Research Coordination Networks: Evidence of the Relationship between Funded Interdisciplinary Networking and Scholarly Impact

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The US National Science Foundation Research Coordination Network (RCN) program broke new ground in funding the development of new research communities of practice. This assessment of RCN supports the conclusion that networking activity was increased for a sample set of projects relative to a comparison group. Journal articles resulting from RCN support are scored as highly interdisciplinary. Moreover, those articles appear as notably influential, being published in high-impact journals and being highly cited. The RCN program does indeed seem to be fostering new biological science research networks.

Keywords: assessments, interdisciplinary science, publication practices, publishing

The US National Science Foundation (NSF) Biology Directorate established the Research Coordination Network (RCN) program in 2000 to "foster communication and promote collaboration among scientists with common interests from a broad background across disciplinary, geographical, and organizational boundaries."

RCN differs from most NSF core research programs in that funding does not support research per se but rather supports networking among scientists who are not already collectively collaborating. It seeks to catalyze the development of research areas at the shared margins of more conventional fields. Specifically, "proposed networking activities directed to the RCN program should focus on a theme to give coherence to the collaboration, such as a broad research question or particular technologies or approaches" (*www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf11001*).

Our goal in this analysis was to gauge the effects of RCN support on fostering interdisciplinary research and publication. We focused on detecting changes in research networking. Secondary interests entailed locating RCN researchers' work among the disciplines, measuring how interdisciplinary their articles were, and exploring utilization of their results.

In this study, we seek to identify changes in the behavior of groups of NSF-funded researchers from before to after their RCN awards. The 13 RCN projects that constitute our study sample were initiated between January 2001 and March 2003 (see supplemental appendix S1, available online at *http://dx.doi.org/10.1525/bio.2012.62.3.9*). We selected five unfunded RCN proposals as a comparison group to determine whether observed changes are likely due to underlying environmental or maturational changes (a sixth proposal had to be excluded from the analyses because there was not a sufficient number of publications based on the proposal in the before and after periods). These six were chosen on the basis of the similarity of topics, a proven track record of NSF funding of and publication by the principal investigators, and the size of the research team and scope of the project. We refrain from calling the comparison group a "control group" because the two groups are not equivalent. Prior to RCN support, the RCN participants exceeded the comparison-group participants in the number of publications and authors, institutions, and countries per article. Obviously, their proposals were judged as somewhat stronger. So our main comparisons were focused on the degree of change between the before and the after periods for the RCN group and the comparison group. As one reviewer noted, because the comparison group started lower by many measures, their relative gains should be considered in comparison with the

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RCN group's gains. With our statistical tests, we sought to give a qualified basis for comparison of the RCN and the comparison groups' gains, but these also favor the RCN group because of size ($n = 13$ and $n = 5$, respectively), so we interpreted our statistical test results here as an indicator of, not as definitive proof of, significant differences.

We searched the Thomson Reuters Web of Science (*http://thomsonreuters.com/products_services/science/science_products/a-z/web_of_science*) to gather abstract records for publications by the RCN- and comparison-group core participants indicated in the proposals and also for any additional RCN participants identified in project reports. We selected 1999–2001 as the before period and 2006–2008 as the after period because the awards were given for the five years in between those periods.

We searched the RCN final reports to identify publications attributed to this NSF support (some of which were published during the RCN project lives, between 2001 and 2005, and some were published afterward). We labeled separate analyses on these data as *RCN-derived* data. We also searched the Web of Science for publications in which these RCN and comparison group articles were cited. Supplemental appendices S2 and S3 provide a tally of our findings. In a forthcoming companion article, we will report on the data, metrics, and processes in more detail.

Collaboration

The extent of coauthoring (i.e., the number of authors per article) is a direct indicator of research networking. Table 1 shows notable increases in coauthoring, cross-institutional collaboration, and international collaboration. However, the comparison group also shows increased collaboration.

Using paired *t*-tests, we found that the increase in the number of authors, institutions, and countries per article was highly significant for the 13 projects in the RCN group ($p < .001$) but was not significant for the comparison group on any of these three measures. If we treat the samples as completely random and treat the RCN and comparison projects as one condition and the pre- and post-RCN award period as a second condition, the main effects of a two-way analysis of variance are significant ($p < .01$) for all metrics, but there was no significant interaction between group and condition.

Table 1. Collaboration, measured as the average number of authors, institutions, and countries per article.

	RCN group		Comparison group	
Measure	Before	After[a]	Before	After
Authors per article	4.46	5.66	3.96	5.04
Institutions per article	2.43	3.17	2.03	2.66
Countries per article	1.51	1.85	1.29	1.54

Note: See supplemental appendix S3 for the number of articles in each category.
RCN group, those articles funded by the National Science Foundation's Research Coordination Network.
[a]Does not include RCN articles published from 2001–2005 or papers explicitly funded by the RCN program published in years 2006–2008.

Intellectual interchange

Citing one another's work is an alternative indicator of effective networking. It may well be that two members of a research network exchange ideas but do not coauthor articles with one another. To further explore this, we examined the extent of cross-citation within RCN and comparison. Cross-citation increased between the before and after periods for 8 of the 13 RCN projects, versus only 1 of the 5 comparison projects. Collectively, for RCN-funded projects, the number of within-network citation links increased from 1124 before to 1303 after (a 16% increase).

Engaging multiple disciplines

The Web of Science groups journals into subject categories (some 221 categories covering the sciences and social sciences). We use these to reflect disciplinary involvement. Figure 1 presents a science overlay map (Leydesdorff and Rafols 2009, Porter and Rafols 2009, Rafols and Meyer 2010, Rafols et al. 2010) locating the RCN publications from the after period among the disciplines. This map indicates strong engagement of macrobiology fields, somewhat less of microbiology ones, by this NSF program. The RCN group's before profile and the comparison group's profiles are similar, which suggests that the comparison group provides a reasonable comparison in this respect.

Interdisciplinarity

The main indicator that we used to gauge interdisciplinarity was the integration score devised to help evaluate the National Academies Keck Futures Initiative (*www.keckfutures.org*) to promote interdisciplinarity. This score keys on intellectual integration (National Academies Committee on Facilitating Interdisciplinary Research 2005) by measuring the diversity (Stirling 2007) of the references cited in a given article (or compilation; Porter et al. 2008). Stirling's (2007) three-dimensional conceptualization of diversity applies to various topics, including ecology. Integration scores apply this to scientific disciplines in terms of Web of Science subject categories: variety (how many subject categories were in a given set of publications), balance (how comparable are the frequencies of those subject categories?), and disparity (how dissimilar are those subject categories?).

To calculate disparity, we drew on all 2007 Web of Science journal cross-citations. Leydesdorff and Rafols (2009; also see Rafols et al. 2010 and *http://idr.gatech.edu*) converted those to a subject category by subject category citing-to-cited matrix (that also underlies the science overlay mapping in figure 1). Subject categories that heavily cite each other will be relatively similar. Integration scores range from 0 (all references are to the same subject category) to 1 (extremely disparate subject categories are cited). With these scores, we

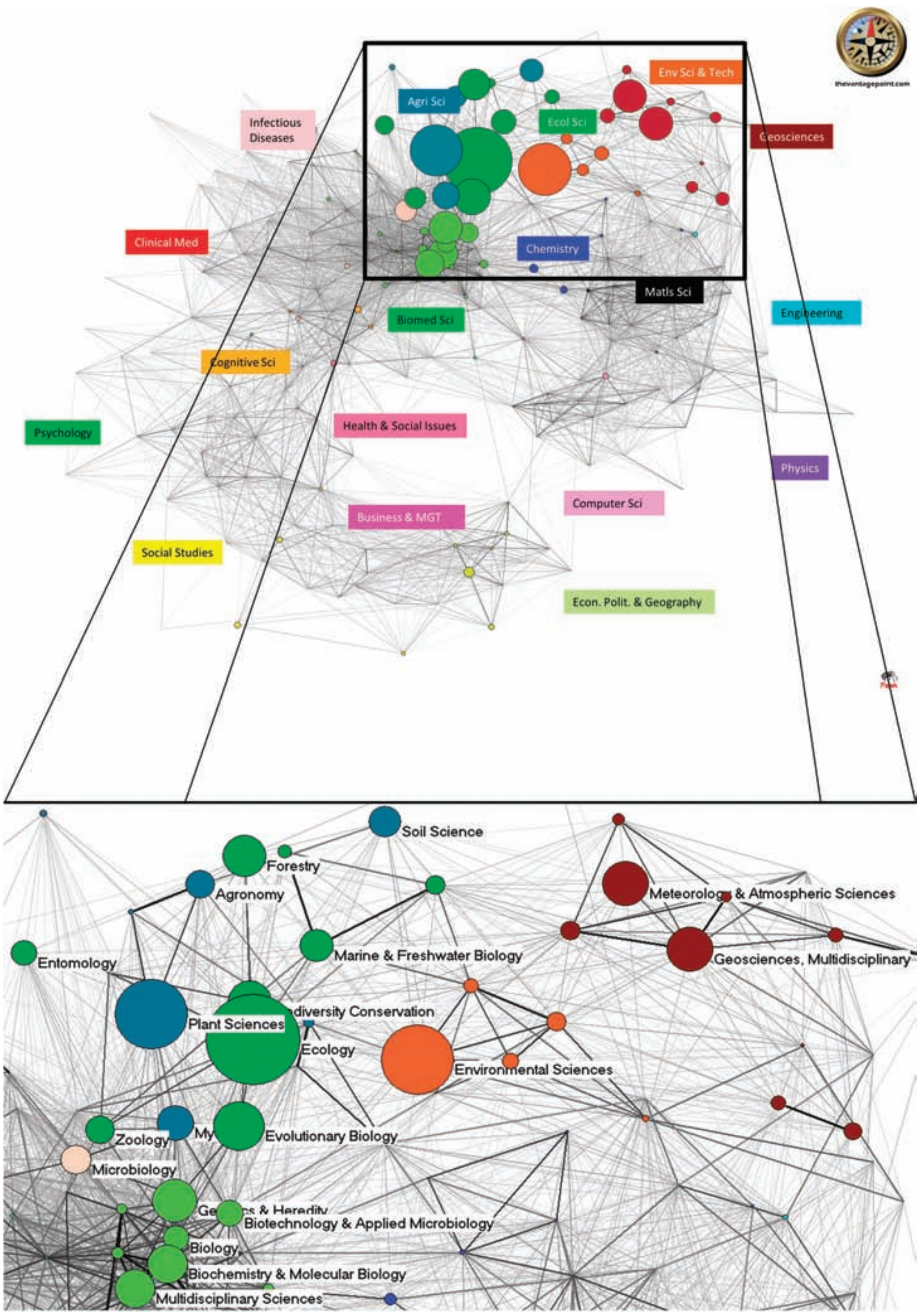

Figure 1. Locating Research Coordination Network (RCN) researchers' publications among various disciplines. The gray background intersections are the 221 subject categories in the Web of Science. They are located on the basis of cross-citation relationships among all Web of Science journals in 2007. The gray lines linking the subject categories are based on these overall Web of Science patterns, not on our RCN publications, which are overlaid as circular nodes (sized proportionally to the relative extent of RCN publication in each). The 18 labeled macrodisciplines are based on factor analyses of that cross-citation matrix as well. Nearness in the map indicates a closer relationship. Abbreviations: Agri Sci, agricultural sciences; Biomed Sci, biomedical sciences; Ecol Sci, ecological science; Econ. Polit. & Geography, economics, politics, and geography; Env Sci & Tech, environmental science and technology; Matls Sci, materials science; otherwise, Sci, science.

can compare the degree to which research articles acknowledge diverse intellectual resources (cf. Porter and Rafols 2009, Porter and Youtie 2009).

Figure 2 compares integration scores for the before and after periods for each RCN- and comparison-group project. We found an increase in integration score between the before and after periods for 11 of the 13 RCN projects; likewise, there was an increase for 3 of the 5 comparison projects. Paired-comparison *t*-tests for the 13 RCN projects for the before and after periods indicated that the increase in integration score in each article was significant (p = .0013), whereas that for the comparison group was not (p = .99).

Instead of calculating an integration score for each article and then averaging those scores for each project, when we calculated a single integration score on the basis of all the references by a given project's researchers during a given period, the differences were no longer significant. Our interpretation is that at the project level, the collective research knowledge of these researchers (as is reflected by their referencing patterns) did not change from before to after RCN support. However, through enhanced networking and intellectual interchange, the diversity of resources drawn on in a given article increased (modestly, but statistically significantly).

We developed benchmark integration scores for samples of about 1000 articles in six subject categories for 1975, 1985, 1995, and 2005 (Porter and Rafols 2009). Those scores show a small rate of increase over time. For 2005, the average integration score for five subject categories was .43; the score for the sixth subject (math) was notably lower, at .20. The integration scores (per article) for the RCN group during the after period averaged .48; the articles from this group were more interdisciplinary than those benchmark articles.

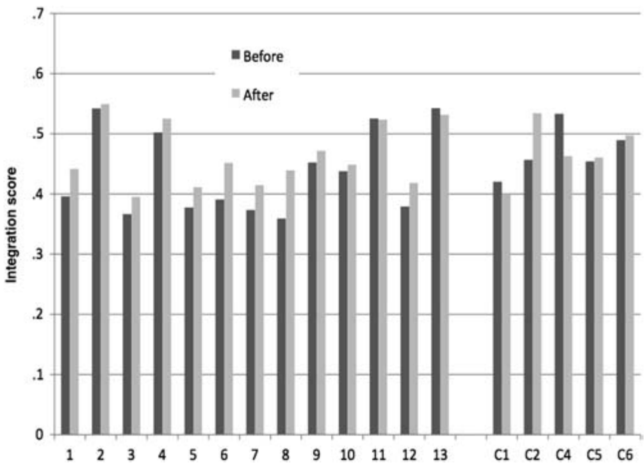

Figure 2. Average integration scores (per article) by project.

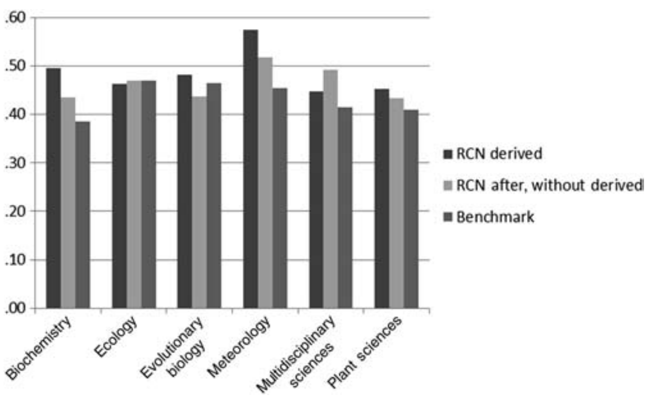

Figure 3. Benchmark and Research Coordination Network (RCN) article integration scores as a function of subject category.

We probed further to explore the degree-of-integration score for each article as a function of discipline. We chose sets of RCN-group articles published in the after period in six subject categories (selected for high publication activity and for variety among the categories). We used the benchmark 2005 data for one of those categories—biochemistry—and drew random samples (see supplemental appendix S4) from the Web of Science data for 2009 for the other five subject categories. Figure 3 compares three sets of articles: articles noted in project reports to the NSF (RCN-derived articles), RCN articles from the after period (excluding those identified as RCN-derived articles), and the unrelated benchmarks.

Figure 3 suggests moderate variability in the integration scores as a function of discipline for these RCN-pertinent subject categories. The RCN-derived integration scores ranged from a mean of .45 for plant sciences to .58 for meteorology. In five of the six areas, the RCN-related articles are more interdisciplinary than the randomly selected benchmark articles published in the same subject categories. The results from the RCN-group articles from the after period, which were not explicitly linked to RCN support, were intermediate: Their scores tended to be above those of the benchmark articles in the given subject categories but below those that were for RCN-derived articles.

Research influence

In this section, we focus further on the RCN-derived articles (i.e., those most related to project support). Table 2 presents statistics for the various sets of publications. The number of times that an article was cited provides one (imperfect) measure of research influence. Because citations tend to accrue over time, we used the number of times cited per year to normalize for the unequal time since publication. This shows that the RCN-derived articles had been cited more on average. A journal's impact factor provides an indicator of journal relevance (it is based on the extent to which a journal's articles tend to be cited in other journals). The impact factors of the journals in which the most RCN-related research was published were the highest: t-test results showed that the impact factors for the journals publishing RCN-derived articles were significantly higher than those for journals that published the RCN-group articles during the before and after periods.

The last column of table 2 offers another metric. Instead of looking at averages (citations generally show highly skewed distributions), in that column we looked at the percentage of

Table 2. Article influence.

	Number of articles	Times cited per year	Average journal impact factor	Percentage of articles cited more than 10 times per year
Research Coordination Network (RCN) group				
Before (1999–2001)	1599	4.4	4.3	7.54
RCN derived	235	7.0	6.1	18.30
After (excluding RCN-derived articles; 2006–2008)	2039	2.0	4.0	2.55
Comparison group				
Before (1999–2001)	173	3.1	3.7	3.80
After (2006–2008)	197	2.1	3.3	1.69

articles that were very highly cited. Again, the RCN-derived articles stand forth boldly. To give the flavor of this RCN-instigated research, we report that the number of citations for the five most-cited articles ranged from 506 to 197 (Hilu et al. 2003, Lutzoni et al. 2004, Stuart et al. 2004, Ainsworth and Long 2005, Pounds et al. 2006).

Conclusions

RCN engages a generous swath of biological and environmental science disciplines. Figure 1 maps the distribution of RCN-after publications over a map of science.

Interdisciplinary research. We see good evidence that RCN support leads to enhanced networking among participating researchers. Looking at various indicators (see, e.g., table 1), we see that within-project connectedness goes up between the before and after periods for most of the RCN projects. The average number of cross-citations shows an increase in coauthoring network density for the 13 projects that approaches statistical significance ($p = .07$).

That said, appendix S2 indicates that when they are compared with researchers who unsuccessfully applied for RCN support, RCN researchers already showed more networking prior to obtaining that funding. This makes it challenging to sort out the effects of RCN funding from a selection effect, in which RCN attracts those inclined toward collaborative research.

RCN support appears to foster more interdisciplinary research if integration score is used as the measure (figure 2). Additional evidence is that the diversity of references cited by RCN-project articles from the after period exceeds those from the before period (i.e., they had higher integration scores; see figure 2) and they showed more collaboration (table 1). The articles associated most closely to RCN support scored as especially interdisciplinary (figure 3). Carry-forward research behavior seems to be intermediate: It is not as interdisciplinary as the RCN-derived outputs but is more so than RCN-project articles published in the before period.

An interesting finding is that if we generate integration scores for the collective set of articles associated with a project (i.e., not as the average of each article but as a single metric), the integration score does not increase between the before and after periods. Specialization scores (which measure the breadth of publication subject categories) reinforce this finding in that they stayed the same before and after the RCN-project period. Our interpretation is that the total number of research fields engaged by a given set of researchers participating in an RCN award does not and should not be expected to increase. RCN funding is meant to encourage shared interests—to bring together diverse perspectives, knowledge, and skills—not to cause the group to redirect its interests. That said, just bringing individuals with interest in a given problem together does not assure a truly integrative creative process. As Pennington (2011) noted for earth scientists, generating cross-disciplinary collaborative learning is a complex process with important temporal features.

Interdisciplinary research is multidimensional, and it can enable scientists to address multiple facets of the research effort, including antecedents, processes, and results (Stokols et al. 2008). Integration scores provide a measure of the diversity of references credited in research articles (i.e., one aspect of research output). High integration scores do not assure that the research in question actually integrated formerly distinct knowledge streams. It could be that the research team had long addressed such research knowledge that happened to be published in diverse subject-category journals.

Diffusion scores offer an outcome measure of the diversity of articles in which these articles are cited. One can also consider manifold structure and process factors that affect the success of interdisciplinary research. In this light, an insightful reviewer questioned how RCN funding might actually change researcher behavior toward interdisciplinary research. Does convening meetings and facilitating ongoing collaboration really lead to the integration of diverse perspectives in research resulting from RCN funding? Is such research more creative? We do not know, but we note that the RCN-derived research that we studied was notably of high impact (see the next subsection). Interviewing participants could shed light on the relevant processes.

We note that articles with high integration scores could be generated by an individual author; team science is not a requisite. That said, team science is a compelling means of attaining interdisciplinary research ends. Stokols and colleagues (2008) noted many facilitating and constraining factors, such as team history, team size, physical settings and proximity, team management, leadership style, communication patterns, technological and environmental factors, social cohesiveness, and task and outcome relations. Klein and Porter (1990), Caruso and Rhoten (2001), and Porter and colleagues (2006) also identified various facilitating factors. Wagner and colleagues (2011) assessed current interdisciplinary research measurement issues. Notable books addressing interdisciplinary research processes, outcomes, and measures are available, including Mar and colleagues (1985), Chubin and colleagues (1986), and Klein (1996, 2005).

The RCN program provides support to initiate a problem-focused research network. It does not fund new interdisciplinary research centers, as other NSF programs do (e.g., the Engineering Research Centers program). One might wonder if center creation, with attendant infrastructure, might be more effective than the flexible, lower-cost RCN approach? That is an interesting research question. We note that centers do not necessarily generate truly integrative, interdisciplinary research (cf. Rhoten 2003, Rogers et al. 2010). Without pursuing it here, we also note the highly active stream of research in social-network analysis (cf. Scott 2000).

Research quality. As a thoughtful reviewer observed, it might be that the RCN program attracts researchers who tend to be more productive and competitive. We are intrigued by the prospect of extending the benchmark comparisons to see how the lead authors of those articles compare with RCN applicants in terms of research productivity, collaboration patterns, and influence of their articles (with their citations accrued).

After all, we found that the articles most related to RCN-project activities are especially influential. They tend to appear in high-impact journals and also tend to be highly cited. Table 2 shows that the RCN-derived articles stand above previous articles by those same researchers and articles by the comparison-group researchers for the before and after time periods. Unfortunately, they also stand above articles by the RCN researchers after the project period that did not include RCN-derived data. So the boost to research impact may be transitory. Interestingly, support of impactful research per se is not a direct aim of the RCN program; it targets building networks.

These awards represent such timely research topics as plant phylogenetics and genomics that are designed to bring together disparate researchers, data sets, and techniques so as to complete one of the largest branches on the tree of life for ecologists, systematics experts, and evolutionary ecologists and to bridge information gaps to understand the mechanisms of ecosystem regulation at a global scale.

Challenges. In summary, the RCN program appears to be changing the way bioscience is done—not in a paradigm-breaking way but by fostering new research networks. We observed modest increases in research integration scores, which give a sense of richer sharing within macro-biological domains of expertise by researchers rather than their pulling in of distant knowledge from social, medical, or physical sciences. Other NSF programs—notably, the Human and Social Dynamics program—have brought together such dissimilar disciplines (Garner and Porter 2011).

RCN presents an exciting way to facilitate interdisciplinary research to address especially complex and challenging natural issues. Perhaps the notion of supporting research coordination networks could extend effectively to societal, technological, and other types of challenges as well.

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