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Question 2

## Prompt

Drawing on current research characterizing the academic scientific workforce and the roles of early career researchers in grant-supported postwar academic science, how might the increasingly team-based structure of scientific research affect the career trajectories for early career researchers who aim for full-time science positions at research intensive universities?

## Introduction: To Understand Career Pathways, Investigate Team Science

A career path in academic science is traditionally understood as a series of well-known steps that constitute both a training and a proving period: undergraduate degree, doctorate, postdoc, tenure track, tenure. The metaphor of the pipeline is often applied this process, and this scientific pipeline is theoretically understood as a mechanism of meritocracy because the researchers who pass more of these credentialing steps are the researchers who produce the best work most consistently. However, whether this ideal is true is debatable. The Survey of Earned Doctorates consistently shows a gap between the number of graduating PhDs who have careers within academic science and the numbers of graduating PhDs who want them (*Doctorate Recipients from U.S. Universities: 2018*, 2019). Although a majority of new doctorate holders rate Academia as their top choice for a post-PhD career (Woolston, 2019) and a majority express a desire to remain in academic research in the medium or long term (Hardy et al., 2016), many are unable to because the number of available tenure track positions is smaller in relation to the increasing number of PhD trained researchers (Cyranoski et al., 2011; Schillebeeckx et al., 2013).

Numerous researchers and commentators within science have argued that the pipeline model's central assumption that there is one possible STEM career path, beginning in the pre-college period, is limited and inaccurate (Cannady et al., 2014; Hill, 2019; Xie & Shauman, 2003). While I agree with these objections, the metaphor has so permeated the discourse on scientific careers that attrition from science is nonetheless framed very often as a form of "leakage" (Alberts et al., 2015), in particular for minoritized groups in science (Cannady et al., 2014; Clark Blickenstaff*, 2005; Schillebeeckx et al., 2013; Wickware, 1997; Xie & Shauman, 2003). Explanations for the leaks in the pipeline sometimes latch onto individual reasons for leaving science, such as a lack of role models (Clark Blickenstaff*, 2005; Wickware, 1997), stereotype threat (Clark Blickenstaff*, 2005), or events in researchers' personal lives, such as having children (Bozeman & Youtie, 2017). Some of the discussion addresses conditions within scientific training, identifying the primary structural cause of the overwhelming attrition rates as the oversupply of PhDs for faculty positions (Alberts et al., 2015; Clark Blickenstaff*, 2005) or a failure to offer adequate professional development to prepare graduates for the academic job market. Solutions often include additional training for "alternative" career paths of PhDs, outside academic science in industry, government, or nonprofit organizations (Isaacson, 2019; Schillebeeckx et al., 2013) and that after a certain duration of years, PhDs should no longer be allowed to accept postdoctoral positions, thus reducing the large pool of PhD scientists (Powell, 2015).

The literature that connects the leaky pipeline to the oversupply of trained scientists certainly identifies a core issue, but the next step I intend to follow in this essay is to ask why this oversupply has been created in the first place. The discussion surrounding the oversupply in PhDs still represents oversupply as resulting from the training of the researchers. However, I argue that the oversupply of trained scientists is entangled with not only the conditions of training, but with the structure of modern scientific work as a whole. PhD students in the sciences are most often working as members of research teams rather than solo authors (Larivière, 2012), making it more important than ever to ensure that we're studying early career researchers in the context of the research team. By thinking not only about individual career trajectories, but the ecosystems of scientific work that structure those trajectories, we can answer the questions about where the oversupply of trained scientists came from much more effectively.

One of the largest, most persistent trends in scientific work which affects it not only on the aggregate level, but in the lived experiences of researchers in the lab is the team-based structures of modern scientific work. Modern measurements of research productivity amplify the benefits of working in teams for scientists with higher citation rates which has created entrenched incentives for performing scientific research in teams (Larivière et al., 2015). However, while the benefits of team science is well documented and discussed (Cook et al., 2015), the effects on individual career trajectories of junior scientists within the larger context of team science is an emerging research area with several recent studies drawing attention to the shorter career trajectories of recent cohorts of scientists (Milojević et al., 2018; Zeng et al., 2019).

Drawing on research concerning team science over the past half century, I argue that the predominance of team science and the increases in team size create an environment where it is less likely for individual researchers to follow the traditional academic career trajectory ending with tenured professor that doctoral training is putatively for. Instead, the division of labor between team members and the hierarchical structures necessary for effectively organizing team science create a larger number of possible career trajectories many of which are very short and focus on specialized tasks. Much of the literature focuses either on team structure or career trajectory, and I posit that there should be more points of connection between these two bodies of literature. Especially in studies of career trajectory, there has to be an understanding of the context of team science that these careers take place in. A stronger investigation of the systemic issues causing the high attrition rates may also help explain the sources of persistent bias in science against minoritized groups. In this essay, I connect the existing literatures about individual career trajectories and the team structures of modern science and work through the points of connection between these literatures.

## Section 1: Where did Team Science come from?

But what do we consider team science, and what makes it modern? The classic origin story is that defensive spending during World War II created the opportunities for large-scale big science research projects, like the development of the atomic bomb. Indeed, supplementing historical views of 20$^{th}$ century science, the works of Derek de Solla Price also track an exponential-like growth in the numbers of scientists, papers, and research funding since the turn of the 20$^{th}$ century in 1900 (Price & Price, 1986). Although my summary of the narrative will be brief, the predominant story is that following the success of the wartime research, policy-makers exemplified by Vannevar Bush in his "Science the Endless Frontier" report solidified the stance that funding for basic research and the advancement of science is a necessary public good (Kaiser, 2012a; Leyden & Menter, 2018). However, cooler heads observe that the transition to team-based science work practices happened more gradually, often originating within the scientific community (as opposed to the outside forces of the US defense department), with examples of physicist-led big science projects beginning before 1940 (Galison et al., 1992). However, Vannevar Bush's "Science, the Endless Frontier" nonetheless provides a useful touchstone for accounting for and exploring the structural characteristics of team science and the underlying attitudes that made them take hold in modern science production.

Part of the underlying philosophy behind Bush's argument for regular government investments in science and the establishment of set procedures for evaluating requests for this funding is the implication that science can be organized as a form of production: if the right inputs of funding and people are arranged in the right organization of teams, science can progress in a regular fashion. This entails an emphasis on the necessity of government funding to keep academic research going without the constraints of industry research (Bush, 1945). The war time projects whose advancements Bush hoped postwar science could replicate demonstrated the foundational attitude of big science projects where each project was funded for a specific large-scale objective, such as building a bomb, breaking a code, or later mapping an entire human genome. In Physics, this involved asking more simple questions, and seeking more concrete well-defined answers (Kaiser, 2012a). The formal organization structures that demanded that a distinct project be declared in advance is critically necessary for big science to function, but while it's not important for little science to work, now little science ventures are also held to this same standard; small-science projects also have to declare a project in advance and ask for funding for it specifically (Stephan, 2012).

Bush was also concerned about an apparent deficit of scientific talent, and emphasized training as a means of developing an entire scientific workforce, and the opening up of the field for any with ability to contribute (Bush, 1945). Bush's call reflects the fears about a shortage of scientific talent, and the widespread efforts to speed production of scientists themselves through expansions in graduate education (Kaiser, 2012a, 2012b). The shift to expanding the science workforce as a whole represents a departure from the romantic notion of the singular genius scientists whom Steven Schapin identifies as the paradigm of the scientist during the 19$^{th}$ century. Steven Schapin wrote that during the mid-20$^{th}$ century, the romantic notion of the long genius is being eroded within the practice of science, as it was becoming more practical to assign a full team of people who are likely to do well with the research task. That way the entire project is not dependent on the work or success of any particular exceptional individual, but is shared by entire pool of collective talent and labor (Shapin, 2010). The key became organizing the larger pool of researchers using hierarchically structured teams as a way of systematizing progress. The intricate collaborations within large scale physics projects surrounding the colliders that Sharon Traweek discusses in Beamtimes and lifetimes, the organization of the massive research group into interlocking, but sometimes competing factions all depends on a series of complex negotiations between researchers all along the spectrum of specialization (Traweek, 1992). This identification and pursuit of measurable research goals from what might otherwise be unwieldy large-scale projects with a lot of moving parts represented an important element of the transition to modern team-science organization.

However, I would argue that big science is not about being big, but about the team-based organization mechanisms that made the continued investments of research more predictable and measurable. Big science requires teams, but the strategies of organization in team science, such as a focus on measurable outcomes, a larger number of working scientists sharing expertise, and resource/equipment sharing, are also useful for pulling results from smaller projects more regularly. Thomas Kuhn's normal science describes how within science there will be long periods where science is functioning under a particular paradigm. Kuhn was talking about ideas when he formulated this concept, but perhaps Kuhn's observation that there are stretches of normal science punctuated by revolutions in the means of reformulating the paradigms of science is also applicable to the structures that organize the ways that science labor is done, and the typical means of structuring scientific work and organized labor on research questions. In this way, the advent of big science changed science not just by increasing the scale of research projects, but by introducing new organization structures for those big research projects necessitated by the size of big science. Team science becomes a general mode of doing science, even when the projects are not large-scale. These divisions of labor and restructuring of the modes of working to do to be able to use the larger funding packages and more complex equipment weren't imposed from above but were self-organized within science as more predictable means of doing things, not only in the large scale, but also in the small.

## Section 2: Modern incentives for Team Science

I've described the ways that team science came to be regarded as the principle paradigm for research work and discussed how the team structures of "big science" projects came to be applied to small-scale projects as well. In a way, the practices and assumptions of team science migrated out of the high stakes realms of big science to structure all of science, including even small-scale scientific endeavors. Furthermore, I argue that this pattern where small-science projects are coming to resemble big science projects has continued into the present day, in the way that small science endeavors are being organized around specific projects and conducted in teams with hierarchical organization. Before talking about how individual career trajectories are being affected by the intensification of team science, I will discuss the ways that that scientific teams are increasing in size and discuss the incentives for the growth in team size.

Across multiple fields of science, the size of both national (Milojević, 2014) and international (Gazni et al., 2012) scientific teams is increasing in size. Milojević et al. have found that within science, team size follows a powerlaw-like distribution; although small teams tend to be exponentially more common than large teams, the large teams at the extreme end of the spectrum are massively large, and in recent years (Milojević, 2014). While stories of team science focus on these resource and personnel intensive big team projects like Cern, the characters of the very common mode of working for most scientists is also changing. While comparatively small teams seem more common, Single authored papers have constituted a decreasing proportion of all publications over the past 50 years (Greene, 2007; Wuchty et al., 2007), indicating that individual researchers spend more of their endeavors working with other researchers. However, while increases in team size have often been attributed to the need to share resources, there are actually similar increases in the proportion of papers coauthored by teams and increases in team size for the social sciences as well (Wuchty et al., 2007). Furthermore, even among the smaller, more common research teams, the median team size is increasing so that what is considered the typical small-team size, in which most scientists work, has been subtly getting larger in recent years. These changes show the real-world play out of the team science paradigm that has successfully taken hold within modern research. Team science is normal science now, and the small to medium-sized research team is the working environment of a sizeable proportion of researchers.

When science is considered a collective task, the effects of cumulative advantage come into play. In the case for team science, many argue the inclusion of more researchers allows for a stronger mix of skills and better collaboration (Bozeman & Youtie, 2017; Guimerà et al., 2005). Concurrent with this time period from 1900 onwards, Lariviere et al. also find increases in the number of authors, affiliations, and countries, showing that there is intensification not just in the number of people in the same place, but in increasing the geographic diversity of teams as higher numbers of papers co-written by collaborators in different institutions and countries (Larivière et al., 2015). Pulling in team members from a wider mix of institutions and countries seems to be associated with a higher citation impact (Katz & Hicks, 1997), and that this effect has been increasing since 1900 (Larivière et al., 2015). Higher rates of collaboration, and collaboration across larger networks of colleagues is associated with higher rates of productivity and scientific impact, showing that not only large collaboration networks, but the right make-up of different types of collaboration and having a cohesive network is essential for success in science (Jadidi et al., 2017). However, while the right balance of team members of different backgrounds may be challenging to gather, the right interdisciplinary mix can produce big results, as greater potential for idea mixing may lead to more cited, more interesting research (Jensen & Lutkouskaya, 2014; Uzzi et al., 2013). With larger teams, there may be more space for researchers with different backgrounds to contribute to each project, cumulatively contributing more diverse skills, expertise, and viewpoints than could be pooled within a smaller team

However, the larger team may also carry advantage for the simple goal of publishing a lot. Cumulative advantage also indicates that the more people are on the team, all working to publish, there may be a greater number of papers published, slightly above what the researchers would have accomplished separately or in smaller teams (Milojević, 2014). The top most cited papers in recent years have been disproportionately written by teams as opposed to single-authored papers, which is a reversal from the past when in the social science, sciences and engineering, the single-authored papers were more likely than team papers to be highly cited (Wuchty et al., 2007). This also makes intuitive sense from the perspective of a principal investigator (PI), who often receives author credit on all the papers that the team that they organize produces. PIs heading research teams see some correlation of productivity and the size of their team, but there are some diminishing returns, with each additional team member contributing a little less than one extra paper (Cook et al., 2015).

In this sense, the working structures of team science take on particular importance because maintaining this high productivity is of the utmost necessity within the context of the modern reward structures of science. The reward structures of science are complex, but the metaphor of the tournament describes science incentive structures where competition for resources happens within teams, and with branching possibilities for both advancement and failure (Freeman et al., 2001; Stephan, 2012). The idea that cumulative scientific successes make later success more likely appears in Latour and Woolgar's concept of the cycle of credit, where scientists pursue credit for their work because of the opportunities the reputation for having done good science opens up to them, such as new partnerships with other scientists, grant funding (Latour & Woolgar, 1986). The tournament model brings the material and economic cumulative benefits into sharper relief, the tournament model accounts for the fact that the accumulation of resources strengthen the case to further apply for more resources (Stephan, 2012). As researchers compete for resources, their incidences of success are necessary to opening other opportunities for competition, and many opportunities are happening simultaneously; because choosing to compete in one area as opposed to another require different resources and has different odds of success, scientists have to strategically position themselves in the right place with the right materials and labor at the right time (Stephan, 2012).

Chief among the resources at play within the scientific tournament are the researchers themselves who constitute the research team, and whose labor contributes to the scientific findings that justify further funding (Lane et al., 2015). The competition to entice for bright graduate students, postdoctoral researchers, and other researchers to join research teams is fierce (Hagstrom, 1964). In many ways, the lead researchers who prioritize bringing in graduate students as team members are making a reasonable deal, since the work of PhD students contributes to about a third of scientific publications in one estimate (Larivière, 2012). However, the rewards of success in the tournament even within winning teams will be distributed unevenly with more going to the senior researchers who had set the agenda (Freeman et al., 2001). While the total number of papers over time is increasing exponentially, when credit for each paper by the number of coauthors as a way to correct for the increasing size of the teams—a practice known as fractional authorship—the individual productivity of scientists has not increased (Fanelli & Larivière, 2016). All this suggests that the benefits of team science accrue not necessarily to individuals within the teams, but to the project teams themselves, and the few individuals at the head of the project teams. Already, we're thinking about the kinds of balances that have to be struck between senior researchers on teams who accrue a great deal more credit for the scientific accomplishments of the group, but whose role keeping the entire research team afloat is also indispensable, and the keeping of the research team afloat depends on these very accumulation of credit and resources through cumulative advantage.

So in conclusion, the cumulative advantage that accrues to research teams, as opposed to the smaller options for individuals, is becoming more necessary to keep up with the demands of science, which requires both more publications and greater outlays of resources. Into this environment, early career researchers, including graduate students and postdocs are important participants in team science, whose work is absolutely crucial to the high productivity necessary to keep their research team afloat. The reason why teams get larger is because larger teams seem to work more effectively, and the way that one fills out a strong, productive research team is with junior researchers, who happen to be on their own career path. In the next section, I will explore how the labor within the research team is organized, and what role early career researchers play in these collaborations.

## Section 3: Hierarchy and Collaboration in Team Science

Although we find empirical evidence that in aggregate larger research teams are able to produce more research than smaller teams or individual authors, there are also more moving parts to team science. Within larger teams of individuals with their delicate intermix of skills, some administrative and organizational work becomes necessary to implement and oversee the division of labor between researchers with different skills and expertise. There are several observed patterns or trends in these ecosystems across scientific fields that participate in team-based science, particularly as the teams grow larger. As teams grow larger, team science is more likely to exhibit bureaucratic practices, like standardization, hierarchy, decentralization, and division of labor (Walsh & Lee, 2015). This next section argues that within the environment of the scientific team, the roles available to individuals will be different than those available to researchers working individually or in smaller groups. Furthermore, the ways that research tasks are divided up and assigned among members of scientific research teams will be affected by the position and prominence of the researchers within the scientific team.

The division of labor is the most straightforward element of bureaucratic structuring, as it means that project specific research tasks will be completed by different individuals within the team whose skills may be better specialized to the task. However, the division of labor is not necessarily neutral, and there are still established hierarchies of research tasks, where some forms of work carry greater prestige and opportunity for advancement than others. In their discussion of the cycle of credit, Latour and Woolgar discuss this stratification between the theoretical "idea work" of lead scientists, who are subsequently seen as irreplaceable and better able to access resources, and the hands-on experimental and the technical work of technicians and junior scientists, who are seen as interchangeable (Latour & Woolgar, 1986). For example, dedicated technicians or specialists will do the same forms of data analysis or equipment use for every project that they're on, while the heads of lab will be more likely lead the direction of the research and delegate the research tasks to the less senior members of the lab or collaboration. More has been written about the role of the technicians recruited to perform particular necessary tasks in the research workflow, and whose expertise also requires a high degree of skill and experience, but who remain alienated from research decisions (Barley & Bechky, 1994; Hagstrom, 1964). However, since technicians are still less frequent in many fields, it's also important to examine the role of junior scientists. Although the number of papers has increased compared to the population of active researcher, the number of papers where individual researchers had the designation of first author has actually decreased (Fanelli & Larivière, 2016). This suggests that even as more researchers are brought in, their work may devote less time for developing their own original research, and more time toward carrying out research tasks necessary for others' research ideas.

This tendency for team science to have stratified roles and bureaucratic organization lead to research structures where teams begin functioning more "like small firms " (Walsh & Lee, 2015) , and head researchers to spend more time and effort on administrative work, such as organizing the work of their labs, and applying for grant funding (Walsh & Lee, 2015). Middle and late career scientists who must deal with these growing administrative overheads often compare this present with a mythic "golden age" of science when scientists were able to pursue real research as a vocation without being bogged down (Holden, 2015). However, observing that the junior scientists whose work entails more research tasks remain enthusiastic about scientific work, Holder advances a fascinating alternative claim that the late career nostalgia instead reflects the division of labor in of the modern research lab. In this understanding, the senior scientists perform much of the administrative work necessary to keeping their labs or research groups running smoothly, while insulating their graduate students and postdocs from these concerns so that their scientific research labor produces scientific findings (Holden, 2015). Looking at the division of labor this way, it is possible to see the stratification in research roles is as a form of bureaucratic symbiosis.

Holden is not alone in identifying a kind of symbiosis between the senior and junior researchers on research teams. In one of the stranger descriptions of the organization of team science, Stinchcombe describes the administrators and workers at a survey research center, as Bees. In Stinchcombe's description, the heads of the survey research centers who set the research questions function as the queen bee, while the researchers who administer the surveys, and analyze the results are the worker bees (Stinchcombe, 1986). With this operational metaphor in place, Stinchecombe models the dynamics of the research center to describe the turnover rates for researchers, the funding requirements necessary for the extant colonies, and the probabilities that individual worker-bee survey researchers will be promoted (Stinchcombe, 1986). While this is a somewhat wacky example, Stinchcombe's metaphor raises the important point that the career trajectories of the researchers are dependent on the larger structure of their working environment. Within Stinchecombe's model parameters, he identifies a balance between the senior and worker researchers, such that within the limits of the system, a large proportion of worker researchers will not advance to the position of senior researcher (Stinchcombe, 1986). While Stinchcombe's model is less complex than the real world, his type of conceptualization is useful because it acknowledges that the path that one takes through science will depend on the structure of the ecosystem one is working in, and one's position within the ecosystem. Much of the discussion of the career paths of scientists, which focuses on the attrition of individual scientists, misses this critical point. Then, to understand the career trajectories of individual researchers, in the next section, we will begin looking at scientific credentialing within the context of team science.

## Section 4: Mentorship, Hiring, and the Ecosystem of Team Science

As we talk about the role of the individual within the ecosystems of team science, I argue that the position and roles of individuals within team science affects the length and trajectory of their careers. However, the next layer in the discussion about individuals and their careers within science is thinking about the credentialing paths that those careers take. When examined on a granular individual level, each individual has a series of career stages and credentialing steps that they must pass to qualify them and strengthen their applications for later positions. The positioning of researchers within the research ecosystem affects the types of work they do, the training that they receive, and the positions that are available for them when they leave.

Research training is envisioned thought of as a mentorship or apprenticeship relationship. If scientific training is commonly understood to happen for scientists in training during the typical actions of scientific research, the participation of early career researchers in scientific training is understood to be central to the training itself. The differentiation of mentorships does matter for early career researchers, and as the early career-researchers' publications and ideas will have a close similarity to their advisor's work, and that a scientists' postdoc work is often even more influential to their later career topic choices than their graduate topics (Liénard et al., 2018). Furthermore, strong mentorship has positive effects on publication for protegees, and it's theorized that successful mentees gain a stronger intuitive grasp on the tacit norms in their field that makes them inexplicably more successful (Liénard et al., 2018; Ma et al., 2020; Sekara et al., 2018). However, more successful students have been able to merge the interests and research questions from the graduate and postdoc positions, and when there is a greater semantic difference between graduate and postdoc work, the scientists who are able to synthesize these will have the greater possibility of success as they continue academic research (Liénard et al., 2018). Training for research work happens well through the mentorship model, so the inability of a large proportion of successful PhDs is not ill-training. When a large of very well-trained scientists are not able to find stable research positions, the issue may have to do with the structure of scientific training, not its content.

Instead, we may want to ask whether the training environment itself is set up to over-produce well-trained researchers. Implicitly the mentorship model for training compares itself with the advisor reproducing to create other researchers. Many studies make this assumption explicit by using reproductive models to simulate the dynamics in the training of new scientists, as the mentor's means of "reproducing" (Larson et al., 2014; Liénard et al., 2018; Malmgren et al., 2010). However, this foundational perception of scientific training as a reproductive relationship of mentors and mentees will by definition overproduce PhD recipients for the number of job openings. In fact, Larson et al. estimate that the average reproductive number for full professors on average is 7 new PhD researchers, which is well in surplus if the motivation for training a new PhD is to replace one professor (Larson et al., 2014). While research jobs within academic science become available at a linear rate, as existing professors retire, PhDs are trained exponentially (Arbesman & Wray, 2013; Larson et al., 2014). This research accurately describes the growth in the number of PhDs in the workforce, and also demonstrates that the mentorship model, which makes sense in individual lab environments, in aggregate will necessarily overproduce researchers for the available job openings.

These findings begin to shed light on the inadequacy on the idea that academic training is purely a mentorship between two parties: If the mentorship paradigm were true, why would senior scientists train multiple students at a time, more than necessary to replace the current pool of scientists when they retire? The relationship between mentor and mentee may be better understood within the context of the cumulative advantages of team science. While the training and material support from an advisor allows the mentee to learn to be a researcher, since the mentee's work is within the context of their advisor's/PI's lab, their research topics and material work also contribute to the larger productivity of their research team. In this way, although training new researchers does constitute a large outlay of time and attention, there may still be enough a cumulative advantage for recruiting additional early career researchers into the research group under team science. Perhaps it is partly for these reasons that the mentors who train a lot of protegees have higher publication rates and a greater likelihood of being inducted into the National Academy of science than those who don't (Malmgren et al., 2010).

Graduate students are very frequent collaborators for their advisors, as certain estimates show on average, each PI includes at least 1 student on 60% of their papers (Bozeman & Youtie, 2017), and about a third of the total research output had some contribution by graduate students (Larivière, 2012). Early career researchers contribute work to the research projects completed jointly with their advisors, and the high rate of contributions to the research agenda of the team may represent some strong incentives for senior researchers to recruit graduate students and postdocs into the research team at high rates. However, from the perspective of early career researchers, it's also possible that the types of work conducted by graduate students and postdocs within the research team is sometimes not tailored to promote their viability as eventual candidates on the job market. Early researcher also tend to switch topics more because they are working on projects within the context of teams and they must pursue research agendas that may not completely match their own (Zeng et al., 2019). This topic switching may also be traced back to the career conditions that require them to contribute work on projects led by others, which makes it more challenging to argue for and coordinate a unified narrative of what their research is about (Zeng et al., 2019). If hiring graduate students and postdocs through research grants that are predicated on their doing work that may not count for their career prospects, training grants have been proposed as a way to alleviate this, or to shift better incentives for graduate students and postdocs.

During hiring, oftentimes the research projects that had been completed individually or for which the candidate was in a leadership role are the only things that "count" for candidates on the job market. The specialized research roles that early career scientists occupy are more likely to be responsible for the bulk of hands-on experimentation and analysis, but they contribute to a lesser extent to counting for tenure and promotion, even though they are critically necessary tasks in scientific projects and on the research team (Leahey et al., 2010). In this way, although increased specialization benefits team science, where particular researchers with a large amount of experience in a few critical research tasks, may actually make it harder to be hired into a general tenure track role (Leahey et al., 2010). Furthermore, higher status "idea" research roles and lower status experimentation or analysis roles are not evenly distributed across gender, as women are frequently more likely to occupy the middle-author positions on research papers that usually represent an experimental or analytical research role rather than the more prestigious first author or last author position (Larivière et al., 2016). As the average productivity for each year in career age is nearly the same for men and women of same career age, the persistent gap between women's and men's achievements in science seem to be explained by the higher attrition rates for women (Jadidi et al., 2017). Combining the understanding that women have higher attrition rates from science than men with the awareness that women tend to occupy lower status roles within the research team than men can help explain this disconnect.

Within the environment where there are more researchers than positions for them, it makes sense then that the careers will necessarily be shorter since some careers will involuntarily end due to not finding a position. Several common hypotheses about the current system argue that the ecosystem is has been unintentionally set up to funnel people into different roles that are not necessarily the R1 research roles. There is considerable research in the hiring market, and there is well-documented systemic inequality in hiring network where researchers from top institutions are disproportionately hired more often (Clauset et al., 2015). This points to the presence of stratification also along the axis of the prestige of the training institution. In the establishment of a research career, scientists must often change institutions, but within these necessary career moves, there is stratification in the institutions that scientists move between. When scientists change institutions, there is a high amount of stratification, where the movements of researchers between institutions will only permit lateral or decreasing moves between institutions with differing levels of prestige (Clauset et al., 2015; Deville et al., 2014). These types of placement rates at institutions of varying prestige levels are also affected by gender (Yang et al., 2019). This makes the early institutions that the researchers start in particularly important for career success. Those who are in the low prestige institutions have a low chance of advancing to higher prestige institutions and leave academic science.

Then where do the credentialed doctoral recipients take position when they do not find long-term positions within academic science at research intensive universities? Industry is presented as another attractive career option for scientists who do not get or are not interested in faculty positions (Ding & Choi, 2011). Industry is a major employer of PhD trained scientists (*Doctorate Recipients from U.S. Universities: 2018*, 2019), so alarm over poor outcomes for earning a PhD is not entirely warranted. The survey of earned doctorates US doctorates still have very low unemployment, and we see a high share of the recent graduates making a high median income in research oriented fields outside academia (Zolas et al., 2015). The graduating doctorates and early career researchers who work outside academic science will most likely be fine. The odd issue in fact is that any career outside academic research science is still seen as "alternative careers" because the scientific training in the PhD is still so oriented towards academic careers (Isaacson, 2019; Schillebeeckx et al., 2013). The accepted assumption that a doctorate is preparation for a career within academic science has demonstrably becomes something of a myth, not only because of the demographic fact that such a large proportion of PhD trained researchers follow industry career trajectories, but also because the working structures of team science require more early career researchers to complete the relatively low-status scientific work than they have positions for in the long term.  So perhaps the question that should be also be asked is whether the current working structures of scientific research are being served by losing the researchers that have been trained over 5-7 years of their doctorates and postdocs.

## Conclusion

Throughout this overview of our current understanding of the conditions of team science and the career paths of the researchers who participate in it, I have explored a complex ecosystem where training seems to be folded seamlessly into the general system of scientific advancement. Under Science's system of incentives, scientific research is necessarily organized into teams, which tend to have higher rates of productivity due to a kind of complex cumulative advantage. Within team science, we see an ecosystem where a smaller number of senior researchers provide guidance to a junior researchers who are commonly understood to be training for senior positions themselves. Because the amounts of work needed to keep a research team afloat requires the work of many junior researchers, many more researchers in training are brought in than are actually needed to fill senior researcher roles (the replacement of the scientific workforce). Instead, the number of new researchers being added to research teams is the number necessary for keeping up with the amount of work needed to show a highly productive research team. In other words, the training of new scientists is keeping pace with the heightening requirements of scientific productivity, and not the replacement of the scientific workforce, which should be what informs the training of new scientists. Based on these studies of career outcomes in the modern scientific team, I believe that this is why there is a chronic oversupply of phd trained scientists who are unable to find permanent positions in the long-term.

So what happens to individual careers in this ecosystem where the scientific team trains many more junior scientists than there are senior positions to fill? The most straightforward effect is that because the capacity for senior scientists is much smaller than for junior scientists, a large proportion of PhD trained scientists will have shortened academic careers that end either shortly after they have their PhD or after they have completed a postdoc. We might argue that the early career researchers who never find permanent positions could be a temporary workforce is part of the structure of team science, which requires a larger labor force to support the research team than can be supported long-term in senior research positions.

But beyond duration, what are some of the mechanics structuring the shape of these careers? Within the scientific team, there are lots of different types of work and types of roles available to researchers, and there will be division of labor to determine who gets what tasks. These research tasks are stratified, such that some are higher status (i.e. conceiving of the experiment & writing the paper) and others are lower-status (i.e. performing experimentation & technical work). The researchers assigned to each tasks become similarly stratified--those securing higher-status tasks are more likely to get high-status tasks in the future, and those with low-status tasks will continue to get those roles. Those doing higher status work will then be stronger candidates on the job market and will have longer careers. There are similar effects for more prestigious programs and institutions, where researchers are also stratified according to institutional prominence. All this together creates an assortment of stratified career paths, where according to prestige and the types of research work, individuals pulled into research teams for training will be routed into different trajectories each affording stratified opportunities for advancement, and expectation of securing additional academic positions.

Most researchers when surveyed describe their experiences of collaboration as mostly positive (Bozeman & Youtie, 2017). In their management-focused study of collaboration practices, Bozeman and Youtie say that with only a few “dream” and “nightmare” exceptions, most research collaboration management practices that researchers use are largely effective and have positive outcomes (Bozeman & Youtie, 2017).  This is reassuring that on an interpersonal level, the practices of scientific collaboration are generally good, and I argue that the collaboration environment is not only about the management styles of individual PIs, but the general structure of the teams and common practices about divisions of labor. I’ve discussed the ways that these structural set-ups of modern team science affect the career outcomes for individuals moving through this system of collaborative science. I aim to study this in my future work, and I’m looking forward to it.

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