Impacts of an interdisciplinary research center on participant publication and collaboration patterns: A case study of the National Institute for Mathematical and Biological Synthesis

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Interdisciplinary research centers are typically viewed as a vehicle for creating opportunities in science where the intricacy of the research problem calls for persistent collaboration across multiple disciplines. This case study analyzed the effects of an interdisciplinary research center on the publication and collaboration behaviors of faculty affiliated with the center. The study also sought to determine through faculty interviews what factors contributed to these effects for participants whose publication and collaboration behaviors were most changed after affiliation. Results of the study indicate that affiliation with the center has a significant positive effect on participant collaboration activities, and a moderate positive effect on publication activities (i.e. publishing in new fields). Factors contributing to success cited by interviewees included organized leadership, a positive atmosphere, breaking into sub-groups, and the ability to collaborate with researchers with whom they would not have interacted outside of the center. This case study may be useful in providing a framework for early evaluation of the effects of interdisciplinary research centers on affiliated participants.

Keywords: interdisciplinary research; scientific collaboration; research center; coauthorship; publication output; bibliometrics.

Interdisciplinary scientific collaboration has been on the rise in recent decades (Stokols et al. 2008b; Trochim et al. 2008; Borner et al. 2010; Falk-Krzesinski et al. 2011; Wagner et al. 2011). The rapid expansion of scientific and technical knowledge has caused increased specialization within scientific fields, and new complex questions arising from this knowledge must be addressed simultaneously through collaboration among specialists from multiple fields (National Academy of Sciences 2004).

Braun and Schubert (2003) showed that the frequency of the terms ‘interdisciplinary’ and ‘multidisciplinary’ in titles of papers covered by the Thomson Institute for Scientific Information’s (ISI) Science Citation Index (SCI) database grew exponentially from 1980 to 1999, doubling in a span of 7 years. Our own search of the ISI database found that the trend has continued, with the frequency of articles containing these words in their titles doubling from 2000 to 2006, and then increasing again by 68% from 2006 to
2012. Though not a direct indicator of the prevalence of interdisciplinary research (IDR), this finding indicates that interest in the phenomenon has increased significantly in recent years. IDR makes it possible to create novel solutions to address new or existing research questions that are beyond the scope of a single discipline or field of research (National Academy of Sciences 2004). The benefits of IDR include enhanced productivity, enhanced inquiry, and improved problem-solving (Melin 2000; Aboelela et al. 2007).

Much debate exists as to what constitutes a ‘discipline’, as well as the definitions of interdisciplinary, multidisciplinary, and transdisciplinary research. For the purpose of the present research, the researcher uses the definition put forth by the National Academies, which states that ‘interdisciplinary research is a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice’ (National Academy of Sciences 2004: 188).

**Interdisciplinary research centers**

A significant vehicle for facilitating IDR is the research center (Tash 2006). Although they can take on many forms, research centers are facilities that provide space and often funding dedicated to research, usually within a specific area. According to National Science Foundation (NSF), research centers ‘exploit opportunities in science, engineering, and technology in which the complexity of the research problem or the resources needed to solve the problem require the advantages of scope, scale, duration, equipment, facilities, and students’ (National Science Foundation 2013). IDR centers are research centers that exist to foster cross-disciplinary approaches to address fundamental and applied research questions. According to the Gale Group’s Research Centers and Services Directory (2013), there are more than 15,900 university-based and other nonprofit research centers in the USA and Canada and more than 37,000 worldwide. According to Stahler Tash, research centers are creating a new model for who performs science, as well as the impacts and purposes of the research. Research centers ‘can substantially enhance a university’s capability to attract external funding, provide opportunities for interdisciplinary collaboration among faculty, and provide considerable visibility and prestige in a defined area of study for the research university’ (Stahler and Tash 1994: 540).

While research centers have been in existence for quite some time, their importance has grown over the last several decades, as evidenced by the increase in funding for these ventures from major federal agencies such as the National Institutes of Health (NIH) and the NSF (Coburn 1995; Tash 2006; Gray 2008). In FY 2012, NSF funded 98 research centers with a total of almost $278 million, while NIH funded 1,397 research centers with nearly $2.7 billion (National Institutes of Health 2013; National Science Foundation 2013). Because of the large amount of resources invested in IDR centers, a need exists to understand these centers from the perspective of what is working, and what is not. There is also a need to determine how the outcomes of these centers are being achieved (Tash 2006).

IDR center evaluations are used for accountability, to improve center efficiency, and to assess outputs, outcomes, cost-benefits, and impacts (Tash 2006). Deciding who, what, and when to evaluate can be problematic, however, due to the complex nature of centers’ research portfolios, missions and the multiple internal and external stakeholder groups that need to be addressed (Gray 2008). Program evaluators still have a relatively modest understanding of how to evaluate the growth and value of IDR centers (Trochim et al. 2008). Evaluation approaches could include efficiency, implementation, or impact studies; incidence, amount, and quality of IDR; cost-benefit analyses; studies of staff and client satisfaction; or studies of the social processes of team science (Tash 2006).

Because of the interdisciplinary focus of many centers, one approach to evaluating IDR centers is to examine the effect of affiliation with the center on the interdisciplinary publication and collaboration activities of its participants. Funding agencies are extremely interested in knowing to what extent cross-disciplinary collaboration is being used by center participants to tackle research problems (Stokols et al. 2008b; Norman et al. 2011). However, this type of evaluation is not without its own complexities. According to Klein (2008), evaluation of IDR is ‘shaped by multiples: multiple actors making multiple decisions in varied organization settings with context-dependent measures of quality’ (s117). While IDR collaborations are quickly becoming the norm (Mansilla 2006; Trochim et al. 2008), researchers and evaluators measuring research performance are struggling to develop valid approaches to quantify and examine the antecedents, processes, and outputs of interdisciplinary team science (Wagner et al. 2011). According to Klein (2008), evaluation of IDR remains one of the ‘least-understood aspects’ of the phenomenon (S116).

The purposes of this study were to (a) assess the early effects of affiliation with an interdisciplinary research center on participant publication and collaboration behaviors, and (b) determine what factors contributed to these effects for participants whose publication and collaboration behaviors changed the most after affiliation. The study sought to analyze the effect of a research center on the patterns and rates of publishing by university faculty using bibliometrics and interview data. This study contributes to the research on evaluation of IDR centers, as relatively few studies have addressed the publication and collaboration behaviors of university faculty affiliated
with IDR centers. In times of budget deficits and spending cuts, it is important to demonstrate the effects federally funded research centers have on the production of new knowledge. Thus, changes in publication outputs of scientists related to federal spending are of great interest to science policy makers. As IDR centers are expected to foster collaborative networks that synergize across disciplines to further research and development, bibliometric studies showing co-authorship across institutional and disciplinary boundaries are also important (National Academy of Sciences 2004; Klein 2008; Stokols et al. 2008a). Determining what mechanisms lead to these changes is of equal importance.

Data and methods

The design of this research project replicated and expanded upon previous research (Ponomariov and Boardman 2010) that examined the effect of a university research center on behaviors of affiliated researchers. Ponomariov and Boardman looked at the effects of affiliation with a university research center on the productivity and collaboration patterns of participating university faculty while controlling for several variables. The current study differs from the previous study, however, in two key respects:

(1) While the previous study examined outputs of participants of a center that had reached the conclusion of its funding cycle (10 years), the present study seeks to know what early effects on participant collaboration and publication behaviors can be discerned.

(2) The present study contains a qualitative element to attempt to understand the contextual influences of the group on changes in interdisciplinary collaboration and publication behaviors of participants.

Each participant in the study belonged to one of six working groups at the National Institute for Mathematical and Biological Synthesis (NIMBioS), a science synthesis center at the University of Tennessee. The mission of NIMBioS is to cultivate cross-disciplinary approaches in mathematical and biological fields and to develop a cadre of researchers who address fundamental and applied biological problems in creative ways. Each participant met up to four times with his/her respective group during the period between April 2009 and August 2011 to address a research problem from an interdisciplinary standpoint. The most commonly reported outputs for these working groups were scholarly journal articles. To determine the effect of center affiliation on participant publication and collaboration behaviors, this mixed methods case study was conducted in two parts: a quantitative bibliometric study of peer-reviewed research articles of participants and a supporting qualitative study consisting of interview data collected from a purposive sample of participants.

We hypothesize that affiliation with the research center is positively related to productivity (number of publications), collaboration measures (co-authorship), and interdisciplinarity (number and type of Web of Science Subject Categories (WOS SCs) in which participants publish). We also hypothesize that common within-group factors contributed to these effects for participants whose productivity and collaboration behaviors were most changed after affiliation. Four research questions guided this study, as follows:

(1) To what extent does affiliation with an interdisciplinary research center affect early publication output?

(2) To what extent does affiliation with the interdisciplinary research center influence the collaboration behaviors of participants?

(3) To what extent does affiliation with the interdisciplinary research center affect the interdisciplinarity of participant research?

(4) For participants who show the greatest impacts in publication and collaboration, what factors contribute to this impact?

Following the method of Porter et al. (2012), publication records for each participant in the study were collected from the ISI WOS’s Science (WOS) Citation Index Expanded (SCI) for two-time periods: 2007–08 as a ‘before’ period and 2010–1 as an ‘after’ period. Publications from 2009 were excluded from the study as it would be difficult to ascertain which publications had been in process before affiliation with the center and which had not, as participants became affiliated with the center in early to mid-2009. As a number of publications arising from working group collaborations were reported as early as the end of 2009, beginning the ‘after’ period at the beginning of 2010 appears to be an appropriate timeframe (National Institute for Mathematical and Biological Synthesis 2012). Notwithstanding the rather quick turnaround of group-related papers, the average publishing delay (time from submission to publication) across several discipline areas has been found to be around 12 months (Bjork and Solomon 2013). For Earth sciences, the average is a bit lower at 11.7 months, and for mathematics the average is a bit higher at 13.3 months. Considering this, a paper published in 2010 could have been initiated in 2009 from research that took place before induction into the working group. However, affiliation with the working group would have occurred during the revise/resubmit stage and thus have influenced the authors’ decisions regarding revision during this time. Perhaps the best validation of the time period lag came from the participants themselves, five of whom during interview indicated that their publications during the ‘post’ time period had been influenced in some way by affiliation with the working groups. Authors were identified by matching their name,
department, and institution from the center database to the ISI entries. Publication records were cross-checked with current participant curriculum vitaea to ensure accuracy.

Publication data were analyzed by year against several demographic control variables to understand what effect affiliation with the interdisciplinary research center may have had on publication and collaboration patterns of participants, following the method of Ponomariov and Boardman (2010). The data were aggregated and analyzed at the level of individual participant by year using Vantage Point text mining software, which is used for analyzing filed tagged data such as WOS output files. After mining and aggregating relevant variables, the data were exported into a spreadsheet. The periodic measurements for each dependent variable were analyzed using random-effects negative binomial regressions in PASW Statistics for Windows, Release Version 19.0. These analyses are well-suited to analyze this type of data as all dependent variables are count variables with positive integer values (Ott and Longnecker 2008).

The main independent variable of interest in the study was ‘NIMBioS affiliation’, which was a dummy variable coded ‘1’ for years in which a participant was affiliated with the center and ‘0’ for years in which he/she was not. In this study, collaboration is defined as co-authorship on scholarly publications. Although there are certainly exceptions, collaboration in scientific research and co-authorship of scholarly output are generally considered directly related. Dependent variables used in the study include number of distinct publications, co-authors, co-author institutions, co-author countries, and WOS subject categories (SCs) per year per participant.

While the first four dependent variables are self-explanatory, the SCs variable requires some explanation. No universally accepted system exists for operationally defining disciplines of researchers in specific research groups found that the researcher discipline areas were defined differently with respect to their departmental affiliations, background (i.e. what they felt they practiced), references in project publications, instrumentalities (i.e. to which discipline their research instruments belong), and citation patterns (i.e. who the audience is for their research) (Rafols and Meyer 2007). Clearly, a systematic categorization of disciplines must be used in bibliometric research. The most widely utilized taxonomy of research fields in bibliometric research are the WOS SCs.

While WOS SCs are used widely as proxies for interdisciplinarity, their limitations in this role must be discussed. While the classification of journals into subject categories by WOS is a convenient taxonomy to use in the study of IDR, some researchers perceive their research domains differently than the bibliometric depictions offered by WOS. Leydesdorff and Cozzens (1993) reported that, based on cross-citation patterns of journals in their own field of sciences studies, journal clustering based on the WOS SCs did not match their own perceptions of their field. Another study by Rafols and Meyer (2007) found that journal based classification does not capture the main contribution of some articles. Using citation analysis of articles, they found that journal-based classification underestimated the contribution of structural biology, overestimated the contribution of cell biology, and could not be used for 35% of the references published in multidisciplinary journals.

Another issue with classification of papers by their journal’s WOS SCs is that some journals are classified by WOS as multidisciplinary, including the highly popular Nature, Science, and Proceeding of the National Academy of Sciences (PNAS). This poses a problem for bibliometric studies in which these types of journals are common. Glänzel et al. (1999) attempted to overcome this shortcoming by reclassifying papers in multidisciplinary journals based upon their cited references. They found around 95% of PNAS papers could be classified in the life sciences subject category based on cited references, whereas Nature and Science papers could be classified into many different categories (with the majority being life sciences and physics) (Glänzel and Schoepflin 1999).

Finally, the use of WOS SCs for the measurement of IDR is biased towards articles in journals indexed in ISI databases. One study found that in most natural and medical science fields, between 80% and 95% of journals in the field are covered in the index; in the social and behavioral sciences, this number is projected to be much lower (Visser et al. 2003). While the study found that coverage was not complete for all sciences, the National Science Board has stated that the journals indexed in ISI SCI and SSCI ‘give reasonably good coverage of a core set of internationally recognized scientific journals, albeit with some English-language bias’ (National Science Board 2000). Despite the drawbacks of using the WOS SCs for citation analysis, however, it remains a commonly accepted, sound bibliometric practice for measuring IDR. For the purposes of this research, the WOS SCs offer the best coverage of which we are aware.

We considered several individual-level control variables as well, including whether or not a person was a social scientist (0: not a social scientist, 1: social scientist), gender (1: male, 0: female), tenure status (1: tenured; 0: not tenured), year of PhD, and publication productivity lagged by one year.

The interview portion of the study follows the Success Case Method (SCM), which is conducted in five steps: focusing and planning a success case study, creating an ‘impact model’ that defines what success should look like, designing and implementing a data collection instrument to search for best (and sometimes worst) cases, interviewing and documenting success cases, and
communicating findings, conclusions, and recommendations (Brinkerhoff 2003).

In the case of the current research, ‘success’ is defined as the biggest change in publication and collaboration practices from before affiliation with the center to after affiliation. Most changed cases were determined by calculating the Publication and Collaboration Index (PCI) change score described here. To determine which participants have shown the most change in publication behaviors, an analysis was performed on the change scores for average number of publications, collaborators, institutions, countries and number of subject categories per year from before and after participant affiliation with the center. Change scores in each of these categories were computed by subtracting the total number after affiliation from the total number before to create a composite score for each participant in each category. Difference scores were then summed to create a PCI score. PCI scores were ranked lowest to highest, and a gender-stratified sample of participants with the highest index scores (e.g. who showed the most change in publication and collaboration behaviors since their affiliation) were invited for interviews. Gender stratification was used because (1) gender was shown to be a significant predictor of the dependent variables regarding publication and collaboration activities in all regression analyses conducted on bibliometric data in the study, and (2) no females were ranked in the top six regarding change in publication and collaboration behaviors. Email invitations were sent to the males with the top three PCI scores, as well as the four females in the study who exhibited positive PCI scores. After one week, emails were sent to the next three top males on the PCI scale until a total of three male interviews were scheduled. As only two of the four females agreed to interview, an additional male interview was conducted for a total of six interviews.

Participant interviews were transcribed and validated using the member check method (Glesne 2006). In accordance with this method, completed transcripts were shared with study participants, who were given the opportunity to provide feedback about whether or not they felt the transcripts represented their ideas accurately. Analysis of final transcribed interviews was conducted using QDA miner to determine what factors may have contributed to the change in publication and collaboration behaviors (Coffey and Atkinson 1996).

Study participants
Subjects of the study were selected from six working groups that had completed their meeting cycles. Although NIMBioS participants may be part of more than one working group, all participants selected for the study had participated in only one working group as of the end of 2011. Participants from the working groups were retrieved from the NIMBioS database, which holds information about all participants at the center (National Institute for Mathematical and Biological Synthesis 2012b). Each group began between April and July of 2009, and had conducted either three or four meetings by 31 August 2011. Groups had between 12 and 21 participants who attended at least one meeting, and comprised a total of 91 different participants. From this pool of 91 working group participants, 46 project participants were selected who met the following criteria:

1. Held a position of faculty researcher at a university: Postdoctoral researchers, university research staff, graduate students, government researchers, and those from private industry were not included in the study because their publication histories were not sufficient for analysis.

2. Physically attended at least one working group meeting: Although each working group considered to meet 3–4 times, all members were not physically present at every meeting. Because much of the collaborative research was carried out off-site, members who attended at least one physical meeting were still considered viable members of their group.

3. Were still members of the working group at its final meeting: Participants in working groups may be added or dropped during the cycle of the group. Some participants may have attended the first or second meeting, but then ceased communication with the group. An assumption is made here that all working group members who are considered active participants at the last meeting are actively involved in the collaborative research and synthesis projects of the group.

4. Were not members of NIMBioS leadership team: Several members of the NIMBioS leadership team who participated in the working groups were excluded from the study to prevent conflict of interest as the study is part of the evaluation of the research center they direct.

The composition of the resulting pool of eligible participants was 39 males and 7 females. Eight participants reported their primary field of research as being in the social sciences, and 32 participants were tenured before becoming affiliated with the institute (See Table 1).

Internal validity
The design of this study is a single group interrupted time-series quasi-experiment. This design controls for several threats to internal validity, including maturation, statistical regression, and testing due to multiple observations over time. For example, these threats usually do not provide a plausible explanation for a shift in variable measurement between time 1 and time 2 that may not have occurred in the previous time periods under observation (Campbell and Stanley 1963). Further, the testing...
threat does not apply to studies using bibliometric analysis.

Typical threats to internal validity for this type of design are instrumentation, selection, and history (Shadish et al. 2002). Instrumentation, however, is not a problem in this study as the data were retrieved from WOS, which is a standardized publication database. Selection is also not an issue as the study only includes faculty who were affiliated with NIMBioS working groups beginning in 2009, and continued with their respective working groups until they concluded. As the historical bibliometric data collected for participants only included those who met these criteria, no changes in publication and collaboration behaviors could be explained by attrition.

The threat of history, or the possibility that something other than affiliation with NIMBioS may have affected the changes in participants, is the biggest challenge to internal validity. Attributing the impact of research policies, such as those of an IDR center like NIMBioS, to specific research outcomes is a known challenge in research evaluation (Georghiou and Roessner 2000). The history threat in the present study is overcome in a number of ways. First, the nature of the longitudinal study provides multiple observations of each faculty member before and after affiliation, improving the reliability of any evidence of changes in publication or collaboration behaviors after affiliation with the center. Second, the participants in the study come from a diverse array of disciplinary backgrounds, institutions, career, and educational paths. Errors in such a diverse group are likely to be uncorrelated rather than showing related trends due to sharing common characteristics beyond affiliation with the center. Third, the regression method used to analyze the bibliometric data allows for controlling for multiple factors that correlate with collaboration and publication activity, such as gender, academic rank, and whether or not someone is in a social science field. Fourth, NIMBioS affiliation is not a ‘one-shot treatment’, but rather a continuous research experience that consists of two to four meetings over a two-year period. This continual exposure, as well as the focus during the 2 years on production of interdisciplinary publications, alleviates the history threat to some degree as participants are engaged in the research and publication process with their groups quite heavily during that time.

Table 1. Demographics of participants

<table>
<thead>
<tr>
<th>Variable</th>
<th>Number of participants</th>
<th>Percent of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>39</td>
<td>85%</td>
</tr>
<tr>
<td>Social scientist</td>
<td>8</td>
<td>17%</td>
</tr>
<tr>
<td>Tenured before NIMBioS affiliation</td>
<td>32</td>
<td>70%</td>
</tr>
<tr>
<td>Number of meetings attended</td>
<td>3</td>
<td>1–4</td>
</tr>
<tr>
<td>Year of PhD</td>
<td>1995</td>
<td>1962–2008</td>
</tr>
</tbody>
</table>

Although this does not preclude participants in the study being involved in other endeavors that might impact their publication and collaboration behaviors, the amount of exposure does increase the plausibility that affiliation with the working group may contribute to any effects found. Finally, the use of interviews serves to elaborate on the history mechanism by collecting firsthand accounts from participants about their views of whether or not they felt like affiliation with NIMBioS had an impact on the changes seen in the bibliometric portion of the study.

External validity

This is a bounded case study, representing one research center. In addition, the design does not use a control group for comparison. As such, generalizability of results to other IDR centers is limited. While the results may not be widely generalizable, the methods used may be replicated for evaluation of other interdisciplinary collaboratories.

Findings

Bibliometric analyses

Table 2 summarizes the results of five regression models used to investigate the effect of NIMBioS affiliation on publication productivity (Model 1), overall collaboration (Model 2), cross-institutional collaboration (Model 3), international collaboration (Model 4), and interdisciplinarity of research (Model 5). Model 1 contains a greater number of observations than models 2–5 as the dependent variable in Model 1 is based on number of publications in each year, whereas variables in the latter models are derived from data associated with publications from each year. In Models 2–5, years in which a person has no publications are not entered into the model because there are no data for those years. For example, while a person can have 0 publications in a given year in Model 1, it is not meaningful to consider in the subsequent models, the number of WOS SCs in which a person has published in years that he or she did not publish (Ponomariov and Boardman 2010).

Results from the regression analyses found that affiliation with NIMBioS working groups was a significant predictor for indicators of collaboration (Models 2, 3, and 4), but not for publication productivity (Model 1) or interdisciplinarity (Model 5). The Incidence Rate Ratio (IRR) represents a change in the dependent variable in terms of percent increase (a number greater than 1) or decrease (a number less than 1). IRRs for the model indicate that after affiliation, participants increased their number of co-authors by 40%, the number of cross-institutional co-authors by 50%, and the number of international co-authors by a factor of 20%.

Qualitative analysis of interdisciplinarity showed a shift in publication SCs toward mathematical fields. In Fig. 1,
Table 2. Effects of NIMBioS affiliation on faculty collaboration and publication activities

<table>
<thead>
<tr>
<th>Parameter</th>
<th>(1) Number publications in year $i$</th>
<th>(2) Total number co-authors in year $i$</th>
<th>(3) Number cross-institutional co-authors in year $i$</th>
<th>(4) Number international co-authors in year $i$</th>
<th>(5) Number WOS SCs in year $i$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IRR</td>
<td>Wald z</td>
<td>IRR</td>
<td>Wald z</td>
<td>IRR</td>
</tr>
<tr>
<td>Affiliated with NIMBioS in year $i$</td>
<td>0.995 (0.985–1.005)</td>
<td>0.002</td>
<td>1.396* (1.100–1.770)</td>
<td>7.553</td>
<td>1.453* (1.149–1.837)</td>
</tr>
<tr>
<td>Number of publications in year $i$-1</td>
<td>1.152b (1.120–1.184)</td>
<td>99.994</td>
<td>1.067b (1.029–1.107)</td>
<td>12.287</td>
<td>1.07b (1.029–1.112)</td>
</tr>
<tr>
<td>Year of PhD degree</td>
<td>1.024</td>
<td>1.024</td>
<td>0.987</td>
<td>2.894</td>
<td>0.986</td>
</tr>
<tr>
<td>(0.985–1.005)</td>
<td></td>
<td></td>
<td>(0.971–1.000)</td>
<td></td>
<td>(0.971–1.000)</td>
</tr>
<tr>
<td>Tenured before affiliation</td>
<td>0.973</td>
<td>0.031</td>
<td>0.939</td>
<td>0.13</td>
<td>0.819</td>
</tr>
<tr>
<td>(0.722–1.312)</td>
<td></td>
<td></td>
<td>(0.551–1.376)</td>
<td></td>
<td>(0.515–0.931)</td>
</tr>
<tr>
<td>Social science</td>
<td>0.802</td>
<td>2.75</td>
<td>0.559b</td>
<td>10.956</td>
<td>0.621a</td>
</tr>
<tr>
<td>(0.617–1.401)</td>
<td></td>
<td></td>
<td>(0.386–0.783)</td>
<td></td>
<td>(0.665–1.179)</td>
</tr>
<tr>
<td>Male</td>
<td>1.886b</td>
<td>15.992</td>
<td>2.022a</td>
<td>9.558</td>
<td>1.963b</td>
</tr>
<tr>
<td>(1.382–2.574)</td>
<td></td>
<td></td>
<td>(1.294–3.160)</td>
<td></td>
<td>(1.298–2.969)</td>
</tr>
<tr>
<td>Observations</td>
<td>184</td>
<td></td>
<td></td>
<td></td>
<td>161</td>
</tr>
<tr>
<td>Number of id</td>
<td>46</td>
<td></td>
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<td>46</td>
</tr>
</tbody>
</table>

95% confidence intervals for IRRs are in parentheses.

*Significant at 5%; bSignificant at 1%.
the subject categories of the participants’ articles indexed in WOS for 2 years prior to participation at NIMBioS and 2 years after initial participation are shown on a network map of the WOS SCs. The gray background intersections are the 224 WOS Subject Categories from the SCI and SSCI indices, located by cross-citation connections among all WOS journals in 2007 (from Leydesdorff and Rafols 2009). The 19 labeled ‘macro-disciplines’ are based on factor analysis of that cross-citation matrix also. The gray lines linking the SCs are based on these overall WOS patterns, not the publications presently under study, and nearness on the map indicates a closer connection among disciplines. Circular node sizes reflect the relative number of publications in the current study. SCs in which publications were more focused before, or in which there was no change in numbers of publications are lighter grey. SCs in which publications are more focused after affiliation appear as black nodes. SCs in which researchers published only after affiliation with the center are represented with white nodes.

The map illustrates a visual perspective of a shift in publication SCs toward mathematical fields, with more gray nodes in the Ecological, Biomedical, and Agricultural Science discipline areas, and more black and white nodes in the Mathematical Methods, Materials Science, Computer Science, and Economics, Politics & Geography discipline areas.

**Interview analyses**

Participants involved in the interviews were told that they had been identified as showing a positive change in publication and/or collaboration behaviors after affiliation with NIMBioS, and that the purpose of the interview was to ascertain whether or not their affiliation with the center may have had any impact on these changes. Although both males and females were interviewed, no discernible differences between the working group experiences of the two genders were found during the interviews. All references to specific disciplines, research topics, institutions, etc., have been removed to protect the anonymity of the interviewees.

Five of the six participants indicated an overall positive experience with their working groups; however, one participant (Participant 1) reported an overall negative experience. Although the bibliometric portion of the study indicated that Participant 1 showed a positive change in collaboration behaviors after affiliation, this participant indicated the change was due to chance because none of the initial work that the group set out to do had been completed. Though the SCM approach does indicate the usefulness of interviewing ‘the most and the least successful participants’, it was not the original intention of the present study (Brinkerhoff 2003: 49). Therefore, although the initial purpose of the interviews was to document the most successful cases, Participant 1 will be treated as a ‘least successful’ case and will be discussed separately from Participants 2–6.

All five success case participants indicated that affiliation with the working group lead them to collaborations with researchers from other disciplinary fields that would not have occurred had they not been a part of the group. In agreement with the bibliometric analysis, none of the five success cases felt that affiliation with their working groups caused an increase in their publication output.
(i.e. the number of papers they were publishing per year). Two of the participants, however, indicated that affiliation with the working group caused them to publish in journals in which they had not previously published.

In response to questions about how the structure of the working group may have contributed to any positive results they experienced from the group, four of the five success case participants mentioned breaking into subgroups as an asset. Another aspect of group structure that was mentioned was an overall positive group atmosphere. In response to questions about how the leadership of the group may have contributed to any positive results they may have experienced, all five participants mentioned the ability of their group leaders to keep the group organized. Another aspect of group leadership that was mentioned by three of the success case participants was the maintenance of a positive and welcoming atmosphere by their leaders. Also, four of the five participants indicated that, even though each group had multiple organizers, their groups had only one clear ‘leader’.

The least successful case participant did not feel he got any benefit from participating in his working group. Although results from the bibliometric study indicated that Participant 1 showed an increase in collaborative activities after affiliation with his working group, he indicated that those activities were unrelated to the working group, and that most were from collaborations that were ongoing before the group started. When asked what aspects of group structure may have contributed to the negative results he experienced, Participant 1 pointed to lack of organization within the group, particularly among participants from one institution. Coupled with the lack of organization, Participant 1 felt the wrong people were involved with the group. He felt that those involved were not in the group for the right reasons. Lack of communication and organization were cited as issues with leadership by Participant 1. A particular problem faced by this participant was that the organizers of the group were part of the institution that Participant 1 indicated was not completing the tasks they were assigned. Although Participant 1 had a negative experience with his working group, he indicated he would like to be part of another NIMBioS working group in the future, but would like to see others follow-through on their tasks.

**Discussion and implications**

This is a bounded case study, representing one research center. As such, generalizability of results to other IDR centers is limited. While the results may not be widely generalizable, the methods used may be replicated for evaluation of other interdisciplinary collaboratories. When comparing study outcomes to other studies involving research evaluation, one must keep in mind that the time frames, methods, sample sizes, and other aspects of research design vary. Thus, although the authors found similarities and differences in the present outcomes as compared to other studies, the results of each study are colored by the aforementioned aspects of research design. The results of this case study indicate that affiliation with this interdisciplinary research center’s working groups affects the collaboration, and to a lesser extent, publication behaviors of affiliated faculty in ways consistent with the mission of the center, which includes a goal to ‘address key biological questions by facilitating the assembly and productive collaboration of interdisciplinary teams’ (National Institute for Mathematical and Biological Synthesis 2007). Publication and collaboration behaviors can be seen as part of a researcher’s scientific and human capital (S&T human capital). According to Bozeman et al. (2001) S&T human capital can be defined as ‘the sum of an individual researcher’s professional network ties, technical knowledge and skills, and resources broadly defined’ (636). In other words, S&T human capital is the sum of an individual’s capacity to carry out research. As such, positive shifts in collaboration and publication behaviors can be seen as increasing the S&T human capital of Interdisciplinary research center participants.

**Collaboration behaviors**

Participants were shown to increase the number of collaborations through co-authorship on several indicators. Increased collaboration is seen as a benefit for a number of reasons. An often cited benefit is the synergistic effect of bringing together people with different skill sets, which increases the overall skill level of the entire team of collaborators (Sonnenwald 2007; Franc et al. 2010). Co-authored publications are seen as well as having greater epistemic authority than single-authored papers, in that co-authorship confers the benefit of inter-subjective verifiability (Wray 2002; Beaver 2004). Collaborative research tends also to be more highly cited than other research (Wray 2002; Wuchty et al. 2007; Haslam and Laham 2009). Citation counts of scientific articles have been found to be correlated with research impact (Garfield et al. 1978; Lee et al. 2002), although much debate has taken place about the limitations of citation analysis as a research method (cf. Cole and Cole 1972; Garfield 1972; Macrobets and Macrobets 1989; Moed 2005).

Participants in this study were found to increase not only their number of co-authors overall after affiliation with the center, but also their number of cross-institutional co-authors and also their international co-authors. This finding echoes that of other studies, which have found that affiliation with an IDR research group increased co-authorship (Ponomariov and Boardman 2010; Garner et al. 2012). Several studies have shown that multiple institution papers are more highly cited than single institution papers, and that papers with foreign collaborators are
more highly cited than domestic papers (Narin and Whitlow 1990; Goldfinch et al. 2003; Hoekman et al. 2010). Katz and Martin (1997) found that collaborating with a co-author from a domestic institution increases the average impact of a paper by 0.75 citations, while collaborating with a co-author from a foreign institution increases the impact by 1.6 citations. Increased citation counts not only increase the visibility of a researcher’s work, but also the status of the researcher within his or her area of research, thus increasing his or her S&T human capital.

**Publication behaviors**
The effect on publication behaviors of participants was less strongly represented, although still evident. Participants were not found to increase their publication output after affiliation with the interdisciplinary research center. This contradicts findings from other evaluation studies of IDR. Garner et al. (2012) found a significant increase in number of articles produced by participants in an NSF RCN program. Ponomariov and Boardman (2010) found that affiliation with an NSF Engineering Research Centers program increased the rate of publication incidence in participants by a rate of 1.5. Possible explanations for the difference in outcomes between the present and previous studies could be related to the time frame of the studies. The present study covered a total period of 5 years, while Garner’s study covered 9 years (1999–2001 as the ‘before’ period and 2006–08 as the ‘after’ period). Ponomariov & Boardman’s study covered the entire publication histories of participants, beginning in 1954, with participants being affiliated with the center between 1 and 9 years. Thus, participants in both comparison studies were affiliated with their respective centers for longer time periods than participants in the present study, giving them more time to increase their S&T human capital in the context of the center, which may have affected their publication rates.

**Gender**
Gender was found to be a significant predictor for both publication productivity and collaboration. This is consistent with findings in the literature that indicate that women tend to have somewhat lower publication rates than men, and also tend to have fewer co-authors in general (Cole and Zuckerman 1984; Long 1992). Factors found to affect research productivity in women include marital status, career ambitions, age, parental status, amount of research time, degree of specialization, discipline, international work (collaboration and co-authorship), and academic rank (Allison and Long 1990; Dundar and Lewis 1998; Prpic 2002; Leahey 2006; Puuska 2010). Interview data did not suggest that the experiences of females within the working group setting were markedly different from that of their male counterparts. One limitation to this conclusion, of course, is that only two females were interviewed. One female interviewed, however, indicated her 90-year-old ailing mother had come to live with her several years before she became affiliated with the working group, and that she felt this had negatively impacted her overall publication productivity during the past several years.

**Interdisciplinarity**
While no effect was found on publication rates of participants after affiliation, there was a slight trend toward publishing in more mathematical fields. Given that only 22% of participants self-identified as being in a primarily mathematical field, this can be taken as an indicator that affiliation may have caused participants from other fields to publish in more mathematical-oriented journals. Interview data support the conclusion that participants were publishing in journals outside of the ones in which they had published in the past, however, a participant-level analysis of self-identified field of study versus publication SCs would need to be done before being able to say definitively if the shift toward publication in more mathematical fields was truly the result of participants publishing outside their fields, or was merely the result of the few mathematicians in the study publishing in mathematical journals in which they had not previously published.

**Contextual influences**
The experience of the success case participants can be associated with current research on contextual influences in interdisciplinary team science. Participants cited a positive, welcoming atmosphere as one of the contributing factors to their success in their groups. Greater social cohesiveness in a group has been shown to lead to increased productivity in several studies (Guzzo and Dickson 1996; Kerr and Tindale 2004). Another contextual factor related to group structure that was mentioned by several participants was breaking into subgroups to work on research problems. Research supports the claim of some participants that these smaller teams were more effective for coordination and decision making (Mullen et al. 1989). An additional factor related to sub-grouping of individuals is the structural interdependence of member’s tasks and rewards. One study of 150 teams of technicians in a corporation found that teams perform best when their tasks and outcomes are either solely group-oriented or solely individual-oriented (Wageman 1995). Higher levels of task interdependence resulted in higher levels of cooperation and more positive interpersonal interactions among group members. As members of working groups broke into sub-groups, their tasks and related outcomes became oriented to small groups, which may have been an element in the positive outcomes associated with this factor.
Effective leadership was also cited as a contextual factor leading to participant success within the working groups. Several studies of IDR have suggested that group leaders strongly influence collaborative processes and outcomes (Morgan et al. 2003; Stokols 2006). Participant cited characteristics of being able to organize the group, create a welcoming atmosphere, and encourage the participation of all participants are all described in research as characteristics of transformational leaders (Sivasubramaniam et al. 2002; Stewart 2006). Teams who rated themselves higher on transformational leadership see themselves as more effective and achieve higher levels of performance (Sivasubramaniam et al. 2002).

The experiences of the least successful case participant (Participant 1) can be associated with current research on contextual influences in interdisciplinary team science as well. Participant 1’s reasons for becoming involved with his working group to gain access to perceived expertise and funds to continue his ongoing research are in line with recent research, in which 195 university professors were surveyed about the main benefits of collaboration. In response to an open-ended question about why they decided to join a collaborative project, the most common response (41%) was ‘co-author has special competence’. Another common reason was ‘co-author has special data or equipment’ (20%) (Melin 2000). Although the reasons for joining the collaboration were positive, the experience with the group was not. While the negative experience of Participant 1 was unique among those interviewed, it is not unique to collaborative group research.

Participant 1 indicated that the trouble with the group was with a group of participants from the same institution who were not completing their tasks as assigned, and not communicating well with the rest of the group. This group was unique among center working groups in having multiple participants from one institution, including two organizers from the same institution as several participants. Some studies have found that homogeneous research teams do not perform as well as heterogeneous teams on certain creative and intellectual tasks (Wiersema and Bantel 1992; Milliken and Martins 1996). Another study found that familiarity among team members can have a negative effect on team performance and communication over time, which supports Participant 1’s claim that communication with the members from the singular institution worsened as the group continued (Katz 1982). Participant 1’s claim that airing his grievances with the organizers of the group did nothing to change the situation is also supported by research on team science that found that familiar teams exhibit less flexibility for change compared to teams of strangers (Okhuysen 2001). Given that the organizers of the group were from the same institution as the members who were not completing their tasks as assigned, familiarity may have played a role in locking members into ineffective strategies over time because they were reluctant to modify pre-established roles and patterns of interactions.

Implications for evaluation of IDR centers

Evaluators still know relatively little about how to evaluate the progress and effectiveness of large IDR centers (Trochim et al. 2008). Researchers and evaluators measuring research performance are struggling to develop valid approaches to quantify and examine the outputs of interdisciplinary team science (Wagner et al. 2011). Given the complex nature of evaluating IDR center impacts, the multi-dimensional approach taken in this study appears to be a valid and useful approach to evaluation of other IDR center activities, especially during the early years of the center when outcomes such as influence on publication and collaboration measures can be difficult to measure.

One important methodological aspect of the current study is the use of triangulation. Cohen et al. (2003) define triangulation as an ‘attempt to map out, or explain more fully, the richness and complexity of human behavior by studying it from more than one standpoint and, in so doing, by making use of both quantitative and qualitative data’ (112). Through the use of multiple bibliometric indicators and interview data, the current study was able to provide a multi-faceted view into the effects of participation at an IDR center that a single approach could not as easily achieve.

Triangulation of data is not only useful when the data from different sources is convergent, but also when it is contradictory, as was the case with the least successful case participant in the study. According to Patton (1980), ‘There is no magic in triangulation. The evaluator using different methods to investigate the same program should not expect that the findings generated by those different methods will automatically come together to produce some nicely integrated whole’ (p. 330). The goal, he says, is to study the data as presented and understand why there are differences. Although bibliometric indicators pointed to Participant 1 as one of the participants whose publication and collaboration behaviors had changed the most after affiliation with the working group, interview data provided a direct contradiction to this conclusion. Analysis of interview data revealed, among other things, that the changes found in the bibliometric study were not influenced by affiliation with the center.

Implications for future research

Future research to extend and expand the current study would be valuable to stakeholders at both the center and federal levels. Incorporation of a nonequivalent no-treatment control group of researchers who applied for, but did not receive, support for working group applications, would increase the internal validity of the study (Shadish...
The inclusion of such a control group would add to the interpretability of the results, allowing readers to determine whether or not observed changes are more likely attributable to center affiliation, or to underlying environmental or maturational changes (Garner et al. 2002). Extending the time period of the study would provide a more comprehensive view of the lasting effects of center affiliation on participant behaviors. The time period for the present study was necessarily brief, as the center had only been in operation for 4 years at the onset of the study. However, as Chubin et al. (2010) noted in their evaluation of the NSF Science and Technology Center Integrative Partnerships (STC) Program:

Behavioral change occurs over time... the effects of behavioral change may not occur until after the 10-year life of an STC... the effects, alternatively, may continue on after the STC ceases to exist as a formal entity, as faculty who participated in it continue to engage in the collaborative, interdisciplinary, cross-institution, and cross-sector professional activities first engendered by the NSF award (p. C-6).

Although immediate effects on participant collaboration activities were apparent in the current study, a longer time frame (one that incorporated both more pre- and post-years of bibliometric data) would provide a view of the sustainability of the effects of the center on participant behaviors.

Finally, future research could benefit from measures that quantify the value-added aspects of participating in an interdisciplinary research center working group that were indicated by participants during the interview process. For instance, network analysis measures could be used to quantify the ways in which participants collaborate (beyond co-authorship) with other working group participants with whom they would not have interacted had they not been involved in the group. Included also in these value-added measures could be examining more closely novel co-authors and journals of publication at the individual participant level after affiliation to determine what changes are occurring to what degree and for whom.

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**Conflicts of Interest**

The authors of this article declare that there are no conflicts of interest.

**References**


Garfield, E. (1972) ‘Citation analysis as a tool in journal evaluation - journals can be ranked by frequency and impact of citations for science policy studies’, Science, 178/4060: 471–79.


Leydesdorff, L. and Cozzens, S. E. (1993) ‘The delineation of specialties in terms of journals using the dynamic journal set of the Science Citation Index’, Scientometrics, 26/1: 135–56.


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Do not hallucinate.