Fostering collisions in interdisciplinary graduate education

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Received 23 August 2019
Revised 9 December 2019
6 April 2020
Accepted 13 April 2020

Abstract

Purpose – Using the lens of social physics, this study aims to examine how, if at all, one graduate training program fostered collisions or meaningful interactions, between students and faculty from different disciplinary backgrounds.

Design/methodology/approach – Qualitative, ethnographic case study methods.

Findings – The University of Maryland's National Research Traineeship program fostered collisions between students and faculty from different disciplinary backgrounds by facilitating exploration, idea flow and engagement within an interdisciplinary scholarly community. These collisions generated productive opportunities for student learning, development and collaborations, but at times also produced non-generative outcomes.

Practical implications – This study names specific, strategic activities (e.g. regular research talks, physical space) that graduate programs can use to facilitate interdisciplinary collaborations among students and faculty and considers the extent to which such activities contribute to organizational change.

Originality/value – This paper applies new theories (collisions and social physics) to understanding interdisciplinary collaboration and identifies aspects of graduate training programs that may be replicable in other institutional settings.

Keywords Graduate education, Interdisciplinary science

Paper type Research paper

Introduction

Some scientific innovation begins with a literal collision. In the case of the European Organization for Nuclear Research (CERN)'s Large Hadron Collider, scientists built a 17-mile, circular tunnel with the goal of accelerating particles to light-speed and crashing them together (Boisot *et al.*, 2011). Through these collisions, scientists revealed the universe's features at the time of the Big Bang. Within the crashing particles also existed a figurative collision: scientists and researchers from different disciplines coming together for a scientific purpose. During the project, over 3,000 individuals (including 1,000 doctoral students) contributed (Boisot *et al.*, 2011). The vast number of scientists involved reflects not only the scientific endeavor's complexity but the adage: two heads (or in this case, 3,000) are better than one.

Despite the benefits of collisions, many universities' structures and policies thwart interactions between students and faculty from different disciplinary backgrounds. Academic departments are siloed (Klein, 2010; Lattuca, 2001; National Academy of Science, Engineering

This article describes projects that have been funded by the National Science Foundation National Research Traineeship (NRT) program, grant NRT-DESE-1449815.

Studies in Graduate and Postdoctoral Education

2398-4686
DOI 10.1108/SGPE-08-2019-0068

and Medicine, 2018), leading to fewer opportunities for students and faculty from different departments to interact. Most graduate programs teach doctoral students how to become disciplinary experts, not interdisciplinary collaborators (Golde, 2005; Weidman *et al.*, 2001). Such structural and cultural arrangements reduce the number of interdisciplinary collisions or meaningful interactions that graduate students experience during their doctoral training.

With these barriers in mind, understanding how graduate training programs can foster interdisciplinary collisions is important for several reasons. Given funding agencies' increased emphasis on interdisciplinary approaches and the potential for interdisciplinary science to solve pressing global issues, interdisciplinary science has become an institutional imperative for many universities (Bozeman and Boardman, 2003; Klein, 2010; Lyall, 2019; Lyall *et al.*, 2013). Explaining how graduate training programs give doctoral students the skills needed to do interdisciplinary research will help institutions better meet their interdisciplinary goals. Likewise, understanding how graduate training programs navigate academic silos and disciplinary divisions to promote student learning is important for facilitating organizational change (Holley, 2009a, 2009b; Sá, 2008). Thus, this study's purpose was to understand how, if at all, one graduate training program facilitated collisions or meaningful interactions, among doctoral students and faculty from different disciplinary backgrounds.

Literature review

As noted, interdisciplinary research has many benefits. Interdisciplinary approaches help scholars tackle complex research questions and social problems (Klein, 2010; National Research Council, 2004). Diverse and interdisciplinary research teams can be more productive and produce higher quality science compared to homogeneous groups (Bunton and Mallon, 2006; Millar, 2013). Recognizing the promise of interdisciplinarity, many funding agencies now require research teams to incorporate interdisciplinary perspectives (Bozeman and Boardman, 2003; Holley, 2009b; Lyall *et al.*, 2013). Agencies also fund graduate education programs to experiment with practices that help to develop students' interdisciplinary skills (Borrego and Newswander, 2010; Gardner, 2011; Lindvig, 2018; Lyall and Meagher, 2012). Thus, institutions have both intrinsic (e.g. potentially better science) and extrinsic motivations (e.g. new research funding) for helping faculty and graduate students engage in interdisciplinary research.

Thus far, higher education institutions have made uneven progress on creating the infrastructure needed to support interdisciplinary collaboration. Some institutions adopted structures intended to facilitate interdisciplinary research (Holley, 2009a, 2009b; Lindvig and Hillersdal, 2019; Lyall *et al.*, 2015; Sá, 2008), such as building interdisciplinary centers, providing seed grants and recruiting interdisciplinary faculty (Holley, 2009a; Mäkinen *et al.*, 2020; Müller and Kaltenbrunner, 2019; Sá, 2008). Other institutions created administrative roles geared at facilitating cross-unit research activities, developed cross-campus networks, and changed their missions to emphasize interdisciplinary collaboration as an institutional goal (Holley, 2009a; Sá, 2008). These efforts suggest that many universities endorse interdisciplinary collaboration as an important institutional value.

Despite these trends, organizational structures and academic culture serve as barriers to interdisciplinary collaboration. On the organizational side, disciplines remain the major way most academic units are structured (Lindvig, 2018; Lyall, 2019; Sá, 2008). This structure places faculty and graduate students into "silos" (Klein, 2010; Lattuca, 2001; National Academy of Science, Engineering, and Medicine, 2018; Sá, 2008), with administrative and physical boundaries (Harris and Holley, 2008; Sá, 2008). Departmental rules related to

promotion and tenure hinder researchers from undertaking interdisciplinary collaborations because faculty will be promoted based on their contributions to their discipline (Lattuca, 2001; Lyall, 2019; Miller, 2010; Müller and Kaltenbrunner, 2019). Academic departments' physical separation across campuses limit the extent to which researchers from different disciplinary backgrounds have opportunities to interact face-to-face. Likewise, the growth of remote work (Fitzgerald, 2017; Ziker, 2014) reduces likelihood of interactions between students and faculty within departments, not to mention outside of them.

Disciplinary silos also create cultural barriers that thwart interdisciplinary research. Disciplinary norms and paradigms shape socialization processes (Becher and Trowler, 2001; Holley, 2009b; Lattuca, 2001; McAlpine and Akerlind, 2010) in ways that make scholars more or less inclined towards interdisciplinarity. Low consensus fields may socialize graduate students and faculty to be more open to interdisciplinary scholarship, while high consensus fields may view interdisciplinarity as less legitimate than purely disciplinary approaches (Frost and Jean, 2003; MacLeod and Nagatsu, 2018; Müller and Kaltenbrunner, 2019; Rabinow and Bennett, 2012). Disciplines with a more applied focus may be more inclined to draw from multiple disciplines to understand practical issues, while fields more focused on theory may be more beholden to disciplinary logics (Becher, 1994; Frost and Jean, 2003). These factors lead to "academic tribalism," wherein disciplinary cultures demarcate boundaries between different knowledge communities (Adams, 1976; Becher and Trowler, 2001).

Graduate training programs are not immune to these barriers to interdisciplinary collaboration. Disciplinary and departmental processes guide graduate admissions (Golde, 2005). Faculty, socialized to their disciplines, often lack the knowledge or skills to mentor students with interdisciplinary interests (Boden *et al.*, 2011; Gardner *et al.*, 2014; Lyall and Meagher, 2012). When students participate in interdisciplinary training, they face difficulty in communicating across different disciplinary languages (Gardner *et al.*, 2012), balancing their home departments' expectations with their interdisciplinary research interests (Felt *et al.*, 2013; Gardner *et al.*, 2012; Lindvig, 2018) and finding a sense of community among peers and faculty (Felt *et al.*, 2013; Lyall, 2019). Interdisciplinary graduate students can often experience confusion and ambiguity related to unclear program goals and expectations (Felt *et al.*, 2013; Gardner, 2011; Gardner *et al.*, 2014; Lindvig, 2018). Finally, as graduate students complete their degrees, the academic market's disciplinary nature can hinder graduate students with interdisciplinary backgrounds from finding jobs (Gardner *et al.*, 2012; Holley, 2018).

In all, studies on interdisciplinarity in academia suggest a push and pull effect. Although funding agencies incentivize interdisciplinary collaborations, organizational structures and disciplinary cultures make such collaborations less likely or difficult for graduate students to navigate. The next section explores how theories of collisions and social physics may enhance understanding of how graduate training programs can restructure interactions to promote interdisciplinary students' development and learning.

Theoretical framework

The literature on the science of creative, innovative and productive organizations guide this study. This work is grounded in the assumption that meaningful interactions or "collisions," between individuals working within organizational settings breed creativity, innovation and productivity (Brown *et al.*, 2013; Harvey, 2014; Pentland, 2012, 2014; Waber *et al.*, 2010, 2014). Collisions refer to meaningful exchanges or interactions between individuals and can be understood through the lens of social physics or the science behind how people exchange ideas in ways that subsequently shape behavior (Pentland, 2014). As individuals collide, they acquire new ideas, strategies and values (Pentland, 2014), which contribute to their

creative and innovative approaches to problems. For instance, researchers measured interactions between employees who worked in a large bank using sociometric badges (Waber *et al.*, 2010) or wearable devices that quantify social interactions in real-time. They found that when the bank put in place practices to increase employee interactions (e.g. scheduling coffee breaks at the same time), worker productivity increased. That is, employees who interacted with a greater number of people (i.e. experienced more collisions) were more productive.

Three major processes facilitate collisions within organizations. First is *exploration* or the process of searching out new and potentially valuable ideas from diverse individuals who have ideas and experiences different from one's own (Pentland, 2014). Organizations can foster exploration by creating opportunities, such as coffee breaks discussed above, for individuals to collide with colleagues outside of their regular group (Pentland, 2012, 2014). Second is *idea flow* or the spreading of new ideas among group members. Organizations with a strong idea flow allow group members to bring in the ideas they gained during the exploratory process, and these ideas subsequently shape habits, preferences and interests (Pentland, 2014). Finally is *engagement* or the process of ongoing exchanges between people within a team (Pentland, 2014). Ongoing, face-to-face interactions, cooperation and joint ownership and trust facilitate engagement by encouraging group members to participate and learn (Pentland, 2014).

Although theories of social physics mostly elucidate the benefits of collisions within organizations, there is evidence that collisions can be non-generative in some circumstances. Individuals can find it difficult to maintain engagement on their own team, while also interacting with people outside of it (Pentland, 2012). Likewise, collisions can sometimes create conflict, particularly when group members disagree on the process they should use to tackle problems, when they feel as though their ideas are not heard or understood or when groups become overloaded with too many choices (Badke-Schaub *et al.*, 2010; Isaksen and Ekvall, 2010; Jehn and Mannix, 2001).

This study translates insights from collisions and social physics to interpret how graduate programs can facilitate meaningful interactions (collisions) between students and faculty from different disciplines. In so doing, this study considers collisions and their outcomes, in ways that differ slightly from prior studies. Existing studies (Pentland, 2012; Waber *et al.*, 2014) examine the processes (exploration, idea flow and engagement) that facilitate collisions using quantitative analysis of social networks, wherein the number of collisions individuals experience are counted or the diversity of individuals' professional networks are quantified. In this study, the goal is not to quantify the number of collisions interdisciplinary scholars experience but rather, to identify the circumstances and conditions under which collisions occur. Furthermore, past studies typically relate the benefits of collisions to quantifiable outcomes such as worker productivity and company profit (Pentland, 2014). In contrast, this study identifies "productive" collisions as ones that spur outcomes such as student learning and development or interdisciplinary collaboration and non-productive collisions as ones that undermine such positive benefits.

This study's use of collisions and social physics also differs from prior conceptions of interdisciplinary interactions. Past researchers conceive of scholars who do interdisciplinary work as knowledge brokers or boundary spanners (Mäkinen, 2018; Mäkinen *et al.*, 2020), who act as intermediaries between different disciplines, thereby facilitating interdisciplinary work. Others consider interdisciplinary scholarship through the lens of encounters (Fitzgerald *et al.*, 2014), entanglements (Fitzgerald and Callard, 2015) or experiments (Rabinow and Bennett, 2012), wherein researchers who undertake interdisciplinary projects experience ambivalence, conflict and highly politicized environments as they participate on

collaborative, cross-disciplinary teams. Such studies tend to highlight the burdens and trials researchers with interdisciplinary interests encounter or the existing organizational structures and/or cultural processes that bar interdisciplinary work. Theories of collisions and social physics focus on the practices and activities that organizations can put in place to restructure the nature of interactions such that cross-disciplinary collaboration is facilitated. That is, rather than focusing on the actions of individual, interdisciplinary scholars navigating structures, theories of collisions and social physics reveal how the structures within graduate programs, such as the one highlighted in this study, can foster student development and organizational change.

Case description

The University of Maryland's Language Science Center (LSC) is an interdisciplinary research and education center. The LSC was founded in 2015, after more than a decade of cross-campus collaboration supported by the Department of Linguistics and a National Science Foundation (NSF) Integrative Graduate Education and Research Traineeship (IGERT) grant. Over 20 units and departments (e.g. linguistics, hearing and speech, neuroscience, psychology, computer science and several educational fields) and 200 faculty, undergraduate and graduate students are affiliated with the Center. The LSC is currently funded in part by a National Science Foundation Research Traineeship (NRT) grant, which focuses on innovation in graduate education. As part of the NRT program, graduate students participate in interdisciplinary training activities (See NRT Graduate Student Training Activities), including developing an interdisciplinary course plan, leading LSC committees, presenting their research at weekly, student research talks called Language Science Lunch Talks (LSLTs) and attending an annual professional training event each January called Winter Storm. Thus, the NRT program, within the larger context of the LSC, was created as an organizational structure to create new or accelerate existing, interdisciplinary collisions among students and faculty interested in the interdisciplinary language sciences:

NRT graduate student training activities

(1) Science policy internships
   - Internship or training experience; enhances application of research to "real-world".

(2) Winter storm
   - Two-week professional skills training.

(3) Lunch talks
   - Weekly research presentations.

(4) Outreach
   - Science outreach activities led by students; includes science demonstrations, high school visits.

(5) Language science day
   - Annual event for language science community; includes research talks, poster session.

(6) Research teams
   - Formal/informal research groups facilitated by NRT/LSC.

(7) Interdisciplinary courses
   - Courses focused on interdisciplinary topics; taught/co-taught by faculty from different departments.

Methods

This study applied the concepts of collisions and social physics to a qualitative, ethnographic case study of the LSC's NRT Program. Case studies are an appropriate method for understanding "contemporary phenomenon within their specific, real-world context" (Yin, 2014), where a case is a "bounded system" (Merriam, 1998). In this study, the case centered on the LSC's NRT program. The LSC's NRT program can be viewed as a critical case, defined as a single case study focused on understanding how a specific theory might apply to a particular circumstance (Yin, 2014). Critical cases can be useful for confirming and/or challenging theories (Patton, 1990; Yin, 2014). This case sought to understand how, if at all, the NRT program facilitated collisions among doctoral students and faculty from different disciplinary backgrounds. In doing so, the study focused on aspects of the NRT program that generated collisions among students and faculty associated with the LSC, specifically examining aspects of the program that seemed to facilitate exploration, idea flow or engagement, as identified by theories of social physics.

Data sources

This study drew from qualitative data sources collected over four years, which included: interviews with NRT students (N = 18) and key institutional informants (N = 6) (e.g. graduate school administrators and faculty involved in the NRT program), student and faculty focus groups (N = 6), document review and over 50 h of ethnographic observations of LSC events. Ethnographic observations focused on participants' behavior, language and interactions with one another (Creswell, 2007; Merriam, 1998), allowing for greater understanding of the culture, values, ideas, norms and expectations (Anderson, 1989) present within the NRT program and LSC.

Analysis and trustworthiness

Data-analysis was deductive and theory-driven (Rossman and Rallis, 2003; Saldaña, 2016). The process was theory-driven in that data were coded with the theories of social physics and collisions in mind. Passages related to the three themes of exploration, idea flow and engagement from the collisions and social physics literature were coded (Table 1 for a description of how data was coded for each theme and data passages that illustrate each theme). However, analysis was also data-driven (Rossman and Rallis, 2003), in that we coded data when they diverged from the theoretical framework. For instance, as noted in the theoretical framework section, collisions are often theorized as being mostly beneficial. Yet, our data-driven analysis revealed that at times, such collisions were unproductive for participants, which we then weaved into our findings.

Trustworthiness was ensured in several ways. The study drew from multiple data sources collected over time which allowed for triangulation of findings across data sources and data saturation (Corbin and Strauss, 2008; Yin, 2014). Observational impressions about the potential developmental benefits and drawbacks of collisions that occurred during NRT activities were compared to interview and focus group data wherein participants discussed the experience of participating in NRT activities. The same observational protocols and interview protocol were used during data collection to ensure consistency (Goetz and LeCompte, 1984). Finally, thematic member-checks (Creswell and Miller, 2000) with participants were conducted by regularly presenting findings to NRT program leaders, faculty and students to receive their feedback.

Table 1. Themes and illustrative data passages

Theme	Illustrative data passages
Exploration: The process of searching out new and potentially valuable ideas from diverse individuals who have ideas and experiences different from one's own (Pentland, 2014). For exploration, we noted places in the data where participants "collided" or meaningfully interacted, with colleagues from different disciplinary backgrounds within the context of the NRT program and the impact of these collisions on students' research ideas and overall experience	*Reinforcing a culture of interdisciplinary exploration* I met with faculty in [professional field], as well as in [social science]. It was clear that there were connections across the different departments. The way that the [social science] faculty pitched the kind of work that they're interested in, it was clear that they use a lot of variety of different methods and had connections in lots of different areas and were very positive about trying to encourage research that spanned disciplinary boundaries instead of treating the disciplines as separate. – Student [Interdisciplinary collaboration is] about learning how to make connections outside of the typical ones, about how to communicate to people who don't have the same background as you do about how to see broader pictures, and to go in and out forest to trees and trees to forest and, and not stay at one level and that's hard, but that's the kind of thing that these types of programs train. – Faculty Member *Making explicit the expectation that students move outside of their home disciplines* Its forced me to do things that I probably wouldn't have even thought about doing without it. Its pushed me out my comfort zone but in good ways like ways that have sort of expanded my skills. – Student When I first took one class, it was [faculty member's] [interdisciplinary language] class. I thought it was fun to do a little bit of the [method] and learn that so I thought it would be a good fit. I thought about some other options some other ways I could broaden my horizons, in either [social science discipline] or [the languages], but I felt like those weren't stretching myself enough. So I felt like this [STEM class] would be a bigger stretch. So I chose it. – Student
Idea flow: The spreading of new ideas within the members of the team or group (Pentland, 2014). For idea flow, we coded passages wherein participants discussed how NRT program activities enabled them to leverage or bring in theories, methods or ideas from outside of their discipline	*Creating regular contact between students and faculty from different disciplines* I've met a lot of people in a lot of other departments, and it's cool just having them kind of at my fingertips, being able to contact them. . .without any stress or just casually. – Student [Language Science Day] was cool because you get to see that they actually do care about some of the same things that I care about. - Student *Providing access to interdisciplinary feedback* I think classes are the best breeding ground for that kind of thing [interdisciplinary collaboration] because. . .that's an opportunity where everyone is sitting down and reading a paper together, and you have to do it, and you have to think about it because you are going to have to write a response to it or something, so you already have these external commitments to think about the same topic that might not be your core research. – Student

(*continued*)

Table 1.

Theme	Illustrative data passages
Engagement: The process of ongoing exchanges between people within a team (Pentland, 2014). Ongoing, face-to-face interactions, cooperation and joint ownership and trust facilitate engagement by encouraging all group members to participate and learn (Pentland, 2014). For engagement, we coded data that illustrated the ways in which the NRT program facilitated exchanges and interactions among the greater language science community.	*Facilitating interactions in the physical space of the Language Science Center* Having opportunities to casually talk to students in other departments makes it [interdisciplinary work] somehow way less scary because they were your friends. And I honestly have found those types of situations to be the easiest. . .it doesn't feel as far away, when you know people in a casual way. . . rather than having to set up like a formal meeting with someone else. – Student I really like the Language Science Lunch Talks, and just having a regular time where you hear from people and other disciplines doing really good things[. . .] I mean, on the one hand you like hear another perspective, on another hand you meet people and interact with people. – Student *Enhancing student ownership over program activities* If this [the LSC] was just about students getting research experience, that wouldn't drive cultural change and that wouldn't drive students to be working together and collaborating who don't necessarily directly collaborate on their research. But, this notion of group efforts on outreach and on, it's talking about your science in ways to others, results in a common purpose that can connect students who might not be as otherwise directly connected. – Faculty Member

Findings

The NRT program fostered collisions between an interdisciplinary group of students and faculty by creating opportunities for exploration, idea flow and engagement. While many of these interdisciplinary collisions were productive, spurring learning and development, collisions sometimes resulted in unintended conflict that was not productive for student learning. These non-productive collisions occurred within the processes of exploration, idea flow and engagement and are discussed within each of these themes.

Exploration

The NRT program fostered exploration, defined as interactions between individuals from different groups (Pentland, 2014), between students and faculty from different disciplines in two ways: reinforcing a culture of interdisciplinary exploration and providing formal and informal opportunities for students to move outside their comfort zones.

One way the NRT program facilitated exploration was by reinforcing a culture wherein individuals were encouraged to seek out perspectives and views from outside of their home discipline. Multiple participants spoke to the ways in which interdisciplinary exploration was part of the NRT program's culture. For example, one faculty member described the beliefs that informed the NRT program's creation. The faculty member said:

> We are of the belief that having interdisciplinary experiences are crucial to transcending [. . .] the structures or the mindset of your own field. We think that that people do better work when they work with other people and when those people have a diverse set of experiences.

Another faculty member described that, unlike academic departments, the NRT program/LSC was organized around research questions, which facilitated cross-departmental exploration. The faculty member explained that many students had research questions that "naturally cross boundaries" and were not tied to silos in the ways that departments are, which "frees us to not stay limited in terms of what we think of as research questions and to look at things from multiple viewpoints." Students affirmed that faculty in the NRT program/LSC signaled the value of interdisciplinary exploration. One student explained that faculty involvement was essential for signaling that "interdisciplinary work is important and beneficial to the graduate students' career or professional aspirations." Interview data, observations and documents consistently showed that the NRT program/LSC faculty and staff valued exploration into different fields as a scholarly endeavor and communicated to students that exploration was important.

Another way the NRT program fostered exploration was by making explicit the expectation that students move outside their comfort zone or home department, during their doctoral program. During the application process, NRT students identified how they would move out their comfort zone to explore another discipline. They specified actions they would take to achieve this goal. For instance, students identified relevant courses in fields such as computer science or psychology that they would take to explore new disciplines. As students moved outside their comfort zones, they attained new skills through collisions with colleagues from other disciplines. One student said:

> I was not a [certain kind of scientist] coming in and, at the time, one of the big parts of the language science program was the external rotation, which was supposed to be a semester doing something outside of your area of core expertise [. . .] I ended up doing a [rotation in a STEM field] and getting totally hooked on that [field's] methodology and the types of questions being asked by that sort of community.

Thus, both formal and informal NRT program activities provided students with access to structured opportunities for exploration. As opposed to programs wherein interdisciplinarity is encouraged but there are few structures or resources to support it, the NRT program created concrete exploration opportunities for students to move outside their comfort zones.

Although some NRT activities facilitated exploration and thus productive collisions for students, some exploratory collisions were less successful. Unproductive collisions sometimes occurred when students participated in interdisciplinary collaborations with unclear or ambiguous goals. Several of the NRT program activities encouraged students to collaborate on interdisciplinary research projects. For instance, during one Winter Storm, the NRT program organized students into interdisciplinary groups focused on different language science areas. Leveraging the students shared interests, groups were supposed to launch an interdisciplinary research project. Despite NRT-support for the projects, students faced challenges in getting the projects off the ground. One student described the challenges and benefits associated with the groups:

> That [group] ended up falling apart this year because we all got too busy. That was challenging because you had to communicate your ideas to someone who has a completely different background than you and you're not even sure what the background is. Figuring out what's common ground and what you can assume, the vocab you use [. . .] It's challenging but it also makes you understand your work better.

Multiple participants went on to explain that their groups met to discuss ideas, but most never ended up moving into data collection. Said another way, although students had the desire to work on interdisciplinary teams and the NRT program provided them with the avenue to do so, there existed an ambiguity or uncertainty what the goal or end result for such collaboration could or should, be.

Idea flow

Idea flow refers to the spreading of ideas among members of a group (Pentland, 2014). The NRT program facilitated idea flow in two ways: by creating regular contact between students and faculty from different disciplines and by giving students access to interdisciplinary feedback.

The NRT program fostered idea flow by organizing activities that promoted regular contact between students and faculty from different disciplines. Through activities such as LSLTs, Winter Storm, Language Science Day (or LSD, an annual event for the UMD language science community) and interdisciplinary seminars, students became aware of the individuals within the community who shared their research interests. Thus, when students had questions, they were able to identify the individuals who might be able to help. One student described how they were able to connect with faculty outside of the department when they needed feedback on an experiment. The student said:

> I have done this [method] that no one in my department had really done. I had to go to the broader language science community, to [faculty members], who helped me figure out how to set [the experiment] up [. . .] That's been really crucial because that's been one of my most important experiments.

Another student explained the ways in which coursework had enabled them to learn new methods or ideas. The student said:

> A lot of people are working on issues related to language acquisition. And it soon became clear in my coursework, that it's not good enough for us to just have good descriptions of the constraints

> [to language acquisition], you also want to be able to explain why or how children come to learn them [. . .] and [. . .] there are a lot of people here [in the NRT/LSC] who have similar interests. And so, I can talk to them and get a sense of what the big questions are and how to approach them.

In other words, the NRT program fostered collisions by bringing visibility to the diverse kinds of researchers within the community and by making connections among students and faculty who might have otherwise stayed within their academic silos.

Opportunities for students to gain interdisciplinary feedback from other students and faculty also facilitated idea flow. For instance, during LSLTs, observations showed students and faculty frequently gave in-depth feedback to student presenters. Audience feedback included questioning assumptions embedded within research approaches, methodological suggestions and encouragement for the presenter to seek out new ways of framing their implications. Such feedback facilitated interdisciplinary idea flow, as audience members came from a range of departments and research areas. Students indicated that feedback was one of the essential ways that they received and gained appreciation for new ideas. One student said:

> [In other places] People are more stingy in their ideas and sharing their ideas. Or they would be hesitant because they are more individual[. . .] But the NRT program is very embracing[. . .] in the sense that it encourages people to share ideas.

By encouraging idea flow through regular events and activities within the LSC, the NRT program encouraged openness and sharing of ideas.

Although feedback facilitated idea flow within the NRT program, activities wherein students received feedback could also be places where unproductive collisions occurred. For instance, during one LSLT, a student presented their research to an audience composed of graduate students and a handful of faculty members. At the beginning of the session, audience members asked a few clarifying questions about prior work in the research area. However, as the presenter turned to their own research, audience questions came at a persistent and rapid rate. Audience members often interrupted the presenter and challenged (albeit respectfully) the assumptions guiding the presenter's research. The student presenter responded to questions thoughtfully and appeared to appreciate the feedback. At the same time, the audience members were not in agreement about the appropriate next steps for the project. Some audience members stepped in to support the presenter's decisions, while others actively questioned those same decisions.

Students experienced these feedback clashes as having both benefits and drawbacks. One student explained benefits they received from watching such exchanges. The student said, "conflict, especially when its between faculty from different disciplines, I find very useful to watch." The student explained that they often watched faculty disagree about how to write research abstracts and eventually faculty realized that although there are different approaches, both have merit. The student explained, "That can be quite empowering because I know that either way I do it, I have the support of someone." In contrast, some students found the conflicting feedback frustrating. One student described giving an LSLT wherein they received an overload of feedback from audience members. The student explain that the talk had become quickly interrupted by the audience and said, "I did my best to lasso them back in, but it got a little derailed. People were in the audience arguing with each other." Likewise, another student said that sometimes during LSLTs, they felt as though they were watching someone get "thrashed." The student noted that the "thrashing is about content" and that they gained valuable insight about how to communicate their own research through observing such collisions. In all, collisions during feedback sessions

sometimes created conflict between students and faculty from different disciplinary backgrounds, which came with both benefits and drawbacks.

Engagement

Engagement refers to on-going, face-to-face interactions between individuals from different groups (Pentland, 2014) or in this case disciplines. The NRT program facilitated engagement by providing a physical meeting space and enhancing student ownership over program activities. Yet, the NRT program also experienced some challenges in maintaining student and faculty engagement over time.

The LSC was renovated in 2015 and is now a brightly-lit space on the main part of UMD's campus. The location of the center serves as a physical bridge between traditional STEM fields on one side of campus and the social sciences, languages and humanities on the other side. The LSC houses offices for program staff, small group meeting rooms and a large open space that is usually set up for small group and individual work but can be converted into a larger event space. LSLTs, LSD poster sessions and Winter Storm all take place within the LSC, along with various student and faculty gatherings. On any given day, observations showed students from different disciplines in the LSC working independently on laptops, meeting in small groups, writing on the white boards, meeting with faculty members or participating in research talks or professional development workshops. As one student explained, the physical location of the LSC enabled possibilities. The student said:

> I hang out in the LSC a lot which is nice. First, because it's beautiful, but also because it's a place where other people can come, and you get to talk to other people who aren't the people in your lab who you see every day. Strike up a conversation.

In all, the physical space of the center made interdisciplinary collisions possible by serving as a physical hub where students and faculty could meet and interact.

Another way that the NRT program facilitated engagement and interdisciplinary collisions was by giving students a sense of ownership over their program. Many program activities reflected the development needs of students themselves. Observations revealed a pattern of student ownership in LSC outreach activities, wherein students developed language science lessons and demonstrations for members of the community. During Maryland Day, an annual campus community event, NRT students led outreach activities for hundreds of members of the public. Although much of the preparation for the event took place prior to the event, students took ownership over their booth to make sure each activity was adequately staffed and each member of the public was engaged in the activity when they stepped into the booth. Outreach activities not only served as an opportunity for students to develop ownership over their graduate program but also for students to develop long-term, collaborative collisions with students from different departments.

Despite these successes, the NRT program experienced challenges in maintaining engagement among a diverse disciplinary group. Constraints emerged as a result of divergent views about the nature of students' development needs. For instance, some students became disengaged from the NRT's professional development events, which tended to focus on preparing students for non-academic careers. One student said:

> It's great to have resources around to think about other jobs to do besides staying in academia and doing research and trying to be a PI, but the truth is that that is what I want to do.

In contrast, other students endorsed the NRT's emphasis on non-academic careers. One student said:

> [The LSC] has done a lot to help me figure out what I wanted to do. A lot of the PD (professional development), doing the informational interviews or doing the IDP (individual development plan), where it forces you to think about what skills do I have, what skills do I want, and what do I actually like doing, has been incredibly helpful.

Other students experienced disengagement within the program as they collided with other students about the purpose of research. For instance, some NRT program activities were aimed at enhancing students' ability to make connections between research and the "real-world." Yet, students varied in the degree to which they felt comfortable or interested in doing so. One student said:

> I want to figure out facts about the world, my goal at the end is not to help people, I want to expand the bound of human knowledge, not find a new treatment per se.

Another student described how this tension manifested during courses with students from different disciplinary backgrounds. The student described a course wherein some classmates wanted to focus on practical applications and others wanted to focus on theoretical explanations. The student said:

> Sometimes, it's frustrating because there are cases where we want to keep talking about something [more theoretical] and it would go back to that kind of discussion [of practical application].

Said another way, collisions between students with different career interests and research orientations could sometimes generate disengagement among students during specific program activities.

Limitations

Some exploration of the limitations of this study is warranted. This study identified some specific features of the NRT program that seemed to scaffold interdisciplinary collisions between students and faculty from different disciplines. Yet, interdisciplinary collisions could have also occurred outside of "official" NRT and LSC activities. While this study's intention was to focus on the extent to which collisions occurred within the NRT program and LSC, these external collisions may have influenced participants' experiences. Second, because the NRT program requires an application, participants in this study were likely those students pre-disposed towards seeking interdisciplinary collisions. Although this is a limitation, this study's purpose was to consider the ways in the NRT and LSC made these collisions easier or more accessible. Third, this study focused specifically on collisions that occurred between students and faculty from different disciplines. Within graduate training programs, it is reasonable to assume that both productive and unproductive collisions occur between students and faculty from within disciplines, and indeed data in this study showed that many participants' meaningfully interacted with students and faculty from within their own discipline. Even so, given the known barriers to productive, interdisciplinary interactions, a focus on collisions across disciplines seems warranted. Finally, although data were collected over time, the NRT program and LSC were already a well-established interdisciplinary community at the time data collection commenced. Thus, results do not necessarily speak changes in collisions over time, but rather the avenues in which collisions emerged and their impact.

Discussion and implications

Most research universities are not organized to facilitate meaningful collisions between faculty and graduate students of different disciplines. Yet, much research shows the rich

benefits to creativity and innovation when individuals from different fields come together (Bunton and Mallon, 2006; Millar, 2013). This study examined how one National Science Foundation-funded, National Research Traineeship (NRT) program facilitated interdisciplinary collisions through idea exploration, idea flow and engagement among individuals from different disciplines that in some way studied language. The study found that the leadership of the program, faculty, staff and doctoral students scaffolded collisions by creating an expectation that members of the community would engage in better science if they engaged with others of different fields through classes, projects and in research exchange. This "default" assumption seemed to frame many aspects of program functioning, including the selection of doctoral students into graduate programs, the selection of classes, organization of program activities and interactions within program space. The study also found that the NRT program intentionally facilitated idea flow between actors of different disciplines within the community through manufactured events (e.g. LSLTs) where students and faculty received feedback from each other. These public events modeled the expectation and value of interdisciplinary approaches through a sort of performance wherein scholars were expected to present their work, receive and consider perspectives from other disciplines and consider their own work from these other perspectives. Finally, the study found the physical space where the NRT program was housed and the structure of the NRT program acted as a sort of "third space" (O'Meara *et al.*, 2018) or crossroads that facilitated regular engagement among students and faculty from different disciplines. Given technology has increased the likelihood for both graduate students and faculty to work from home and the fact that doctoral students from different disciplines areas "live" in different buildings across a large campus – this cross-roads space emphasize the importance of putting in place symbolic and concrete places where interdisciplinary connections can occur (Felt *et al.*, 2013; Lyall and Meagher, 2012; Mäkinen *et al.*, 2020). In other words, intentional NRT program activities nurtured meaningful collisions by allowing for exploration, encouraging students to share ideas and fostering engagement, rather than merely hoping that productive, interdisciplinary collisions would spontaneously occur by accident.

That being said, results showed that when collisions were not carefully scaffolded, they could have little positive benefit to scholars and/or even negative repercussions. For example, communicating across academic tribes can be difficult (Becher and Trowler, 2001). As in prior studies (Felt *et al.*, 2013; Fitzgerald *et al.*, 2014; Gardner *et al.*, 2014; Lyall, 2019), participants in this study experienced conflicts in different uses of terminology or lack of common terminology, unfamiliarity and/or sometimes suspicion of methods used by other fields and paradigm differences in the assumption as to whether it was important to do basic or applied work. Some disciplines (e.g. computer science), often informed by norms within their field, were more interested in non-academic career options than others. Also, because the basic reward system and organizational structure remained the same, both faculty members and graduate students had primary homes and workloads in their departments that took priority over interdisciplinary projects. As such, if an interdisciplinary research project or opportunity was not set up with clear goals, roles and structure, the project could easily fall apart. Though the NRT program supported organic, student-owned engagements around interdisciplinary issues, sometimes what those collisions most needed to thrive was strategic, purposeful curricular or research structures. These findings are consistent with previous work on interdisciplinary graduate education, especially in terms of understanding the structural challenges and siloes that thwart student learning and development from occurring (Gardner *et al.*, 2012; Gardner *et al.*, 2014; Lindvig, 2018; Lindvig and Hillersdal, 2019; Lyall, 2019).

While the study overall found the theories of collisions and social physics to be useful to understanding how graduate programs can enhance interdisciplinary collaborations, there were some critical limitations to the application of these theories to this case. One question that remains is the degree to which this case represents an NRT program that disrupted organizational norms that keep collisions from occurring and created new collisions that would not have existed before and/or simply acted as a safe haven for those predisposed to creating collisions as scholars. If the outcomes are the same (that is, in both cases, valuable interdisciplinary interactions occur), one might ask how important it is to determine whether this program acted more as a Large Hadron Collider, manufacturing collisions that would not have occurred, or a cove where those predisposed towards interdisciplinary collaboration go to engage in collisions more fruitfully. Of course, higher education needs both kinds of apparatus – places that create new collisions and places that shelter the ones already predisposed to take place. However, additional case studies of programs of different persuasion might reveal which structures and supports are most useful for each kind of space.

Conclusion

Like studies of the Large Hadron Collider (Boisot *et al.*, 2011), this study revealed some of the important ways that graduate education programs can foster interdisciplinary collisions among graduate students and faculty from different disciplines and the challenges and benefits of doing so. By facilitating exploration, idea flow and engagement, graduate programs can not only give graduate students opportunities to develop their skills as interdisciplinary researchers but also contribute to organizational and cultural change that enables the possibility of interdisciplinary research across higher education institutions.

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