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Knowledge creation through collaboration: The role of shared institutional affiliations and physical proximity

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Abstract

This paper examines how shared affiliations within an institution (e.g., same primary appointment, same secondary appointment, same research center, same laboratory/facility) and physical proximity (e.g., walking distance between collaborator offices) shape knowledge creation through biomedical science collaboration in general, and interdisciplinary collaboration in particular. Using archival and publication data, we examine pairwise research collaborations among 1,138 faculty members over a 12-year period at a medical school in the United States. Modeling at the dyadic level, we find that faculty members with more shared institutional affiliations are positively associated with knowledge creation and knowledge impact, and that this association is moderated by the physical proximity of collaborators. We further find that the positive influence of disciplinary diversity (e.g., collaborators from different fields) on knowledge impact is stronger among pairs that share more affiliations and is significantly reduced as the physical distance among collaborators increases. These results support the idea that shared institutional affiliations and physical proximity can increase interpersonal contact, providing more opportunities to develop trust and mutual understanding, and thus alleviating some of the coordination issues that can arise with higher disciplinary diversity. We discuss the implications for future research on scientific collaborations, managerial practice regarding office space allocation, and strategic planning of initiatives aimed at promoting interdisciplinary collaboration.

1 | INTRODUCTION

Collaboration is a necessary feature of scientific work in solving the complex questions and challenges in modern society (National Research Council, 2015). While scientific collaboration can provide several advantages ranging from functional specialization, division of labor, and resource sharing to fruitful cross-pollination of ideas, it can also increase a variety of coordination costs that impede productivity (Fox & Faver, 1984). Contextual factors such as where collaborators work, how their institutions are structured, and the nature of their organizational connections influence the extent to which coordination costs undermine collaboration (Cummings & Kiesler, 2007). Thus from both an academic and practitioner perspective, it is critical to understand what contextual factors influence

(a) knowledge creation and (b) knowledge impact through scientific research collaboration.

Prior attempts at answering these questions have typically examined contextual factors in isolation. For example, one stream of research describes how shared institutional affiliations (e.g., same department or same research center/institute) influence science collaborations by establishing the social boundaries, rules, and norms that facilitate or restrict information exchange among affiliates (Dahlander & McFarland, 2013). A separate stream explains how physical proximity impacts collaboration by shaping the costs of informal or formal in-person interactions that can facilitate information exchange critical to effective collaborations (He, Wu, & Zhang, 2019; Kabo, Cotton-Nessler, Hwang, Levenstein, & Owen-Smith, 2014). However, it is important to integrate these distinct but interconnected streams of research (e.g., Claudel, Massaro, Santi, Murray, & Ratti, 2017; Sailer & McCulloh, 2012) to explain how contextual factors may interact to promote or hinder knowledge creation and the knowledge impact of scientific collaboration. This study advances our understanding of the processes underlying collaboration by bringing together research on shared institutional affiliations and physical proximity to examine their joint role in knowledge creation and impact in academic journal publications.

Prior work has shown that both shared affiliations and physical proximity are important factors in interpersonal communication, which is foundational to establishing trust and developing a common understanding, particularly when frequent face-to-face interaction is valuable to the collaboration (Bechky, 2003; Handy, 1995; Kraut, Fussell, Brennan, & Siegel, 2002). Previous studies that have separately examined shared affiliations or physical proximity may have inadvertently confounded the impact of these two factors on collaboration success (e.g., when members of the same department all sit in the same hallway). In this study we take advantage of affiliation and location variation in a medical school to examine how shared institutional affiliations and physical proximity interact to shape collaborative knowledge creation and impact.

While science collaboration has been studied in many ways (Katz & Martin, 1997), we conceptualize *knowledge creation* as the processes and conditions involved in coauthored *publications* of scientific research in peer-reviewed academic journals (Birnholtz, Guha, Yuan, Gay, & Heller, 2013). We are also interested in the impact of publications derived from collaborations. Since publications are a common goal of science collaborations, *knowledge impact* is generally measured by the number of *citations* a publication receives from other academic works. This measure of knowledge impact captures how much the knowledge diffused or influenced various scientific communities (Wang, 2016).

In the sections below, we first conceptualize how the combination of shared institutional affiliations and physical proximity can increase the interpersonal contact between current and potential collaborators—thus mitigating coordination costs and facilitating trust and common understanding. This, in turn, can increase collaborative knowledge creation through coauthored publications and increase the citations received from other scientific works. Next, we use publication and archival data on biomedical collaborations at the dyadic level to model the separate and interactive impacts of shared institutional affiliations, physical proximity, and disciplinary diversity on scientific collaboration. The findings support our conceptual framework, suggesting that physical space is a critical factor in determining whether these institutionally derived opportunities for collaboration will be successful. Finally, we discuss the implications for future research and managerial practice regarding office space allocation and strategic planning of initiatives aimed at promoting knowledge creation and impact through interdisciplinary collaboration.

2 | THEORETICAL BACKGROUND AND HYPOTHESES

2.1 | Shared institutional affiliations

Prior work on science collaborations shows the influence of various dimensions of interpersonal similarity and relatedness on the propensity to collaborate (Birnholtz, 2007). Shared affiliations is an important dimension of similarity that can impact an individual's chances of encountering and associating with another collaborator. Within an academic research university, faculty are embedded in webs of networks based on their professional affiliations with a variety of organizations including their primary department as well as secondary appointments and affiliations with research centers or institutes. To a greater or lesser extent, these organizations establish the physical boundaries, positions, rules, and norms that govern affiliate activities (Chung, Kwon, & Lee, 2016). These shared positions or activities structure these affiliation networks and can facilitate or restrict opportunities for social interaction and access to information and resources (Feld, 1981). Thus, shared institutional affiliations can play a significant role in science collaborations, potentially creating contact among affiliates who would not otherwise meet.

In prior studies, the most common way to conceptualize affiliation similarities among pairs of collaborators is whether or not the researchers belong to the same primary department or research center (Biancani, McFarland, & Dahlander, 2014; Dahlander & McFarland, 2013). The influence of each institutional affiliation is often treated separately and operationalized as a binary measurement

based on affiliate membership lists. Although less explored in studies of science collaboration, a "multiple embeddings" approach to affiliation networks recognizes that people operate in webs of affiliations with different roles and responsibilities that can shape the relative salience of a particular affiliation at a given time (Snow, Zurcher Jr, & Ekland-Olson, 1980). The timing as well as the nature of the activities and interactions with respect to one affiliation can impact the "identity salience" of another affiliation (McAdam & Paulsen, 1993). In the context of science collaborations, this lens encourages a more generalized conceptualization of affiliation networks that captures a fuller picture of a researcher's identities and potential engagements derived from their various institutional affiliations.

Prior work finds that working in the same department is an important factor in facilitating collaboration (Dahlander & McFarland, 2013). Primary department and lab/facility affiliations are more constrained (Merton, 1976, p. 25) since they are organized around shared training, teaching, research areas, or space with formal rules governing evaluation and promotion (i.e., compensation and career tracks), committee assignments, meetings, and where time is spent on a daily basis. However, less constrained institutional affiliations based on secondary departments as well as research center or institute memberships can also have shared practices that shape interaction and potentially fuel collaboration (Biancani et al., 2014).

Although rules and norms likely vary by department, individuals with secondary department appointments may participate more in activities like dissertation committees, weekly seminars, special events, and be directly linked to communication channels about recent or ongoing research. Research centers or institutes typically bring together research faculty and affiliates conducting projects around similar topics or subfields. Many centers organize weekly lectures/talks for faculty to share ongoing work, coordinate special events, and offer opportunities for funding (Biancani, Dahlander, McFarland, & Smith, 2018). Overall, we expect faculty with more shared institutional affiliations to publish more together and have more impact (citations) because shared affiliations can increase informal opportunities for interaction among affiliates and reduce the coordination costs during a collaboration. Therefore, we hypothesize:

H1a. Shared institutional affiliations will be positively associated with *knowledge creation* among pairs of faculty.

H1b. Shared institutional affiliations will be positively associated with *knowledge impact* among pairs of faculty.

2.2 | Physical proximity

A large body of psychological and sociological research details how propinquity or space is critical to social tie formation (Allen, 1977; Small & Adler, 2019). In general, as the distance between two collaborators increases, the costs of getting together increase and face-to-face contact decreases, which makes formal discussion, direct observation and monitoring, and informal communication more difficult and less frequent (Kiesler & Cummings, 2002; Kraut & Streeter, 1995). For those who are located within the same institution, walking path overlap and physical proximity increase the likelihood of starting a collaboration and being awarded grants (Kabo et al., 2014; Kabo, Hwang, Levenstein, & Owen-Smith, 2015). It is important to replicate this established finding in the literature (He et al., 2019) before extending physical proximity as a moderating effect on the association between shared institutional affiliations and knowledge creation and impact.

H2a. Greater walking distance will be negatively associated with *knowledge creation* among pairs of faculty.

H2b. Greater walking distance will negatively associated with *knowledge impact* among pairs of faculty.

2.3 | Moderating influence of physical proximity on shared institutional affiliations

Conceptually, the direct association between physical proximity and collaboration is driven by the increase in interpersonal contact between current and potential collaborators (Catalini, 2018), which facilitates trust and common understanding (Cramton, 2001; Handy, 1995; Okhuysen & Bechky, 2009): While likely helpful for all collaborators, we theorize that this interpersonal contact is more beneficial to pairs of collaborators with more shared institutional affiliations. In particular, physically proximate collaborators are more likely to informally "bump-into" each other in unplanned places, such as hallways, elevators, parking lots, and cafeterias (Kabo et al., 2015), and create informal opportunities to develop common interests and discuss smaller issues that might otherwise be overlooked (Kraut, Egido, & Galegher, 1990).

This benefits collaborations by strengthening social dimensions of professional relationships that help establish rapport and trust (Festinger, Schachter, & Back, 1950). Moreover, for faculty pursuing multiple research ideas, these informal interactions can serve as a

frequent physical reminder of task assignments and upcoming deadlines (Spillane, Shirrell, & Sweet, 2017), thus sustaining their attention on a project that might otherwise fall in priority. Collaborators who share department and center affiliations have extra sources of potential contact that faculty with no shared institutional affiliations does not have, such as monthly department meetings, or special events for center affiliates. Thus, physical proximity should increase the value of having shared institutional affiliations.

H3a. Shared institutional affiliations will be less positively associated with *knowledge creation* among pairs of faculty when walking distance is greater.

H3b. Shared institutional affiliations will be less positively associated with *knowledge impact* among pairs of faculty when walking distance is greater.

2.4 | Disciplinary diversity in collaborations

Scientific research is conducted by increasingly interdisciplinary collaborations (Cummings, Kiesler, Bosagh Zadeh, & Balakrishnan, 2013; Lee, Walsh, & Wang, 2015; Wuchty, Jones, & Uzzi, 2007). Regarding the benefits to knowledge impact, the mixed findings in the literature indicate a complex association between disciplinary diversity and science collaboration with several trade-offs. On the one hand, collaborations with more disciplinary diversity can bring together different pieces of knowledge and skills for addressing more complex scientific problems (Shibayama, Baba, & Walsh, 2015) and also realize performance gains via effort (e.g., more people working on tasks), expertise (e.g., solve problems more quickly), and division of labor (e.g., efficiently divide up tasks). Positively linked to knowledge impact, Deichmann et al. (2020) find that coauthored publications with more knowledge diversity acquired more citations and had wider impact when generated by more highly connected contributors.

On the other hand, more diversity can also intensify coordination and communication challenges facing collaborators (Steiner, 1972). Collaborations integrating a more diverse range of information and contributions require more connectivity among collaborators to perform well (Reagans & Zuckerman, 2001) and bridging different knowledge domains increases the need to coordinate efforts and manage dependencies among members (Malone & Crowston, 1994). Other findings suggest that collaborations with too much diversity can suffer from interpersonal conflict that hinders social cohesion (Pelled, Eisenhardt, &

Xin, 1999) and coordination costs that lead to fragmentation and inefficiencies that diminish scientific results and knowledge creation (Lungeanu & Contractor, 2014; Sud & Thelwall, 2016). Overall, these mixed findings in the literature highlight the need for a better understanding of the moderating factors that enable some collaborations to capitalize on the knowledge, skills, and experiences derived from disciplinary diversity while minimizing the possible coordination process losses and interpersonal conflict from reduced cohesion.

Shared institutional affiliations and proximity may be important moderating factors in the association between disciplinary diversity and knowledge impact. We argue that the bond established through more shared affiliations can serve as a foundation for strengthening connectivity among collaborators—shown to be particularly important to collaborations with a more diverse exchange of skills, knowledge, and experiences (Deichmann et al., 2020; Reagans & Zuckerman, 2001). In addition, we argue that shorter distances between collaborators can help mitigate some of the steeper coordination challenges to multidisciplinary research (e.g., disciplinary differences in research standards and norms, theoretical foundations, methodologies, and database management practices). As the physical distance between collaborators decreases, the cost of attending formal meetings decreases, thus facilitating more frequent in-person information exchange that might particularly benefit more diverse collaborations.

H4a. Shared institutional affiliations will be more positively associated with *knowledge impact* among pairs of faculty when disciplinary diversity is greater.

H4b. Walking distance will be more negatively associated with *knowledge impact* among pairs of faculty when disciplinary diversity is greater.

3 | DATA AND METHODS

3.1 | Sample and setting

We examine collaboration pairs among 1,138 biomedical faculty members over a 12-year period (2007–2018) at a medical school in the United States. To be included in our sample, the researcher must hold a "primary" faculty appointment in one of the 23 basic science or clinical departments within the medical school and have at least one coauthored research publication between 2007 and 2013. Although some collaborations are supported by other non-primary faculty positions such as post-docs,

doctoral students, adjuncts, lecturers, or visitors, we focus on coauthorship pairs among primary faculty because they are principally responsible for the funding that supports the collaboration and they perform many coordination activities and design tasks while other roles are often oriented towards task execution. Moreover, we focus on primary faculty because of their high durability and embeddedness within the institution while other roles are often temporary appointments and prone to turnover, which would hinder our analysis of intra-institution collaborations over time.

3.2 | Data sources

To identify our target population, we started with a directory listing of all faculty in the medical school which included the faculty's primary department and title. To narrow in on the primary faculty set, we confirmed this list with each department's official website, which lists key attributes including each individual's primary department, appointment type (e.g., primary faculty, secondary appointments), and laboratory/facility address on campus. Furthermore, we collected administrative records on all facilities operated by the medical school, including the primary faculty office location. We verified the faculty space by comparing the records from this administrative data and internal directory records, and asked university administrators to confirm the primary faculty space in the few cases with conflicting information.

For walking distance between collaborators, we used the amount of time (in minutes) it takes to walk to/from the primary offices of the coauthors. This time is calculated using the "walking" method with the Google distance matrix distance API, which calculates the time based on the optimal walking route (via walkable paths and sidewalks) between the buildings. Furthermore, after visiting many of the buildings in the medical school, we factored in the floor number of the faculty offices by adding an extra minute for every floor the walker must ascend/descend to reach their coauthor's office (similar estimates were obtained whether we included/excluded this extra minute per floor). This enabled us to create a walking distance matrix for each potential collaboration dyad among all primary faculty in the medical school.

Next, we collected all the publication information for each primary faculty member from their individual online "scholars" profile, which is created by the university for all faculty members. Each faculty profile is an enhanced CV that lists relevant dates for all appointments, affiliations, and publications associated with the faculty. These profiles are connected to faculty unique researcher IDs (e.g., ORCID, Scopus ID) and publication

records are automatically updated every 6 months by the university IT system to include recent publications and corrections. The added benefit of using these scholars profile webpages is that every publication listed on any faculty profile is digitally linked to a unique publication profile page that contains key bibliometric information (e.g., coauthors, year published, journal title, publication type). Within the structured list of coauthors, each publication profile page identifies all coauthors in the university system and hyperlinks to each faculty's individual page. This enabled us to create a precise intra-organizational relational database of collaborative *Publications*. Moreover, nearly all publications pages provided unique IDs (e.g., DOI, PubMed ID, Scopus ID) or direct links to the publication's official journal webpage, Scopus webpage, or Google Scholar page. For our analysis, we chose to focus only on peer-review academic journal articles, and therefore we filtered out other types of publications (e.g., book chapters, book reviews, news articles).

Next we used the unique identifying information (e.g., DOI, PubMed ID, Scopus ID, article title) for the entire publication set (collected in the previous step) to search and find every publication indexed in the NIH iCite, Scopus, and Google Scholar databases. These databases report several descriptive citation metrics for each publication including the *Citations (count)*, which captures the number of times each publication has been cited by other academic publications. From these databases, we extracted the *Citations (count)* of every publication as one of our primary dependent variables. Furthermore, we used the academic journal titles from the publication set to collect the Journal Citation Reports (JCR) 5-year *Journal impact factor* assigned to all academic journals by the Web of Science. Using the publication's unique IDs, we then linked the *Citations (count)* and *Journal impact factor* measurements with the appropriate publication, each corresponding to primary faculty coauthors in our sample. Based on this data, we created a dyadic panel dataset of publication collaborations between 2007 and 2018, which enabled us to estimate dyadic level models of intra-organizational collaboration over time.

4 | VARIABLE DEFINITIONS

4.1 | Dependent variables

With respect to collaboration [i,j] over time [t], our analysis focuses on *Publications* as the main measure of knowledge creation and *Citations* as the main measure of knowledge impact. *Publications (count)* measures the number of academic journal publications that were

coauthored by faculty i and j through year t. As an alternative measure, estimated as a robustness check, *Years published (count)* measures the number of unique years a coauthored publication occurred between faculty i and j through year t.

To capture the knowledge impact of a coauthored publication between faculty i and j in year t, *Citations (count)* measures the total number of times a given publication has been cited by other publications according to Google Scholar. As robustness check, we also estimated models using the *Citations* reported by NIH and Scopus databases, which are highly correlated ($r > .95$), and produced similar estimates. As a further robustness check, we also tested an alternative measure[1] of knowledge impact based on the journal where the coauthored article was published; *Journal impact factor* measures the average number of times articles from the journal—published in the past 5 years—have been cited.

4.2 | Independent variables

The main variables in the analysis are measures of shared institutional affiliations, physical proximity, and disciplinary diversity. In a given year t, we measure four dimensions of shared institutional affiliations. *Same department (primary)* is a binary measure of whether faculty i and j share the same department with respect to their primary appointment.[2] *Same department (secondary)* is a binary measure of whether faculty i and j in year t share a secondary appointment in the same department. *Same center* is a binary measure of whether faculty i and j in year t share an affiliate appointment in the same research center or institute on campus.

Lastly, *same facility* is a binary measure of whether faculty i and j have an office in the same laboratory or facility on campus.[3] We include this fourth dimension as an institutional affiliation because there are many large medical research facilities on campus that serve as hubs for certain kinds of biomedical research. These large facilities house different kinds of scientists who are not necessarily affiliated by department or research center. Thus, faculty can share a laboratory or facility affiliation without necessarily sharing another institutional affiliation. Altogether, these four indicators comprise the *shared institutional affiliations* index, which measures the total number of institutional affiliations shared by faculty i and j in year t.

For physical proximity, *walking distance (minutes)* measures the duration of time it would take to walk between the primary offices of faculty i and j in year t, as calculated by Google's distance matrix API. We measure

disciplinary diversity as the number of distinct departments[4] represented among all medical school coauthors listed on the publication in year t.

We also include several individual-level control measures in the models to help account for faculty traits that may influence one's propensity to affiliate or openness to collaboration.[5] *Affiliations* is a count of the faculty's primary appointment, secondary department affiliations, research center/institute affiliations, and laboratory/facility affiliations in year t. Because all faculty only have one primary department affiliation, variation in the measure comes from affiliations in secondary departments, research centers/institutes, and laboratories/facilities. *Basic science* is a binary measure of whether a faculty collaborator is in a basic science department (rather than a clinical department). *Rank* is a scaled measure of a faculty's academic title in year t, which signals seniority in the university (1 = *Assistant Professor*, 2 = *Associate Professor*, 3 = *Full Professor*). We also include two additional controls related to space. *Building size* measures the total number of primary faculty with an office in a particular building in year t. This helps control for whether faculty have more potential collaborators within their office building. *Wet lab* is a binary variable indicating whether, in year t, an individual is the primary occupant of a laboratory designed for safely analyzing biological matter (e.g., drugs, enzymes) using liquid or gaseous chemicals or substances. We include summary statistics and correlations for our key independent, dependent, and individual-level control variables in Table 1.

It is important to point out that many faculty in the medical school are distributed in different facilities, as opposed to many non-medical school departments that tend to concentrate faculty offices in a particular floor or wing of a single facility. Only 19% of faculty in our sample are collocated in the same building and floor as their primary department core location. This is in part because many faculty have labs that serve as their primary research space and clinical faculty are located in different parts of the larger hospital ecosystem housed in separate facilities (e.g., main hospital, specialist clinics, and research complexes).

4.3 | Analytic methods

To set up the dyadic framework, we model all possible i, j, t combinations between 2007 and 2018 and estimate associations with knowledge creation and knowledge impact derived from collaborations. At the dyadic level, we use an OLS linear regression model with multiway cluster-robust standard errors. Compared to the

TABLE 1 Descriptive statistics and correlation matrix: dyad-level ($N = 7,763,436$)

#	Variable	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Affiliations(i)	3.35	1.56	1.00															
2	Basic Science(i)	0.08	0.27	0.14	1.00														
3	Rank(i)	1.91	0.83	0.27	0.11	1.00													
4	Building size(i)	45.47	35.22	−0.23	−0.17	−0.05	1.00												
5	Wet lab(i)	0.14	0.35	0.15	0.03	0.04	−0.12	1.00											
6	Same department (primary)	0.13	0.33	−0.03	−0.09	−0.03	0.03	−0.01	1.00										
7	Same department (secondary)	0.02	0.13	0.09	0.03	0.04	−0.02	0.02	−0.04	1.00									
8	Same center/institute	0.07	0.26	0.19	0.08	0.05	−0.08	0.04	0.01	0.08	1.00								
9	Same lab/facility	0.03	0.18	−0.03	−0.01	−0.01	0.11	−0.02	0.10	0.02	0.02	1.00							
10	Shared institutional affiliations	0.26	0.53	0.09	−0.01	0.01	0.02	0.01	0.69	0.27	0.53	0.48	1.00						
11	Walking distance (minutes)	22.43	34.80	0.02	0.04	0.00	−0.05	−0.01	−0.05	−0.02	−0.06	−0.09	−0.11	1.00					
12	Disciplinary diversity	0.01	0.14	0.02	0.00	0.02	−0.01	0.00	0.04	0.04	0.06	0.04	0.09	−0.01	1.00				
13	Publications (count)	0.02	0.57	0.02	0.00	0.02	−0.01	0.00	0.05	0.02	0.06	0.05	0.11	−0.01	0.48	1.00			
14	Years published (count)	0.004	0.10	0.01	0.00	0.02	−0.01	0.00	0.05	0.02	0.05	0.04	0.09	−0.01	0.63	0.67	1.00		
15	Citations (count)	0.14	7.52	0.01	0.00	0.00	0.00	0.00	0.02	0.01	0.03	0.01	0.04	−0.01	0.29	0.15	0.14	1.00	
16	Journal Impact Factor	0.02	0.70	0.01	0.00	0.01	−0.01	0.00	0.04	0.02	0.05	0.03	0.08	−0.01	0.54	0.33	0.39	0.49	1.00

traditional Huber-White standard error which only allows clustering on one variable, this multiway approach developed by Cameron, Gelbach, and Miller (2011) enables the clustering of standard errors for more than one variable. The multiway clustering addresses the non-independence issue in dyadic modeling by clustering the standard errors based on each individual [i—j] as well as the intersection of the dyad [i∩j]. This approach is functionally equivalent to procedures like QAP regression in addressing individual and reciprocal autocorrelation issues in dyadic models (Cameron et al., 2011) and performs efficiently on large datasets (Biancani et al., 2014; Kleinbaum, 2018).

5 | RESULTS

5.1 | Main effects of shared institutional affiliations and physical proximity (H1a/H1b, H2a/H2b)

We find that faculty members with more shared institutional affiliations, which include primary and secondary department appointments, research center/institute membership, and lab/facility location, are positively associated with knowledge creation and knowledge impact. As shown in Table 2 (model 2), a one-unit increase in the number of shared institutional affiliations for a faculty pair is associated with a 0.11 unit increase in publications ($p < .01$), thus lending support for H1a. Affiliations shape ones identity and the relative salience of other affiliations (Snow et al., 1980), fostering a common bond between affiliates that, in turn, can fuel existing or new research collaborations leading to academic journal publications.

Also, we find that faculty with more shared institutional affiliations are more likely to create higher impact knowledge. As shown in Table 3 (model 2), a one unit increase in the shared institutional affiliations between a faculty pair is associated with a 0.59 unit increase in citations ($p < .01$), thus supporting H1b. In addition to shaping affiliates' identity, academic institutions are organized around common activities (e.g., committees, meetings, seminars) that govern how, where, and with whom affiliates spend much of their time (Feld, 1981)—and thus can create sustained opportunities for affiliated pairs to interact and discuss issues "on the fly," which has been shown to improve collaborative work (Kraut et al., 1990).

Regarding proximity effects, the estimates from our models suggest that walking distance has a negative, significant influence on knowledge creation and knowledge impact. Interpreting results in Table 2 (model 3), a one unit increase in the walking distance between a faculty pair is associated with a 0.003 unit decrease in publications ($p < .01$), thus supporting H2a. Larger distance

between two collaborators can decrease unplanned, informal interactions (Kabo et al., 2015), reducing opportunities for faculty to share common interests and strengthen relationships, thus making a joint research collaboration less likely to result in a publication.

Similarly, we find greater walking distances between a faculty pair reduces the knowledge impact of their collaboration. As shown in Table 3 (model 3), a unit increase in the walking distance between a faculty pair is associated with a reduction of 0.02 citations ($p < .01$), which lends support for H2b. Greater distance between collaborators can increase the costs of attending in-person meetings to formally discuss important issues (Kiesler & Cummings, 2002) and decrease the chances of informally "bumping into" collaborators, thus reducing opportunities for exchanging smaller updates and physical reminders of project tasks.

5.2 | Interaction effect (H3a/H3b)

We observe that walking distance significantly moderates the positive influence of shared institutional affiliations on publications (supporting H3a). As shown in Figure 1, at all pairwise distances, faculty dyads with more shared institutional affiliations tend to publish more together, but this positive association is weaker among pairs that are further apart relative to more proximate pairs. Reporting marginal effects based on the interaction (Table 2, model 4), when a faculty pair is about 9 minutes apart (walking distance), the average marginal effect of shared institutional affiliations is a 0.13 unit increase in publications—but for an otherwise identical pair separated by a 16 minute walk, the average marginal effect of shared institutional affiliations is only a 0.05 unit increase in publications. This suggests shared affiliations may help establish a context through which affiliates can interact and discover complimentary interests and strengthen existing relationships (Reagans, 2011)—however, proximity is a significant moderating factor that shapes how influential these institutionally derived opportunities are on knowledge creation.

In support of H3b, we find the knowledge impact of collaborative publications is shaped by the interaction of shared institutional affiliations and physical distance. The positive impact of shared affiliations is largest when dyads have high shared institutional affiliations and are separated by short distances. However, the positive association between shared institutional affiliations and citations is reduced as the distance between the faculty collaborators increases (see Figure 1). Interpreting the marginal effects based on the interaction (Table 3, model 4), when a faculty pair are about 9 minutes apart (walking distance), the average marginal effect of shared

TABLE 2 Dyadic regression estimates: Shared institutional affiliations and walking distance on knowledge creation

	Publications (count)	Publications (count)	Publications (count)	Publications (count)	Years published (count)	Years published (count)	Years published (count)	Years published (count)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Affiliations(i)	0.01*** (0.0001)	0.002*** (0.0001)	0.002*** (0.0001)	0.002*** (0.0001)	0.001*** (0.0000)	0.0001*** (0.0000)	0.0001*** (0.0000)	0.0002*** (0.0000)
Basic Science(i)	−0.01*** (0.001)	−0.01*** (0.001)	−0.01*** (0.001)	−0.01*** (0.001)	−0.002*** (0.0001)	−0.001*** (0.0001)	−0.001*** (0.0001)	−0.002*** (0.0001)
Rank(i)	0.01*** (0.0003)	0.01*** (0.0003)	0.01*** (0.0003)	0.01*** (0.0003)	0.002*** (0.0000)	0.002*** (0.0000)	0.002*** (0.0000)	0.002*** (0.0000)
ln(building size(i))	−0.002*** (0.0003)	−0.01*** (0.0003)	−0.01*** (0.0003)	−0.01*** (0.0003)	−0.0003*** (0.0000)	−0.001*** (0.0000)	−0.001*** (0.0000)	−0.001*** (0.0000)
Wet lab(i)	−0.01*** (0.001)	−0.01*** (0.001)	−0.01*** (0.001)	−0.01*** (0.001)	−0.001*** (0.0001)	−0.001*** (0.0001)	−0.001*** (0.0001)	−0.001*** (0.0001)
Shared institutional affiliations		0.11*** (0.0004)	0.11*** (0.0004)	0.09*** (0.0004)		0.02*** (0.0001)	0.02*** (0.0001)	0.01*** (0.0001)
ln(walking distance (minutes))			−0.003*** (0.0002)	−0.001*** (0.0002)			−0.0004*** (0.0000)	−0.0002*** (0.0000)
Shared institutional affiliations * ln(walking distance (minutes))				−0.04*** (0.0003)				−0.005*** (0.0001)
Constant	−0.01*** (0.001)	0.02*** (0.001)	0.02*** (0.001)	0.01*** (0.001)	−0.0001 (0.0002)	0.003*** (0.0002)	0.003*** (0.0002)	0.003*** (0.0002)
Observations	7,763,436	7,763,436	7,763,436	7,763,436	7,763,436	7,763,436	7,763,436	7,763,436

Note: Mean-centered predictors for interaction.

$*p < .1$, $**p < .05$, $***p < .01$.

TABLE 3 Dyadic regression estimates: Shared institutional affiliations and walking distance on knowledge impact

	Citations (count)	Citations (count)	Citations (count)	Citations (count)	Journal Impact Factor	Journal Impact Factor	Journal Impact Factor	Journal Impact Factor
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Affiliations(i)	0.04*** (0.002)	0.02*** (0.002)	0.02*** (0.002)	0.02*** (0.002)	0.01*** (0.0002)	0.002*** (0.0002)	0.002*** (0.0002)	0.003*** (0.0002)
Basic Science(i)	−0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	−0.0005 (0.01)	−0.01*** (0.001)	−0.005*** (0.001)	−0.005*** (0.001)	−0.01*** (0.001)
Rank(i)	0.01*** (0.003)	0.02*** (0.003)	0.02*** (0.003)	0.02*** (0.003)	0.01*** (0.0003)	0.01*** (0.0003)	0.01*** (0.0003)	0.01*** (0.0003)
ln(building size(i))	−0.01*** (0.003)	−0.03*** (0.003)	−0.03*** (0.003)	−0.03*** (0.003)	−0.001*** (0.0003)	−0.004*** (0.0003)	−0.004*** (0.0003)	−0.005*** (0.0003)
Wet lab(i)	−0.05*** (0.01)	−0.05*** (0.01)	−0.05*** (0.01)	−0.05*** (0.01)	−0.01*** (0.001)	−0.01*** (0.001)	−0.01*** (0.001)	−0.01*** (0.001)
Shared institutional affiliations		0.59*** (0.01)	0.58*** (0.01)	0.51*** (0.01)		0.10*** (0.0005)	0.10*** (0.0005)	0.09*** (0.001)
ln(walking distance (minutes))			−0.02*** (0.003)	−0.01*** (0.003)			−0.003*** (0.0002)	−0.001*** (0.0002)
Shared institutional affiliations * ln(walking distance (minutes))				−0.12*** (0.004)				−0.02*** (0.0004)
Constant	0.04** (0.02)	0.15*** (0.02)	0.16*** (0.02)	0.15*** (0.02)	−0.0003 (0.001)	0.02*** (0.001)	0.02*** (0.001)	0.02*** (0.001)
Observations	7,763,436	7,763,436	7,763,436	7,763,436	7,763,436	7,763,436	7,763,436	7,763,436

Note: Mean-centered predictors for interaction.

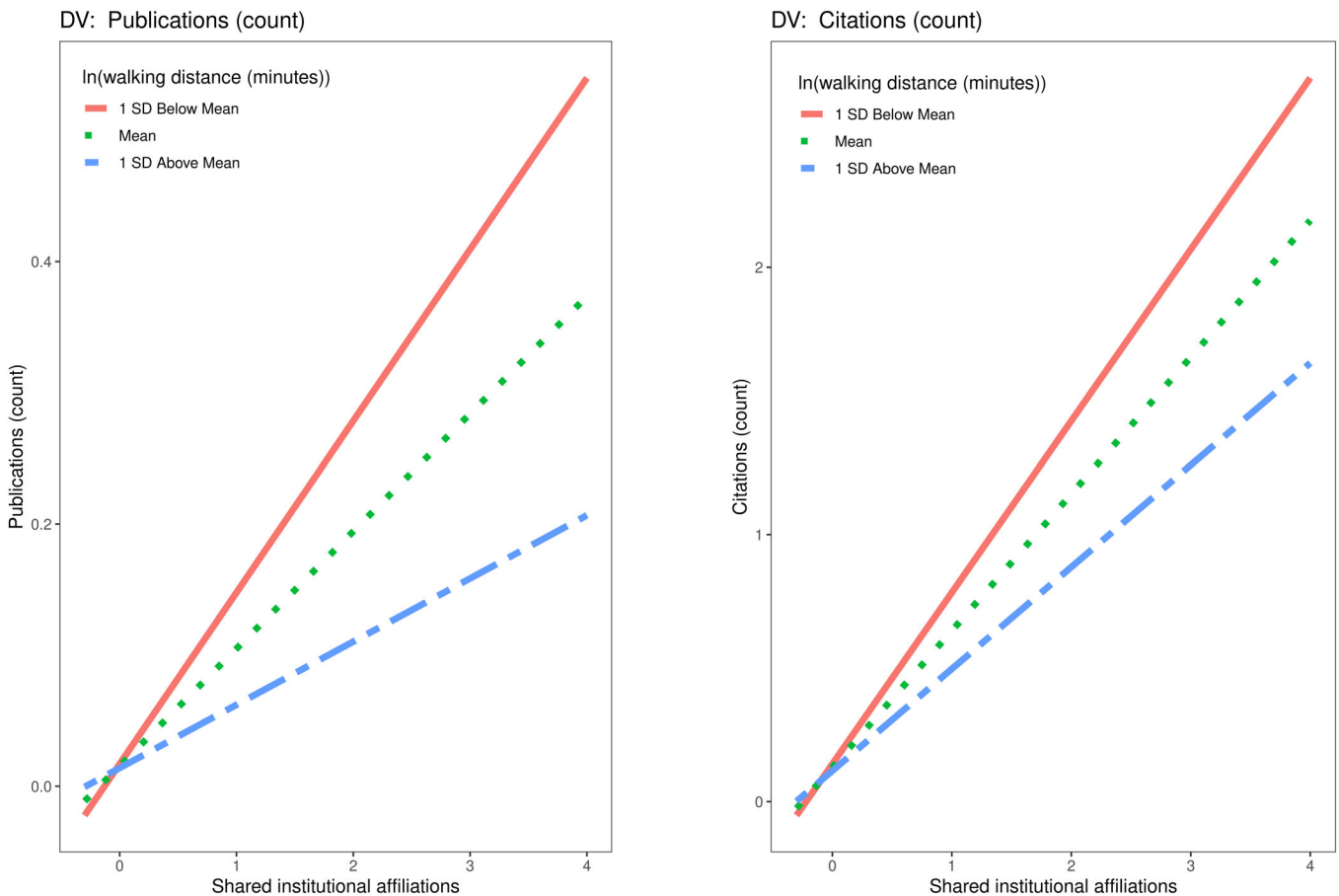*$p < .1$, **$p < .05$, ***$p < .01$.

FIGURE 1 Slopes of shared institutional affiliations at different walking distances for the interaction effect on knowledge creation (publications) and knowledge impact (citations)

institutional affiliations is a 0.64 unit increase in citations—but for an otherwise identical pair separated by about 16 minutes of walking distance, the average marginal effect of shared institutional affiliations is only a 0.38 unit increase in citations. Overall, these results suggest that more shared affiliations can help pairs establish a foundational bond for working together, but being physically out-of-sight and out-of-mind from a collaborator reduces opportunities to enhance this mutual connection, and thus weakening its value to the collaboration. Conversely, more proximate collaborators that share affiliations have more opportunities to develop a stronger working rapport with quality communication and trust (Festinger et al., 1950), which is important to effective scientific collaborations (Kraut et al., 1990).

5.3 | Interaction effect with disciplinary diversity (H4a/H4b)

Next, in all models in Table 4, we find a positive, significant main effect of disciplinary diversity on publication

impact, suggesting that faculty collaborations from multiple fields are positively associated with citations. Moreover, as shown in Table 4 (model 3), we find that disciplinary diversity positively moderates the positive association between shared institutional affiliations and citations (supporting H4a). For faculty pairs who are part of more diverse collaborations (3 distinct disciplines on a publication), a one-unit increase in shared institutional affiliations is associated with a 9.46 unit increase in citations (see Figure 2). Conversely, for an otherwise identical pair working on a less diverse collaboration (1 discipline), a one-unit increase in shared institutional affiliations is associated with a 3.22 unit increase in citations. This finding is consistent with our theory derived from existing work that mutual bonds established through shared affiliations can help provide a foundation for developing close-knit connectivity—which is particularly important to performance outcomes among collaborations integrating a more diverse range of knowledge and experiences (Reagans & Zuckerman, 2001).

Moving to the interaction with proximity, as shown in Table 4 (model 4), we find a negative, significant

TABLE 4 Dyadic regression estimates: Disciplinary diversity, shared institutional affiliations, and walking distance on knowledge impact

	Citations (count)	Citations (count)	Citations (count)	Citations (count)
	(1)	**(2)**	**(3)**	**(4)**
Affiliations(i)	0.02*** (0.002)	0.01*** (0.002)	0.01*** (0.002)	0.01*** (0.002)
Basic Science(i)	0.01 (0.01)	0.03*** (0.01)	0.03*** (0.01)	0.03*** (0.01)
Rank(i)	0.02*** (0.003)	−0.01*** (0.003)	−0.01*** (0.003)	−0.01*** (0.003)
ln(building size(i))	−0.03*** (0.003)	−0.01** (0.003)	−0.004 (0.003)	−0.01** (0.003)
Wet lab(i)	−0.05*** (0.01)	−0.03*** (0.01)	−0.02*** (0.01)	−0.03*** (0.01)
Shared institutional affiliations	0.58*** (0.01)	0.22*** (0.01)	0.12*** (0.01)	0.20*** (0.01)
ln(walking distance (minutes))	−0.02*** (0.003)	−0.005* (0.002)	−0.004* (0.002)	−0.003* (0.002)
Disciplinary Diversity		15.13*** (0.02)	12.81*** (0.02)	14.71*** (0.02)
Shared institutional affiliations * Disciplinary Diversity			3.12*** (0.02)	
ln(walking distance (minutes)) * Disciplinary Diversity				−1.02*** (0.01)
Constant	0.16*** (0.02)	0.12*** (0.01)	0.15*** (0.02)	0.11*** (0.01)
Observations	7,763,436	7,763,436	7,763,436	7,763,436

Note: Mean-centered predictors for interaction.

*p < .1, **p < .05, ***p < .01.
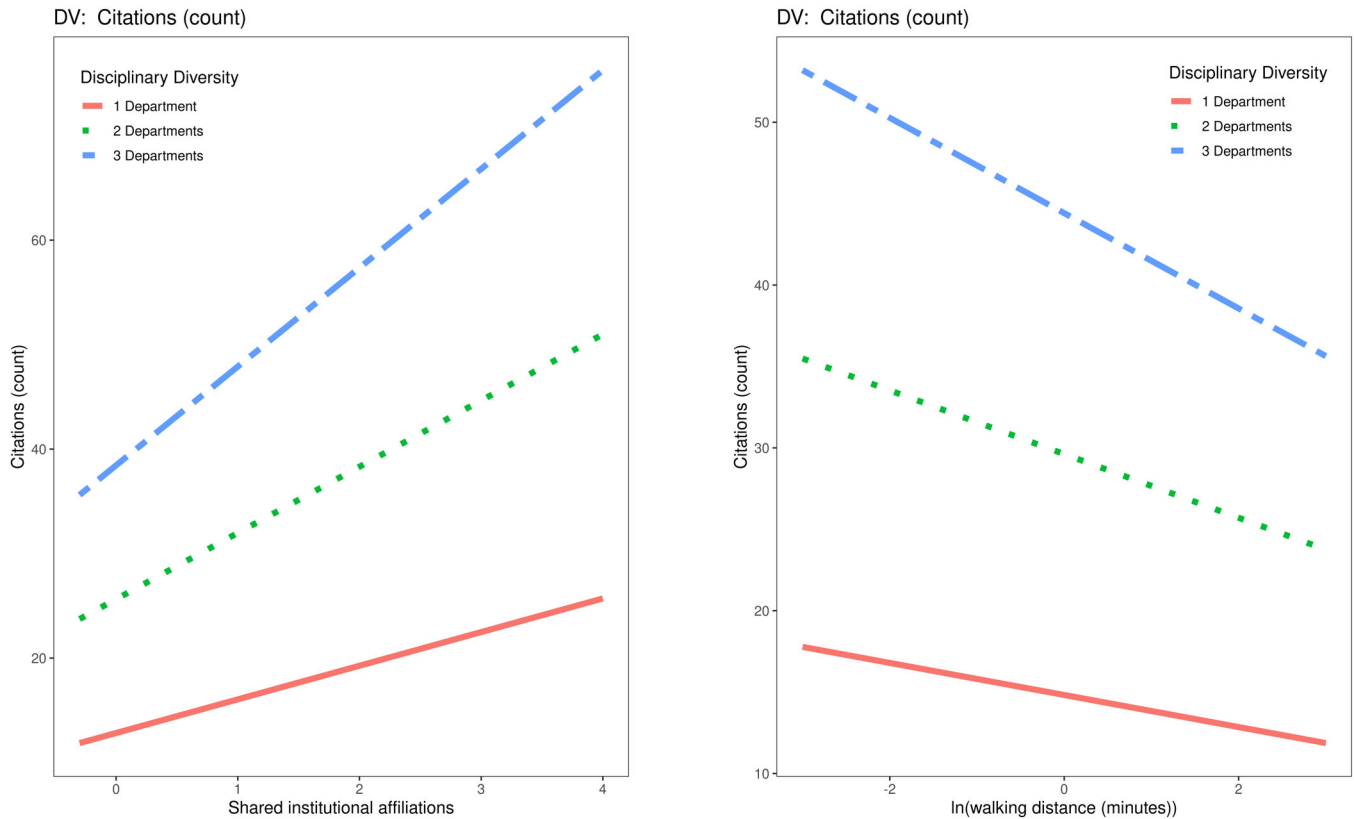
FIGURE 2 Slopes of shared institutional affiliations (left) and walking distance (right) at different levels of disciplinary diversity for the interaction effect on knowledge impact (citations)

moderating effect of walking distance on the association between disciplinary diversity and publication impact (supporting H4b). As shown in the interaction slopes in Figure 2, for faculty who are part of more diverse collaborations, the publication impact is significantly lower when the faculty are separated by larger walking distances, relative to faculty on less diverse collaborations. For faculty pairs who are part of more diverse collaborations (3 distinct disciplines on a publication), a one-unit increase in walking distance is associated with a 2.84 unit decrease in citations. However, for an otherwise identical pair working on a less diverse collaboration (1 discipline), a one-unit increase in walking distance is associated with a 0.94 unit decrease in citations. As the underlying mechanism for this association, we suggest that shorter walking distances can reduce coordination costs such as attending face-to-face meetings that have been shown to mitigate common problems that arise in more complex collaborations (Lungeanu & Contractor, 2014; Sud & Thelwall, 2016).

6 | DISCUSSION

Overall, our results support the idea that shared institutional affiliations and physical proximity can play an integrative role in shaping knowledge creation and impact through collaboration. We find that walking distance has a significant, negative effect on collaboration while also mitigating the positive effect of shared institutional affiliations. Among faculty members with a high degree of shared institutional affiliations, we find the positive impact of shared affiliations is reduced when the walking distance is greater (relative to average or low shared affiliations). When paired with other findings in the literature, we can suggest some plausible explanations for these observed associations.

The first and often the biggest barrier to individuals collaborating together to create knowledge is simply seeing the opportunity. For busy faculty pursuing research projects on top of clinical, teaching, service, and mentoring responsibilities, physically seeing a collaborator can help keep project details (e.g., assignments, deadlines) focal in one's mind. For faculty pairs, closer proximity and sharing an affiliation increases the likelihood of serendipitous interactions (Kabo, 2016; Kraut et al., 2002) in their day-to-day work, providing opportunities to be made aware of each other's "biographies" (Goffman, 1983) and their scientific interests (Kabo et al., 2014; Spillane et al., 2017). In turn, this can help faculty realize opportunities for collaboration as well as facilitate relationship development and communication

that can make ongoing collaborations more effective and improve outcomes (Reagans, 2011).

Another interesting aspect of our results is the interaction of disciplinary diversity with both shared affiliations and proximity on the knowledge impact of publications. Our results are consistent with the idea that more shared affiliations can help provide a foundation for strengthening group connectivity—posited as a critical factor in realizing potential performance gains from collaborations integrating more diverse contributions (Reagans & Zuckerman, 2001). Moreover, we find that as the walking distance increases between pairs of contributors, the most diverse collaborations are negatively impacted in terms of knowledge impact. We believe this suggests that space could be an important contextual factor in explaining some of the mixed results in the literature regarding the impact of disciplinary diversity on collaboration outcomes.

As demonstrated by prior research on coordination costs, more heterogeneous collaborations require more effort and communication to coordinate efforts (Cummings & Kiesler, 2007; Fox & Faver, 1984) due to the different knowledge, experience, and work processes coming together towards a unified objective. Closer proximity decreases the cost of physically attending meetings, thus facilitating more consistent face-to-face interactions. These encounters are particularly valuable to information exchange in diverse collaborations—facilitating trust-building and common understanding (Allen & Henn, 2007) and working through sensitive situations or problems such as aligning clear, mutually beneficial objectives, interpreting ambiguous findings, and keeping parties accountable for roles and assignments (Owen-Smith, 2001). Altogether, these potential mechanisms offer an explanation for the negative, moderating effect of physical distance on the association between disciplinary diversity and knowledge impact.

6.1 | Contributions

Our analysis of key contextual factors in collaborative knowledge creation provides several theoretical and methodological contributions to the literature. At a theoretical level, this study integrates two different streams of research on shared institutional affiliations and physical proximity to better understand their separate and interactive impacts on scientific collaborations. Our findings advance a framework of science collaboration by which institutional affiliations establish an institutional space so that affiliated faculty can become aware of and interact with each other in planned or unscripted ways. In the context of intra-organizational collaboration, the nature of the shared affiliations is not prescriptive in terms of

how often faculty are required to interact. Rather affiliations reflect the combinations of interconnected faculty associations and interests that facilitate the events, norms, and practices that shape where faculty move on campus and how they act towards other faculty in that space. Although we are unable to observe direct interactions with our data, prior work on homophily suggests individuals with a shared affiliation have more contact and potential encounters (Kabo, 2016). Thus, one explanation for the observed associations is faculty that share particular institutional affiliations tend to have more unplanned or planned interpersonal interactions (relative to unaffiliated faculty), which is associated with more scientific knowledge creation and impact.

Furthermore, our findings indicate that the relative influence of shared institutional affiliations is contingent on the physical distance separating collaborators. Larger geographic distance seems to weaken the informal boundaries and norms of the shared affiliations, decreasing the frequency of interpersonal interaction and in turn reducing the positive effects of shared affiliations on science collaborations. This framework extends previous conceptions of institutional affiliations with respect to a single institutional affiliation in favor of more generalized combinations of institutional affiliations within a single organization (in our case the medical school within a university).

As mentioned above, previous work has conceptualized and operationalized institutional affiliations primarily with respect to a single institutional affiliation, such as a shared primary department appointment (Claudel et al., 2017; Dahlander & McFarland, 2013). Our analysis also offers a methodological extension of this idea by creating a shared institutional affiliations index as a generalized measure of overlap in institutional affiliations. Recognizing that interconnected affiliations with various departments, centers/institutes, and labs/facilities can shape sets of practices, behaviors, and physical patterns of movement (e.g., meetings, events, seminars, lunches), this shared institutional affiliations index operationalizes and captures the number of each faculty's combination of institutional affiliations. Given our robust findings using this index, future studies can employ this measure to better understand how shared institutional affiliations impact other forms of collaboration or include other types of unmeasured or informal affiliations not captured in the data. Lastly, although our analysis focuses on contextual factors in scientific collaboration, future research could integrate other factors including additional attributes about the collaborators themselves or the composition of the collaboration teams for a deeper understanding of the moderating influences on knowledge creation and impact.

6.2 | Limitations

Our study has some limitations to consider when generalizing based on the results. First, our sample only includes collaborations of biomedical researchers in a single university in the United States, which may be impacted by unmeasured institutional or cultural factors that may not generalize to other universities or academic fields. Although we focused on collaboration in a scientific field (health and biomedical sciences) that accounts for nearly half (48%) of all scientific publications in the United States (and 36% globally) (White, 2019), additional research could investigate whether our findings generalize to other fields (e.g., Engineering, Social Sciences).

Second, the sample of successfully published collaborations could be biased in terms of measuring who actively contributed to the knowledge creation and how collaborations reached their ultimate size and composition. Like prior studies analyzing research collaboration using publication coauthorship (Hall et al., 2018; Lee et al., 2015), our analysis conceptualizes the collaboration as the coauthors listed on the final publication and does not capture the nature or degree of collaborator involvement and how the collaboration changed during the knowledge creation process through the addition or subtraction of other contributors. Given norms in lab-based research (e.g., biomedical sciences) that give the most credit to the first and last authors listed on a publication (Johann & Mayer, 2019), we estimated the same models on the subset of collaborations where only first/last authorship counts as a publication for the dyad. This robustness check yielded a very similar pattern of significant results. Nevertheless, future work could explore ways of operationalizing collaboration through survey questionnaires or other methods that capture the subjective nature of collaboration.

Another limitation is that our analysis does not address how one should weigh the relative collaborative gains/losses of moving faculty to a different location on campus and thus we caution using these findings (alone) to inform relocation of existing faculty. Our study also does not observe and measure the interpersonal interactions enabled by shared institutional affiliations and physical proximity (and the synergistic combination). In our framework, we argue that these structural factors help create opportunities for facilitating interaction and supporting collaboration. However, without direct observation, we cannot definitively rule out alterative explanations that may better explain the association between shared institutional affiliations, physical proximity, and knowledge creation/impact. Future qualitative research could investigate the potential interactions enabled by

shared affiliations and proximity to better understand how they support scientific collaboration.

6.3 | Implications

Our findings also have some practical implications for university and department administrators in charge of space allocation. Our results, when paired with existing literature, suggest that the office where faculty are assigned creates an opportunity structure that influences which faculty pairs collaborate. Administrators might consider institutional affiliations and physical proximity between other faculty as key contextual factors when assigning space to new faculty hires. Given that such a small percentage of faculty move offices after arriving on campus for the first time, our results are likely more relevant to hiring new faculty than to moving existing faculty. For example, if a renovation or new facility is created that is geographically proximate to a large existing research center, our results suggests the institutional affiliations of newly hired faculty is an important factor to consider when assigning office space (rather than placing new hires into an open space simply based on availability).

Finally, though we use existing theory and research to support our results, the observed associations can help inform strategies for university initiatives aimed at spurring interdisciplinary collaboration. While there is sound theoretical basis for pursuing diversity and interdisciplinary scientific research, as demonstrated in successful cases of cross-pollination and complimentary expertise, the mixed findings in the literature regarding its impact on research productivity clearly suggest there are important moderating or conditional factors that must be in place to be able to capitalize on the gains while minimizing the coordination costs. Our findings suggest institutional affiliations and proximity among faculty should be important contextual factors to consider when designing initiatives aimed at bridging disciplines or research centers. Based on the geographic distribution of department faculty on campus, this barrier could be more or less difficult for certain parts of the institution. Administrators in charge of such initiatives might think about creative ways to incentivize or facilitate interaction among physically proximate faculty who share multiple institutional affiliations.

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ENDNOTES

[1] We also estimated models with different publication outcome measures including: relative citation ratio, citations per year, field citation rate, citation percentile. These measures are highly correlated ($r > .84$) and yielded similar estimates. These alterative measures help control for the fact that more recent publications have less allocated time to acquire citations. As an additional robustness check, we also estimated models using only collaborative publications occurring in different 4 year windows between 2007 and 2015 and obtained similar results as the model estimates for the full time period.

[2] As a robustness check, we tested for potential institutional variation in the extent to which researchers collaborate (e.g., epistemological nature of certain disciplines). After calculating whether an institution (department, center, or facility) was relatively high or low in collaborations for each year (t), we ran the dyadic models in our analysis on each of these subgroup pairs (high-high; high-low; low-low). The pattern of results were similar across all the subgroup pairs (for each affiliation type: department, center, or facility) and closely matched the estimates from the full sample of dyads—suggesting our results are not biased from dyad collaborations from particularly collaborative units of the institution.

[3] Given that some faculty (i/j) might have relocated during the time period, as a robustness check, we estimated models after adding a control variable accounting for whether there was an address change for the corresponding first/last author i or j in year t and recalculated dyadic distances (for relevant i,j,t cases prior to the office change) based on the pre-move office location. We also took into account three building renovations that occurred during the time period of the study (in which some faculty moved offices). The results of these models were very similar to the original estimates, suggesting our results are not meaningfully biased from potential office changes during our time period.

[4] As a robustness check, we also calculated disciplinary diversity as a proportion of the total number of co-authors on a publication and obtained similar estimates in the models.

[5] As a robustness check, we ran additional models after adding dyad-level pre-panel controls based on each faculty's baseline propensity to create knowledge (pre-panel publications (dyad avg)) and produce high-impact knowledge (pre-panel avg citations (dyad avg))—these models yielded the same pattern of results as those presented in the paper.

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