozeman (2005) that, "When publishing productivity is measured by... a scientist's total number of publications, collaboration is a strong predictor of publishing productivity" (p. 683). Laband and Tollison (2000) demonstrate that coauthored papers are more likely to be accepted for publication than single-authored papers; and a number of studies suggest the co-authorship results in greater quality as well as greater quantity--i.e., higher citation counts (Wuchty et al., 2007; He et.al., 2009).

In addition to increased productivity, collaboration offers many important benefits to both individual faculty and their academic units. As research problems have increased in complexity and the equipment needed to solve them has increased in cost, team-based research, often across disciplines, has become essential. The exponential growth of scientific knowledge makes it increasingly difficult for a solo researcher to keep up with developments even in her own discipline, much less beyond it. In these circumstances, division of labor offers crucial efficiencies, especially when one's partners have complimentary expertise. Collaboration among people with different intellectual tool kits drives knowledge creation and innovation. Collaborators learn from each other as they solve problems together. They point each other in the right direction, providing easier access to new and novel information. For young faculty especially, collaboration with a more experienced researcher is often the only way to acquire crucial tacit knowledge. Good collaboration involves devil's advocacy, an internal referring process that weeds out unfruitful approaches before time is wasted on them. It gives researchers a safe way to reality check their views. Most important of all for us at NJIT Advance, collaboration diminishes social isolation and provides network access to increased social capital. In short, when it works well, strategic collaboration offers the very advantages that women faculty need most in order to thrive: the ability to do more high quality work in less time--and the ability to signal the value of their work to the research community as a whole.

Given the obvious benefits of collaboration, change agents (including those of us at NJIT Advance) are often tempted to run intellectual "speed dating" mixers for faculty, encouraging mentees to accumulate as many collaborative partners as possible. Young women faculty get this
advice especially often, under the heading of "networking." For example, Rankin and Nielsen (2006) write, "Generally speaking, the more people you know the more chances you will have to benefit from your network" (110). This well-intentioned suggestion ignores two important problems, however. 1) Collaborations have costs as well as benefits; and 2) not all collaborators are equal. In social networks, as in real estate, it is often “location, location, location” that creates value.

Like any interpersonal relationship, every faculty research collaboration involves time, effort, and angst. International collaboration, often touted as especially productive (He, 2009), incurs obvious costs in time and money for travel and less obvious "transaction costs" that result from differences in language and cultural expectations (Duque et al., 2005). At NJIT and other technological universities where the faculty cohort is ethnically diverse and contains many people born and raised outside the United States, even internal collaboration often involves complex cross-cultural communication issues. Although division of labor potentially saves time and effort, actually reaping the "assembly effect" latent in group work \((1+1+1=5)\) requires a sophisticated understanding of small group process, expertise in effective project management, and, not least, experience in conflict resolution. (And skill in psychiatric counseling, some might add.)

We've all experienced the frustration of discovering that someone on our team has not carried his weight and that we will have to do the work ourselves. And many of us have had the even more daunting experience of discovering that our work has been credited to another member of our group, perhaps the very person who did not pull his weight. (q.v. Margaret Rossiter's "Matilda Effect.") This is a particularly crucial issue when we use SNA to design mentoring programs for young faculty. On the one hand, we want to match them with well-positioned senior researchers from whom they can acquire tacit knowledge. At the same time, we need to protect them from being exploited. We also want to help them strike a balance between being together and being alone, both modes being essential to creativity and innovation. Living today in what Sherry Turkle calls an iPhone-driven "culture of distraction," this balance may be especially hard to find. We can do something, however, to help young faculty (and not-so-young faculty as well) reduce the most basic transaction cost associated with professional collaboration: locating and assessing potential research partners. In the remainder of this paper we describe how we have begun to do this at NJIT Advance, using data from our social network analysis to power two web-based mentoring tools: the Research Interests Map and the Faculty Connections Visualizer.

The Impact of Co-authorship on Productivity & Advancement--NJIT Advance Data: We began by trying to establish that our assumptions were true and that collaboration (specifically, co-authoring) was in fact positively correlated with productivity (measured as publication count) and a predictor of faculty career advancement. We tested a third hypothesis--

\textbf{H3. STEM faculty who coauthor more will publish more than faculty who coauthor less--}on all of the tenured/tenure track STEM faculty in the sample \((n=327--38\text{ female; 289 male})\). As expected, the correlation was strong: 0.79180, \(p<.0001\). A regression analysis confirmed our results: \(F=611.18, p<.0001, df=1, R^2=0.638\). Again, because we were especially interested in the impact of co-authorship on pre-tenure junior faculty, an at-risk group, we also tested this hypothesis on a cohort composed of STEM faculty who were hired at the rank of assistant professor from 2000-2003. And again, the hypothesis was strongly supported (Correlation: 0.74069, \(p<.000\); Regression Analysis: \(F=46.19, p<.0001, df=1\). We tested the relationship between co-authorship and rank change (retention/advancement) directly as well, hypothesizing that \textbf{H4 STEM faculty who co-author more are more successful in terms of rank increase.} The correlations were less strong but still statistically
significant (0.74069, p<.0001) and confirmed by regression (F=46.19, p<.0001, df=1, \( R^2 = 0.549 \)). In short, co-authorship does seem to be a behavior positively correlated with productivity. Although this is a work in progress and we are continuing to expand and refine our dataset, these initial results encourage us to continue our efforts to diminish the isolation of female faculty by stimulating and supporting interdisciplinary research collaboration.

**The Impact of Network Centrality on Productivity & Advancement:** In addition to these fairly straightforward modes of bibliometric analysis, we wanted to use the more subtle tools available in SNA to explore the core concepts that shape our project: that network *structure* is positively correlated with faculty career success and that we can leverage SNA data to give women faculty a network edge. We began by using SPSS to re-run our co-authorship and productivity tests on all 371 NJIT faculty members, STEM and non-STEM, who published at least one co-authored article from 2000-2010 (i.e., the faculty population in our network). This time we looked at another variable as well: the number of graduate students with whom each faculty member had collaborated on a paper. Our results confirmed that the number of co-authored publications positively influences the total number of publications (and hence, indirectly, career advancement); however, the number of publications co-authored with students is actually twice as influential as the number of publication co-authored with other NJIT faculty. (The standardized coefficients beta values were .314 for total publications co-authored with faculty and .674 for publications co-authored with students.) Both of these factors together—the number of co-authored publications + the number of students—explained 84% of the variance in the total number of publications. (i.e., The adjusted \( R \) square was .843.)

This analysis, in turn, lends support to what we have learned informally from focus groups with younger faculty: that in starting up their labs, the resource they most desire, and have the greatest difficulty acquiring, is graduate students whom they can train to help them. Their start-up packages are relatively small, and they may not yet have grant funds for stipends; but even when they do, they often need the help of more experienced faculty in identifying and attracting students with the right expertise, especially if they also lack funds for crucial equipment. In these circumstances, mentoring programs have a crucial role to play in brokering mutually fruitful relationships between established researchers, who have equipment and graduate students, and young faculty members who can bring complimentary expertise, and a burst of fresh energy, into a collaboration.

This kind of mentoring collaboration has long been the fundamental building block of the Old Boy's Club, and it is still very much in place, at NJIT and elsewhere. One piece of data in our set illustrates the extraordinary competitive advantage that a senior researcher with many doctoral students can confer on a junior colleague. In our study of the faculty cohort hired as assistant professors from 2000-2003, we noted that those who did not move up in rank from assistant to associate had an average (mean) publication rate of 5.73 publications per year, while those who were promoted from assistant to associate had an average (mean) publication rate of 8.67 publications per year. Compare these norms to the publication record for one assistant professor ("Professor Y") in STEM department X. In the first three years of his career, he produced a total of 117 publications—a rate of 39 papers a year! Eighty-eight of those publications had at least one non-NJIT faculty co-author, in many cases his thesis advisor at another university. However, 54 of his papers had NJIT faculty co-authors, and he co-authored 43 times with NJIT graduate students. What is his secret? Aside from talent, drive, and expertise in an extremely hot research area, Professor Y has a crucial network edge. He began his career at NJIT as a post-doc to one of the university's most prolific and well-funded researchers, Professor
Z, a man who from 2000-2010 produced over 150 publications, including more than 100 co-authored with one or more of his large stable of graduate students. Professor Y now works as a junior colleague to Professor Z, part of a successful research team.

This case illustrates quite well the mechanism of preferential attachment—a network phenomenon that is also a replicable template for success. That is, in the NJIT network as elsewhere, new nodes (faculty researchers) tend to connect themselves to existing nodes that are already well-connected. In this manner, "the rich get richer." In a world in which the "rich" are still largely male, this feedback loop makes it difficult to affect real institutional change, however. (Networks generated by preferential attachment are extremely resistant to attack. Nearly 80% of the ties can be cut before the structure collapses.) (Mali, 2012). This suggests that funding agencies such as NSF might want to consider recalibrating their interventions. Giving money to isolated women faculty researchers (as in POWRE) clearly does not accomplish systemic change; however, strategies that try to drive change from the top down by reconfiguring university leadership may also miss the mark. Changes in the organization chart do not necessarily produce changes in social network structure. A better strategy might be to exploit the mechanism of preferential attachment by funding clusters of women researchers, post-docs, and graduate students, building the network around existing "stars"—senior faculty who have high centrality values.

Understanding Network Centrality: The case of Professor Y and Professor Z is instructive but anecdotal. To understand the dynamic relationship between STEM faculty ties and STEM faculty advancement over time, we need to look directly at network structure. We used three classical social network centrality measures to examine our NJIT co-authorship network: Degree, Eigenvector, and Betweenness. Individuals that score high in degree centrality have the shortest paths to all others. i.e., they are “well-connected.” Such connectedness is a potential career asset, providing access to more sources of information and novel ideas than a solo author can easily acquire. (However, as we suggested above, each collaboration entails costs as well as benefits, so an infinite number of co-authors does not necessarily confer infinite benefits.) Eigenvector Centrality measures the extent to which someone is connected to well-connected people. The Betweenness Centrality of a node in a network is defined as the number of shortest paths between other pairs of nodes that pass through that node (Freeman, 1977). In our co-authorship network, a high Betweenness value identifies a researcher who is in a bridging position. It reflects the extent to which she has the ability to broker the flow of information between others (Newman, 2004).

We had a special interest in Betweenness. Our original NSF proposal was designed to exploit what sociologist Mark Granovetter (1973, 1982) has called “the strength of weak ties" and Ronald Burt (1998) has called "structural holes"—that is, the advantages of being a bridge between people otherwise disconnected in the social structure (Burt, 1998). As it turns out, at NJIT Betweenness Centrality does indeed give faculty a small but crucial network edge. We established this by testing a fifth hypothesis, first against the attribute data for all STEM faculty in our study: **H5. In the NJIT STEM faculty co-authorship network, faculty with higher Betweenness Centrality will publish more than faculty with lower Betweenness Centrality.** Our initial results confirmed that Betweenness was strongly correlated with productivity in publishing, across all four modes of co-authorship that we studied (p < .0001). A regression analysis with Betweenness as the independent variable and total publications as dependent variable indicated that Betweenness is a strong predictor of publication productivity (F=233.65, p < .0001). This result was confirmed, albeit less strongly, when we ran a similar test on the
dataset of 371 faculty members (non-STEM and STEM combined) who had co-authored at least one article with another NJIT faculty member from 2000-2010. In short, at NJIT the most important predictors of productivity are, in rank order: co-authoring with non-NJIT researchers (“cosmopolitan collaboration”); co-authoring with NJIT graduate students (the “worker bee connection”); co-authoring with NJIT colleagues; and last, but not least, Betweenness Centrality. For STEM faculty who had an initial rank of Assistant or Associate Professor during our study (n=230—f29, m201), both Betweenness (0.323, p<.0001) and cosmopolitan collaboration (0.400, p<.0001) were positively correlated with rank change.

**SNA Data and Tools for Effective Faculty Mentoring:** This longitudinal NJIT data adds support to a growing body of literature that attests to the impact of collaboration and network structure on the retention and promotion of junior STEM faculty (e.g., Abbasi, 2011). Advocacy groups are beginning to join forces with social network analysts in an effort to explore how strategically designed mentoring programs can leverage the power of bridging social capital on behalf of women and underrepresented minorities. For example, Buchwald and Wiegman (2011) report their success in using SNA to structure and assess a support program for American Indian and Alaskan Native scientists. They stress, “It is critical to know who is in the network neighborhood, who needs our awareness, who can be reached, and which paths lead there” (p. 780). Hill (2008) makes a similar point about a different STEM population: computer scientists at a major US research university. Her results show a positive correlation between Betweenness Centrality and publication rate, suggesting that cosmopolitan, bridging collaborations are strategically smart. “These findings tell us that it is important to look outwards for innovation and knowledge creation; both intra- and inter-departmentally” (p. 8). Kuzhabekova (2011) summarizes the many reasons that mentors might want to encourage their faculty mentees to adopt a bridging strategy in collaboration; however, she adds an important caveat. Although bridging is the clearly the most productive strategy, it is also the most difficult to use because of the high transaction costs involved in identifying, assessing, and establishing contact with potential collaborators, especially across disciplines.

At NJIT Advance, we have tried to increase the benefits of collaboration by reducing the transaction costs, especially the cost of finding potential collaborators. We have done this in a number of fairly traditional ways. For example, we have hosted interdisciplinary research colloquia in order to increase information flow across departments. We have also organized larger cross-sector research showcases and poster sessions designed to stimulate translational research and academic entrepreneurship among NJIT women faculty and to provide opportunities for them to present their work to a wider audience. Our approach to mentoring reaches across boundaries as well. Our Faculty Career Advancement Network pilot program (FacultyCan), uses teaming, endeavoring to match each new faculty member with both a senior and junior mentor, one of whom is from a different department. We make a special effort to connect mentees to mentors who have similar research interests and complimentary skill sets. We begin this process by using a survey instrument to collect data about each new faculty member's goals, preferences, and research areas. To help them find appropriate mentors, we plug their data into our new Research Interests Map tool and create a pool of possible choices.

Developed by an NJIT Advance consultant, the Research Interests Map is a web-based tool that visualizes existing and potential research connections among faculty members. Each faculty member is a named node on the map. Lines connect the node to her/his research topics. These connections are based on keywords that faculty have entered manually using the tool's interface or keywords that we added from survey responses or retrieved automatically from
faculty publications. In order to prevent keywords from being either too general (e.g. "chemistry") or too narrow (e.g. "single-walled carbon nanotubes in aqueous environments"), faculty are prompted to choose three terms from a drop-down list and then allowed to add two terms of their choosing.

Users can search the Research Interests Map either by faculty name or by research topic. A topic search generates a map of faculty who work in that area. An animation function allows the user to arrange the nodes on the map, a useful feature when there are many connections. The user can disclose additional research areas for each faculty member by double-clicking on the person's node. The network can be expanded further, level by level, by clicking on each of the new research topics and new faculty nodes that appear, until the structure looks like a ball of yarn. Single-clicking on a faculty node produces a pop-up box containing the faculty member's name, email address, and a link to the person's full profile on the NJIT Website, which contains much additional information, including a list of publications.

In addition to deploying the Research Interests Map in our mentoring program, we have also used the tool to facilitate research collaboration directly—e.g., to generate a list of possible participants in a new, interdisciplinary research center. Demonstrations of the tool at our research showcases have sparked interest from industry partners who are looking for cross-sector research collaborators and from neighboring universities looking to stimulate greater research economies across institutional boundaries. Undergraduate and graduate students also find the tool helpful in identifying potential supervisors for their thesis work and independent study projects. A beta version of the tool is now available to the public on the NJIT Advance website at [http://advance.njit.edu/](http://advance.njit.edu/).

The Research Interests Map tool shows connections among faculty who work in the same research areas but who may not know each other at all. That is, it identifies people with whom you might want to collaborate. A second tool, the Faculty Connections Visualizer, shows actual network connections (collaborative research ties) among faculty—ties between co-authors or co-PIs on grants, etc. That is, the Faculty Connections Visualizer identifies people with whom you already collaborate. When fully developed, we believe that the Faculty Connections Visualizer, together with the Research Interests Map, will allow individual faculty and departments to take meaningful snapshots of professional networks as they develop.

**Conclusion:** In their final form, fully integrated into faculty mentoring, these new tools will help actualize a core goal of the NJIT Advance program and similar programs across the country: to increase institutional transparency, making visible the hidden connections that describe far better than aggregate data do the shape of the social and cultural space in which faculty members live out their careers. We believe that the network mapping tool will be especially effective in creating leverage for change by giving junior faculty access to the kind of aerial view of the organizational landscape normally available only to strategically positioned senior boundary spanners—a kind of GPS System for Career Management. It will also give academic administrators a more effective means of identifying problematic characteristics of the units they manage. Finally, as we have suggested in the collaboration, productivity, and advancement study presented in this paper, social network mapping techniques and tools can bring added value to the task of program assessment, especially for institutional transformation projects, allowing us to track subtle changes in organizational culture as they unfold over time.
References


Notes

1 According to de Haan (1997), there are six components of collaboration in STEM: co-authoring publications; co-authoring of grants; belonging to the same research center; co-editing journals; serving on the same doctoral committee; and working together to organize a professional conference.

2 See (e.g., Narin et. al., 1991; Luukkanen et al., 1993; Cockburn and Henderson, 1999; Melin, 2000; Newman, 2004; McFadyen and Cannella, 2004; He et. al. 2005; Wagner and Leydesdorff, 2005; Cummings and Kiesler, 2007; Abbasi 2011).

3 A recent policy agreement between the university and the faculty union now links the annual report requirement to merit pay increases, thus guaranteeing that a steady stream of self-reported bibliographic data will flow into DM. By mining Digital Measures, the university can sustain network data collection with relatively little maintenance cost after the grant ends. In addition, DM includes data on faculty research proposals submitted (funded and not-funded), work-in-progress, and committee assignments, allowing ADVANCE researchers to identify new faculty ties as they emerge.

4 We are in the process of updating the file to include data on the number of research proposals submitted and their status (funded/ not funded).

5 At NJIT, departmental P&T committees recommend candidates for promotion and tenure to a multi-disciplinary institutional P&T committee which, in turn, makes recommendations to the provost. In the past, P&T committees used a fractional count, dividing up credit for a co-authored publication among the authors. This is no longer the practice, although candidates are expected to provide evidence that they can conduct solo research. In our study, we use a "normal count," giving each co-author credit for a publication.

6 Because of serious budgetary constraints, NJIT has done very little hiring in the last few years, so we chose a rolling three year start date for our sample in order to include enough assistant professors for a valid analysis. Going forward, the university plans a robust round of hiring, using funds freed up by a incentivizing senior faculty to retire.

7 Lariviere et. al. cite the following studies in support of their conclusion that women publish less than men: Fox 2005; Prpic 2002; Scheibinger 2003; Xie and Shauman 1998, 2003; Zuckerman 1991; Ezekowitz et al. 2000; Fox 2005; Leahey 2007; Nahkaie 2002; Bordons et al. 2003; Gonzalez-Brambila and Veloso 2007; Mauleo’n and Bordons 2006; Prpic 2002.

8 The numbers of student-co-authored papers (43) plus the number of NJIT-faculty co-authored papers (54) plus the number of non-NJIT co-authored papers (88) adds up to more than the total number of publications (117) because many of papers contain a combination of co-authors (NJIT faculty, external faculty, NJIT grad student).