Beyond technical mastery: inequality in doctoral research skill development in the biological sciences

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Abstract

Purpose – The purpose of this study is to examine how doctoral students in the biological sciences understand their research skill development and explore potential racial/ethnic and gender inequalities in the scientific learning process.

Design/methodology/approach – Based on interviews with 87 doctoral students in the biological sciences, this study explores how doctoral students describe development of their research skills. More specifically, a constructivist grounded theory approach is employed to understand how doctoral students make meaning of their research skill development process and how that may vary by gender and race/ethnicity.

Findings – The findings reveal two emergent groups, "technicians" who focus on discrete tasks and data collection, and "interpreters" who combine technical expertise with attention to the larger scientific field. Although both groups are developing important skills, "interpreters" have a broader range of skills that support successful scholarly careers in science. Notably, white men are overrepresented among the "interpreters," whereas white women and students from minoritized racial/ethnic groups are concentrated among the "technicians."

Originality/value – While prior literature provides valuable insights into the inequalities across various aspects of doctoral socialization, scholars have rarely attended to examining inequalities in research skill development. This study provides new insights into the process of scientific learning in graduate school. Findings reveal that research skill development is not a uniform experience, and that doctoral education fosters different kinds of learning that vary by gender and race/ethnicity.

Keywords Doctoral education, Research skills, Inequality, STEM, Qualitative methods

Paper type Research paper

Introduction

Despite the growing representation of women and minoritized racial/ethnic groups in doctoral programs in the USA, notable disparities in academic careers persist (Espinosa *et al.*, 2019;

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National Science Foundation, 2018). Almost 90% of tenure-track faculty in the USA are white and close to 60% are men (National Center for Education Statistics, 2022). The underrepresentation of women and minoritized racial/ethnic groups is even more pronounced in STEM fields (Bennett *et al.*, 2020). While much has been written about various factors that contribute to these disparities, prior literature has dedicated less attention to understanding how gender and racial/ethnic inequalities among faculty may be related to graduate school experiences, and in particular research skill development. Developing research skills is fundamental to doctoral education as students progress from novices to independent researchers through learning the practices of their discipline or field (Austin and McDaniels, 2006; Golde, 2006) and developing their scholarly identities and intentions to pursue research careers (Burt, 2019; Forbrig, 2020; Holley, 2009). Thus, inequitable opportunities for research skill development could have notable implications for transitions into the labor market and pursuit of academic careers.

Prior literature on graduate students' experiences has noted ample ways in which women and students from minoritized racial/ethnic groups have less positive interactions with both peers and faculty (Garcia *et al.*, 2020; Grim *et al.*, 2021; McGee and Martin, 2011; Williams *et al.*, 2018). This literature, however, has rarely paid attention to research skill development. Based on interviews with 87 third-year doctoral students in the biological sciences, we find that graduate students discuss research and their scientific practice in two different ways: "technicians" focus on discrete tasks and data collection, and "interpreters" understand their research practices as part of a larger process of scientific discovery. Notably, distribution of students across those two groups varies by gender and race/ethnicity. White males are overrepresented among the "interpreters", whereas women and students from minoritized racial/ethnic groups are concentrated among the "technicians."

These findings illuminate a crucial dimension of inequality in graduate education. While all doctoral students are developing important research skills and knowledge, only "interpreters" (who are disproportionately white men) are acquiring broader skills that help them situate their scientific work in the larger disciplinary field. Although prior literature has noted other sources of inequality in socialization experiences, these findings illuminate research skill development as an important site of inequality. Inequality in research skill development has notable consequences for scientific learning that may reverberate beyond graduate school, hampering equity in academia more broadly.

Conceptual framework and literature review

Graduate student socialization and research skill development

Socialization has been the primary framework for understanding graduate student experiences (Gardner, 2009; Weidman, 2010) and is understood as a process of internalization where students learn the skills, knowledge, attitudes, dispositions and values of their disciplinary community (Austin and McDaniels, 2006). Doctoral study cultivates a number of different skill attributes, qualities and professional competencies, including the ability to conduct intensive scientific research (Craswell, 2007; Gilbert *et al.*, 2004). Development of research skills is central to doctoral student socialization as graduate students progress from novice to independent researchers (Golde, 2006) and transition from consumers to producers of knowledge (Weidman, 2010).

Although developing research skills is a crucial aspect of graduate education and identity development, relatively few studies have examined how students develop research skills (Feldon *et al.*, 2011; Feldon, Maher, *et al.*, 2016; Feldon *et al.*, 2019; Harrison and Schunn, 2004). In a recent study, Feldon and Colleagues (2019) relied on a longitudinal sample of graduate students to examine trajectories of research skill development over time using latent growth curve analyses. The findings revealed substantial differences in research skill development and showed that students who had postdocs or senior graduate

students actively involved in laboratory discussions exhibited more positive trajectories of research skill development. Other socialization experiences, such as teaching (Feldon *et al.*, 2011), co-authorship (Feldon, Shukla, *et al.*, 2016), interactions with postdocs (Blaney *et al.*, 2020) and supervised research with faculty (Kaur *et al.*, 2021; Overall *et al.*, 2011) have also been identified as contributing to research skill development. These studies, however, rarely consider how research skill development may vary across sociodemographic groups.

Inequality in graduate student socialization experiences

While inequality has not always been a prominent dimension of socialization research, recent work has illuminated how race and gender produce inequities and shape student experiences in doctoral science programs (Griffin *et al.*, 2020; Maher *et al.*, 2019). Graduate program cultures in the STEM fields tend to support masculine norms (Bostwick and Weinberg, 2018; Sallee, 2011) and women report less supportive relationships with advisors (Dinsmore and Roksa, 2020; Noy and Ray, 2012). In addition, peers may play a more prominent role in their socialization experiences (Šaras *et al.*, 2018). Experiences with faculty and peers have important implications for perceived fit between gender identity and scientific practice (Clark *et al.*, 2016) and shape emerging identities for female graduate students in STEM disciplines (Szelényi *et al.*, 2016).

Students from minoritized racial/ethnic groups contend with racialized cultures that have negative consequences for their experiences and outcomes (Griffin, 2020; Gildersleeve *et al.*, 2011; Williams *et al.*, 2018). One of the crucial experiences in doctoral education is mentoring, and minoritized students describe more negative mentoring experiences (Dinsmore and Roksa, 2020; McCoy *et al.*, 2015; Ramirez, 2017). Ramirez (2017) described how institutionalized racism shaped the experiences of Latinx doctoral students, resulting in unequal access to professional development opportunities and faculty mentorship. More generally, marginalized students encounter racialized experiences that foster self-doubt in performing the scientific role (McGee, 2020). Burt (2019), for example, reported that black doctoral students' social identities actively shaped their research group experiences and understandings of faculty life, which had direct implications for their pursuit of professorial pathways. The socialization process is thus infused with inequality as organizational life is mediated by gender and race/ethnicity.

While prior literature provides valuable insights into inequalities in socialization experiences, scholars have rarely attended to examining inequalities in research skill development. Moreover, a few recent studies addressing this dimension of socialization often focus on first-year doctoral students and provide mixed results. For example, Lachance *et al.* (2020) found that perceived skill self-efficacy increased during the first semester of doctoral training equally for women and men, whereas Flaster *et al.* (2020) indicated that women and minoritized students reported significantly lower levels of perceived disciplinary knowledge than their male and white counterparts (see also Owens and Lilly, 2017). One study that has considered research skill development beyond the first year reported no gender or racial/ethnic differences (Feldon *et al.*, 2019).

The present study advances this nascent area of inquiry by examining perceptions of research skill development among PhD students in the biological sciences at the end of their third year of doctoral education. More specifically, we examine how students' perceptions of their research skills vary by gender and race/ethnicity. This exploration has important implications for understanding inequalities in scientific learning and development of independent researchers.

Research design

Institution and participants

Data for this project are based on the interview portion of a mixed-methods study of students who entered biological science PhD programs in the USA in the Fall of 2014. More

specifically, the study is focused on "bench biology" – doctoral programs in fields including microbiology, cellular and molecular biology, genetics and developmental biology. Students participating in the study completed annual surveys. In addition, a sub-sample of survey respondents were invited to participate in interviews. Given our interest in inequality in students' experiences, interviews were conducted at the institutions that had study participants from minorized racial/ethnic groups. Analyses presented herein are based on interviews with 87 students: 24 students from minoritized racial/ethnic groups (including African American, Latinx and American Indian), 45 white women and 18 white men. We did not disaggregate the minoritized category by gender due to the small number of cases (only 8 men and 16 women).

At the start of the study, participants completed a survey where they self-identified race/ethnicity and gender. Racial/ethnic categories included American Indian or Alaska Native, Asian or Asian American, Black or African American, Latino/Latina, Hawaiian and Other Pacific islander, Other [fill in] and white. They could select multiple categories. We include any student who has selected Black/African American, Latino/Latina or American Indian as one of their racial/ethnic categories as being a member of the minoritized racial/ethnic group. Overall, 10% of students in the sample selected more than one racial/ethnic category. In the case that students selected multiple racial/ethnic identities, that is noted in the text. Moreover, the survey included two gender categories (male and female). During qualitative data collection, participants were asked to indicate their preferred gender pronouns. Although given the opportunity, none of the participants changed their gender identity from what was indicated in the survey.

The third year is the ideal setting for addressing our research questions. Students in the biological sciences rotate through different laboratories in their first year. They begin working in their permanent laboratories in their second year and are established in that space by the third year. They have become integral contributors to the research in their labs by that point in time, as well as started to conduct their own studies. This time represents the crucial nexus between being a graduate student and becoming an independent researcher, i.e. learning the skills and beginning to practice them in one's own work. Moreover, focusing on a STEM field is warranted given extensive literature documenting challenges women and racial/ethnic minorities face in the STEM disciplines (Chang *et al.*, 2011; De Welde and Laursen, 2011).

Data collection and analysis

The qualitative portion of the study relies on in-depth semi-structured interviews (Patton, 1990). The analysis presented in this paper is based on interviews conducted via phone between June and September 2017. We focus on questions related to students' perceptions of research skills, including:

Q1. What research-related skills or knowledge have you developed this past year?

Q2. How would you describe your research-related strengths and research-related weaknesses?

We use a constructivist grounded theory approach to data analysis (Charmaz, 2000). Constructivist approaches stress a relativist ontology that is epistemologically subjective (Denzin and Lincoln, 2000). This approach was a good fit for the study because we were interested in understanding how students' perceptions of research skill development reflect meaningful distinctions in the nature of scientific research. Grounded theory aims to generate concepts inductively and is particularly useful in understanding individuals' lived experiences as they navigate social processes (Corbin and Strauss, 2008).

All interviews were recorded, transcribed and coded using Dedoose software. In line with a grounded theory approach to data analysis, the first author developed an initial set of open codes based on reading through all of the manuscripts. As analysis progressed, we moved from more concrete codes to conceptual themes and categories that reflected the larger meaning that participants gave their experiences. This stage involved the use of axial coding wherein we used open codes and memos to make connections between categories. Finally, selective coding was used to craft a narrative about how the process of research skill development is given meaning by doctoral students. Both authors reviewed the codes and revised the codebook until reaching a consensus about the central categories (Saldaña, 2013). Through this process, two primary themes emerged for each question: science as technical activities (focusing on data collection and scientific procedure); and science as interpretation (emphasizing meaning and context in the larger field). We coded each dimension (research skill development, strengths and weaknesses) as falling either in the "technical" or "interpretation" category. Following, we classified participants as either technicians or interpreters.

Students in the technical classification (technicians) contained no interpretation codes across any of the dimensions. This means that they were coded as "technical" across all dimensions (research skill development, strengths and weaknesses). The interpreter category included a few students who were coded as interpreters across all three dimensions. The majority (83%) of students in the interpreter category contained both technical and interpretation codes across the three dimensions examined.

Technicians focused on collecting data, technical and methodological procedures and empirically carrying out their research. Interpreters engaged in technical activities as well, but they also discussed the meaning of their research and its relationship to the greater disciplinary field of knowledge. Based on our analytical logic, the coding scheme reflects more of a continuum than a binary. Interpreters were also procedurally proficient, but their perceptions of the research process extended beyond technical execution toward understanding the broader context and scientific implications of data. To protect the identities of the participants, we use pseudonyms throughout our discussion of the interviews and do not disclose participants' institutions.

Trustworthiness and positionality

By engaging in a constant comparative approach to data analysis, our codebook captured emergent findings and reinforced consistency in core themes. The initial codebook was generated collaboratively, and we followed peer debriefing protocol in making sense of the data through critical discussion of interpretation (Carspecken, 1996). To ensure trustworthiness, the first author coded all transcripts independently and wrote detailed analytic memos (Saldaña, 2013) focusing on specific excerpts, patterns and themes across the narratives. Memos were then shared with the second author for review and critical discussion. Qualitative research analysis has been characterized as a "dialogic collaborative process" (Paulus *et al.*, 2008) that involves substantial interaction between researchers (Creswell and Creswell, 2018). Collaborative dialogue was vital in establishing rigor and transparency throughout the analysis, and key findings were shaped through ongoing conversations grounded in the data. In addition to these steps, another researcher who is not an author on the paper coded 25% of the transcripts. The intercoder reliability was 90%, which meets the common standard used in the field (Barber and Walczak, 2009; O'Connor and Joffe, 2020).

In any endeavor of knowledge creation, researchers' subjectivities play a meaningful role across each stage of the study. Because interviews for this study were part of a larger project, the authors did not collect the interview data. Interviews were conducted over the

phone by researchers who identified as a white woman and an African American woman. The authors of this manuscript identify as a white man and a white woman. In addition, the authors hold advanced degrees in sociology and higher education. Thus, we are positioned as cultural outsiders in the context of natural sciences and bring a social scientific lens to bear on these environments.

Limitations

While this study makes important contributions to research on doctoral education, there are a few limitations worth noting. First, it is important to acknowledge the limitations of interview data at one point in time. While this approach provides a valuable window into the lived experiences of the students in this study midway through their programs, it does not reveal how these patterns may evolve over time. In future research, it would be especially valuable to explore how students' understanding of skill development and the patterns of inequality may change over time.

In addition, this study is focused on a specific discipline. While our results in the biological sciences may be more generalizable to experiences in similar STEM doctoral programs with lab settings, future studies are needed to examine how students' understandings of their research skill development vary across different disciplinary contexts, including the social sciences and humanities.

Findings

Data analysis revealed two distinct ways of practicing science that reflect significant differences in how students develop research skills and knowledge as emerging researchers. The first group, representing 60% of the overall sample, which we term "technicians," practiced science by focusing on discrete task execution, mastering specific techniques and collecting data. Conversely, the second group, which we call "interpreters," practiced science more like a scholar or a principal investigator (PI) would: they engaged the larger context of scientific knowledge creation by considering interpretation and meaning of their data, as well as contribution to the discipline.

Technicians and interpreters not only differed markedly from each other in their practice of science but also revealed notable inequalities across race/ethnicity and gender. White men were greatly overrepresented in the interpreter category, whereas white women and students from marginalized racial/ethnic groups were over-represented among the technicians. More specifically, 72% of white men were interpreters, compared to only 31% of white women and 33% of students from minoritized racial/ethnic groups (Table 1).

Technicians and skill mastery

The experience of technicians was defined by an intense focus on the production of data through task mastery and technical skills. For technicians, being a scientist involved the increasingly more efficient performance of technical skills that signify proficiency. While

Table 1. Distribution of participants across analytical categories

Sociodemographic group	Interpreter (%)	Technician (%)
Minoritized racial/ethnic groups	33	67
White women	31	69
White men	72	28

Source: Created by authors

producing data is a vital scientific skill, technicians did not make explicit connections between their data and the importance to the field.

Research skills and knowledge. Technicians understood the research process as the efficient execution of techniques. They focused on disciplinary technical expertise, efficiency and the production of data. When asked what research-related skills and knowledge she had developed over the past three years in her doctoral program, Ashley, a white woman, explained, "I have developed a lot of technical lab skills. I have also been analyzing some deep sequencing data. With that, I've developed a lot of bio and grammatic tools." A focus on expertise-oriented language and specialization was echoed in the responses of many technicians. Technicians understood their development as researchers in an empirical fashion that emphasized technical mastery. Aaron, an African American man, noted the following when asked about his research skill development:

> I've learned how to do a lot of new techniques for my project. I learned how to do chemistry [. . .] and a lot of new techniques for PCR and computation analysis as well.

Technicians centered their skill and knowledge development around learning and mastering particular methodologies rooted in disciplinary expectations. In this sense, technicians understood being a scientist as executing discrete mechanical tasks with enhanced precision and confidence. When asked about her development as a researcher so far, Claire, a white woman, focused solely on conducting basic routines in the lab, "A lot of statistics and data analysis I would say. During my first two years I got pretty comfortable just doing the basic lab procedures that we do every day." In a similar fashion, Justin, a white man, discussed how his development had centered on perfecting the same technical skills over and over again: "I would say I'm doing a lot of the same techniques in lab. I would probably say overall, I'm improving in them, just more practice." Technicians often emphasized the repetitive nature of learning and relearning how to perform their technical craft more effectively. Doing was made more effective over time, as students engaged in a seemingly endless flow of task-based behaviors. At times, doing lab tasks in repetition seemed to overwhelm everything else. As Aaron further explained: "I just keep doing repetitions and keep doing everything to [. . .] try to learn it." Chase, a Latinx man, reinforced this perspective when commenting, "science is just repeat, repeat, repeat."

Technicians understood the practice of science as the production of data and efficient mastery of procedure above all else. They framed their development as researchers through empirical skills with little attention to the larger scientific process.

Perceived strengths and weaknesses. When asked about their strengths as researchers, technicians routinely emphasized technical ability and characteristics that allowed them to execute tasks. They stressed uniformity and consistency in the performance of specialized skills. Mary, a white woman, elaborated on these themes:

> I think one of my biggest strengths is that I'm very technically capable. I have a lot of research experience, as I mentioned, and that has given me the foundation to be able to very reliably do experiments, and very complicated experiments, and do them well.

Here, technicians emphasized their confidence in reliably generating data with precision. Similar to their descriptions of skills and knowledge, responses stressed the value of tangible practices that relied on disciplinary expertise. Students often highlighted the value of consistency and repetition in their strength as a researcher. As Victoria, a white woman, said: "I'm extremely detail oriented. I always make sure that whatever I'm doing, I do to the best of my ability and make sure that I really think things through and perform the protocols the same way."

Technicians emphasized concrete procedures such as data collection and research design, with little engagement beyond procedural prowess. They focused on the performance of scientific practices to produce and manage data. Tyler, who identified as an African American, American Indian and white man, focused heavily on data collection as his primary strength, "I think my strengths would be data collection and analysis. I'm really good at actually collecting data." The designing of experiments was another common topic of discussion among the technicians. As Diana, an African American woman, related when asked about her strengths as a researcher:

> [. . .] being able to design experiments and choose the right application for those experiments and answer the questions that I ask. Figure out which assays [scientific procedure in biology], what's best, I think that has been a great strength for me thus far.

Diana's response is typical of technicians, whose understandings of personal strengths focused on concrete actions and scientific procedures.

Perceived weaknesses revealed similar patterns of understanding. When discussing weaknesses, technicians routinely reflected on gaps in their sub-disciplinary expertise, talking in length about increasingly specialized aspects of biological science. David, a Latinx man, talked about not feeling comfortable with a specific procedure because of his lack of knowledge:

> I didn't do physics in my undergrad or my grad program. When it comes to electrospinning, it's a lot of reading and intuition and hoping things go right [. . .] my limitation is my lack of knowledge in certain areas.

The specialized nature of disciplinary research skill development was notable in its singular focus. Technicians defined their value as researchers through the routine execution of discrete tasks. When asked about her weaknesses as a researcher, Amber, a white woman, noted: "One of my weaknesses and something I've really been trying to work on is a lot of my bio-informatics knowledge." Amber distilled her research development goals even further than a set of technical practices to focus on a single, more specialized skill. Others echoed a similar language of technical skill proficiency when speaking about their weaknesses. Casey, an African American man, quickly identified technical skill mastery as his most important area for improvement, noting:

> I would definitely say I'm not as good at some of the technical skills in our field [. . .] I think that's definitely something that I'm working to become more technically proficient.

The graduate students in the study all worked in research labs and technicians often expressed the tension of meeting lab expectations in light of their previous research experience and training. At times this tension spilled over in discussing weaknesses, where technicians relayed the importance of having to become fast experts in specialized techniques. When asked about her weaknesses as a researcher, Brooke, a white woman, said:

> [. . .] my previous experience working in a research lab, I never had any exposure to programming. In that sense, I'm kind of starting from ground zero. It's like learning a new language [. . .] that's also why I haven't started to analyze my own data that I'm collecting, because I just don't know how to yet.

Across all of the questions addressing their research development, technicians focused on technical capability that dominated their conceptions of the research process.

Interpreters and the larger field

The second group of students, which we term interpreters, practiced and understood science in more expansive ways. Interpreters understood the practice of science as a combination of

task completion and interpretation – i.e. framing their data within the larger field of science. Interpreters paired skill mastery with ways of thinking that imbued data with meaning and context.

Research skills and knowledge. Interpreters understood the research process in ways that stressed conceptual context beyond technical skills. Interpreters fused technical skills with qualitative aspects of scientific practice that imbued data with additional meaning. Interpreters talked about the discretionary aspects of knowledge production such as creative thinking, idea generation, analysis, judgment and how their results fit within the bigger picture of the scientific enterprise. When discussing their development as researchers, interpreters often stressed the importance of understanding the larger scientific process implicated in conducting research. Eric, a white man, described the value of this knowledge when outlining his own development in graduate school, noting: "I came to grad school more to acquire skills and learn the scientific process and to become an expert in that."

At times interpreters made direct connections between the broader disciplinary narrative and theory development. When asked about developing skills and knowledge, Mark, a white man, shared this perspective:

> [. . .] how to connect the dots and put together what the current, broader literature is saying about a particular aspect that I'm studying [. . .] you realize what's feasible and what's easily approachable and testable with the current limits of science.

Mark echoed the language of other interpreters, highlighting important components of the larger scientific enterprise that shapes individual research. When asked what research related skills and knowledge she had developed over the past three years in her doctoral program, Megan, a white woman, noted:

> This last year, well, I did a lot of idea development [. . .] I spent a lot of time trying to see how my ideas fit into the literature and what was novel about my ideas and what wasn't.

Megan's conception of research skills and knowledge is multifaceted and includes attention to the meaning of data for the larger field.

Interpreters often described the importance of learning how their data could tell a story for the greater community of scholars. As Helen, a white woman, explained when discussing her development over time, she has learned to move beyond doing experiments "without clear purpose" to the ability to recognize how data relates to the larger field:

> We're more developing skills and trying to get the project to a point where it's publishable. I'm thinking more in terms of, "What can I do now to make this a part of my publishable story?," instead of just getting experiments done.

Interpreters used language in a more conceptual fashion than technicians, and their responses highlight notable differences in perceptions of the research process. While technicians emphasized detail, precision, routine and specificity, interpreters tended to speak about larger contexts, scientific generalities and narrative arcs across time. Theresa, a Latinx woman, honed in on the value of learning what we do not know based on previous research:

> After going through all the literature, being able to recognize what we don't know and what we need more work on and why it's important, I think is also an important thing to be able to do.

As a whole, interpreters contextualized the products of science through an awareness of the larger field that gave data importance. For interpreters, the research process included the ability to identify how data contributed to a wider scientific conversation.

Perceived strengths and weaknesses. When discussing their strengths as researchers, interpreters talked about understanding the bigger picture of science as a vital aspect of their development. As Matt, a white man, noted:

> A strength of mine, I think, would be seeing the bigger picture a little bit more. Not getting stuck down in the details or the specifics of the data, but looking more so at the bigger story.

William, another white man, expressed how the practice of science involves a connection between doing scientific procedure and understanding the larger context: "I would probably say knowing the field fairly well and being able to design experiments in an intelligent way using that knowledge." When talking about her strengths as a researcher, Cynthia, who identified as a Latinx and white woman, stressed the analytical and discretionary aspects of research skill development, noting: "My strengths are in creative thinking, in reasoning, and putting clues from the literature together."

Jake, a white man, spoke in length about science on a grand scale that involves the interconnection of disciplinary ideas. When asked about his strengths as a researcher, he emphasized the value of synthesizing knowledge across multiple fields to make novel contributions to science as a whole, saying, "I think my biggest strength would probably be combining fields, combining ideas, making connections that other people would never think of."

Jake's language is typical of interpreters, who understood scientific practice as an endeavor that requires a combination of technical and conceptual mastery.

Interpreters maintained similar language when discussing their weaknesses. They were aware that research involved more than technical skills but expressed a lack of confidence in their ability to think through the larger context. When asked about her weaknesses as a researcher, Emily, a white woman, noted: "I still have problems coming up, I would say, with big-picture future directions for a project." Students sometimes framed grasping the "big picture" as an obstacle to finishing their graduate programs. As Greg, a white man, explained when discussing his weaknesses as a researcher:

> I'd say that sort of big picture, asking – trying to figure out what are the right questions to ask. It's probably something that I definitely feel like I struggle with. It has [. . .] even backed up my Ph.D. career.

While technicians consistently emphasized the value of increasing specialization, interpreters reflected on the dangers of scientific tunnel vision. They emphasized cultivating disciplinary skills without losing sight of the grander narrative that shapes the research process, or as Katrina, who identified as a Latinx and white woman put it, of "being able to summarize everything." Interpreters often noted the importance of understanding the literature to fit their work into meaningful scientific context. From their perspective as emerging researchers, a command of the literature enabled them to give data meaning. Tim, a white man, reflected on his constant struggle to keep up with new academic knowledge in the field: "One weakness is just not knowing the full breadth of my field yet, so I always feel like I'm coming into something that I'm not an expert on yet, but being expected to operate at expert level."

Discussion

While research skill development is critical for development of scholarly identity (Burt, 2019) and transitioning from novice to independent researchers (Austin and McDaniels, 2006; Golde, 2006), few studies have examined how the research skill development process may vary by race/ethnicity and gender. Based on interviews with 87 students enrolled in biological science PhD programs, we find that doctoral students develop research skills unevenly, revealing notable inequalities. White men are substantially overrepresented in the

interpreter category, in which students interpreters contextualize their research within the larger field of inquiry. In contrast, women and students from minoritized racial/ethnic groups are concentrated in the technician category. Technicians tend to focus on data production without attention to the larger field, often attending primarily to executing specialized tasks.

These findings indicate that certain aspects of the graduate student socialization process are not uniform experiences, and that doctoral education can foster different kinds of scientific learning that vary by gender and race/ethnicity. Doctoral education supports different kinds of research skill development including both concrete technical knowledge and more abstract and contextual thinking (Bryan and Guccione, 2018; Mowbray and Halse, 2010). Presented findings reveal inconsistencies in research skill development that help doctoral students situate their work in the larger field. Historically, the socialization literature has not given sufficient attention to the role of inequality in the transmission of skills, values and dispositions (Twale *et al.*, 2016). With traditional socialization models primarily reflecting a process in which students assimilate into the culture of their graduate programs, scholars have not always adequately captured the experiences of women and students from minoritized racial/ethnic groups. Our findings contribute to the more recent literature illuminating how graduate student socialization involves a critical interplay between structures and student identities (Weidman and DeAngelo, 2020).

While our study reveals inequitable patterns of research skill development, it is not designed to explain them. Prior literature, however, describes how socialization is mediated by racialized and gendered structures that have significant impacts on the experiences of diverse graduate students (McCoy *et al.*, 2017; Ramirez, 2017; Williams *et al.*, 2018). In particular, experiences with advisors may be a crucial site in the cultivation of unequal socialization outcomes, including research skill development. Advising relationships play a powerful role in doctoral student experiences and supporting emerging scholarly identities (Barnard, and Shultz, 2020; Curtin *et al.*, 2016; Lechuga, 2011; Wofford *et al.*, 2021), and prior research demonstrates that gender and race mediate doctoral student advising relationships (Griffin, 2020; Noy and Ray, 2012).

Presented findings also may have important implications for inequality in scholarly career paths. Previous research indicates that faculty tend to value more interpretive skills such as independent thinking and creativity among their doctoral students (Lechuga, 2011), and students from diverse backgrounds may be less aware that developing these kinds of skills is part of graduate training (Wofford *et al.*, 2021). Tenure-track academic faculty emphasize the kind of "bigger picture" knowledge that is more typical of interpreters as these skills are valued among future professors in the academic workplace. Alignment between interpreter orientations and faculty expectations could have notable implications for raced and gendered differences in career outcomes. With white males disproportionately represented in the interpreter category, they are likely to be best positioned for faculty positions, further reinforcing and reproducing systemic inequalities among the professoriate.

Implications for practice

Our findings indicate that graduate programs are cultivating different versions of scientific practice that vary by race and gender, which raises important concerns about equity in science. College learning environments have historically served as spaces of exclusion (McGee, 2020), and graduate students from all backgrounds should be actively supported in developing robust research skills. Administrative leaders and faculty in graduate programs would benefit from integrating unwritten disciplinary expectations into learning opportunities for graduate students such as the publishing process, professional practices in the field and academic writing for a specific disciplinary community. In particular, they need to prioritize the explicit teaching of interpretative skills throughout the program. This could include implementing required workshops or courses that

better prepare students to think more like scholars as part of their research development – with a deliberate focus on moving beyond the technical aspects of scientific work. It could also mean urging faculty to make different types of skills explicit throughout the curriculum. In addition, graduate mentor training could emphasize the importance of developing interpretive and contextual thinking skills in working with doctoral students on their research projects. Instead of assuming that students will "get it" through observation, mentors could explicitly teach interpretive skills. These endeavors could be buttressed by summer bridge programs for students historically excluded from STEM that demystify academic science and explicitly discuss different forms of skills and knowledge needed to excel in an academic context (Winkle-Wagner *et al.*, 2020).

In addition, faculty mentors have the crucial responsibility of nurturing the next generation of scholars. While faculty may have benign intentions, mentoring is still subject to implicit race and gender-based discriminatory practices that may result in disempowering scholarly identity for women and students from minoritized groups (McCoy *et al.*, 2015). Faculty mentors must actively empower women and minoritized students to see themselves as scholars. Minoritized doctoral students in STEM may be especially likely to benefit from research-based community practice opportunities and a sense of care in their advising relationships that promotes deeper personal connections (Griffin *et al.*, 2020). By training faculty advisors to be more intentional in cultivating interpretive contextual thinking skills for all students, graduate programs can help disrupt patterns of inequality in skill development. Mentors cannot only provide doctoral students with opportunities to engage in the discrete practice of scientific data production; they need to be intentional about encouraging the type of conceptual thinking required to interpret data's meaning in the larger scientific field.

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