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Autonomy and Privilege in Doctoral Education: An Analysis of STEM Students' Academic and Professional Trajectories

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ABSTRACT

Guided by theories of socialization and possible selves, this study examines how STEM doctoral students perceive their academic and professional trajectories. More specifically, we rely on four years of interview data from 66 doctoral students in the biological sciences to explore students' perceived trajectories, focusing on the salient identities and experiences that shape the way students identify and describe their graduate experiences over time. Findings reveal wide variation in terms of how students described their trajectories, with some students describing linear trajectories and/or unchanging career interests, while others described their developmental trajectories as highly turbulent and non-linear. These perceived trajectories were largely shaped by student-advisor interactions, the value students placed on becoming "independent" scientists, and the privilege students brought with them to their graduate programs.

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A central goal of doctoral education in science, technology, engineering, and mathematics (STEM) is providing robust training for future researchers and professional scientists (Barnard & Shultz, 2019), which is critical to the advancement of knowledge and fulfillment of workforce demands (National Science Board, 2015). On average, U.S. doctoral students in STEM programs spend nearly six years pursuing their Ph.D. (National Center for Science and Engineering Statistics, 2019), during which individuals are expected to acquire specialized knowledge to facilitate entry into the scientific workforce. However, few empirical studies have examined doctoral student skill acquisition and career pathways (e.g., Mantai, 2017).

One widely held belief about doctoral student development is that students' research skills improve throughout their training, largely as a result of faculty mentorship (Austin & McDaniels, 2006). In many STEM disciplines, the laboratory setting is a formative influence, providing funding to work on

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research, a community of disciplinary peers, and access to developmental opportunities where students can improve their skills (Maher et al., 2020). Yet, longitudinal studies suggest that only a third of STEM doctoral students improve their research skills consistently throughout their training (Feldon et al., 2019). Others have found that STEM doctoral students' commitment to a research career at the end of their program is largely a product of their incoming commitment (Paglis et al., 2006) and that faculty mentors play little role in shaping students' professional aspirations (Gibbs et al., 2015). Collectively, research findings are inconsistent with frequent assumptions about student development, suggesting a need for further inquiry.

We examine how students construct meaning of their training experiences and professional development, providing new insight into doctoral student trajectories, theories of graduate training, and inequities therein. Specifically, we analyzed longitudinal interview data from 66 STEM doctoral students to explore the following:

(1) How do STEM doctoral students make meaning of their academic and professional trajectories?
(2) What are the salient social identities and experiences that shape students' perceptions of their academic and professional trajectories?

Theoretical perspectives and relevant literature

We frame our study at the intersection of graduate socialization (Weidman & DeAngelo, 2020) and possible selves (Markus & Nurius, 1986). Socialization has long been the dominant framework for the study of doctoral education in the United States (Gardner, 2008) and entails "a process of internalizing the expectations, standards, and norms of a given [discipline], which includes learning the relevant skills, knowledge, habits, attitudes, and values of the group that one is joining" (Austin & McDaniels, 2006, p. 400). To further guide our inquiry, we introduce research on possible selves, which reflects "how individuals think about their potential and about their future. Possible selves are the ... manifestation of enduring goals, aspirations, motives, fears, and threats [and] provide the specific self-relevant form, meaning, organization, and direction to these dynamics" (Markus & Nurius, 1986, p. 954). Below, we discuss key literature on STEM doctoral socialization, how possible selves can frame our understanding of student trajectories, and larger contexts informing doctoral student experiences.

STEM doctoral student socialization

Graduate socialization conceptualizes doctoral student development as occurring in four stages: anticipatory, formal (i.e., coursework), informal (i.e., supervised research and mentorship from advisors), and personal (i.e., seeing oneself as an independent scholar) (Weidman & DeAngelo, 2020). This framework provided a lens for our exploration of how students made meaning of their trajectories at each stage of training. Historically, STEM doctoral socialization has been understood through a cognitive apprenticeship model, where students advance through their training stages by gaining skills from their principal investigator (PI) who often serves as the faculty advisor (Maher et al., 2013). Such apprenticeship relationships may be complicated, as faculty and institutions often prioritize training future academics (Thiry et al., 2015), despite students following increasingly diverse career pathways (Austin, 2010). Therefore, studies of doctoral training must recognize the importance of interactions with peers and others, as well as the agency students yield when navigating these dynamics (Portnoi et al., 2015).

Indeed, recent research reveals the importance of relationships with peers and other labmates. For example, postdocs and other senior research staff may influence how doctoral students learn day-to-day scientific activities (Blaney et al., 2020; Feldon et al., 2019). St. Clair et al. (2019) found that students who discussed their career interests with their peers were more likely to actively seek career development opportunities. While research groups are a prime environment in which support systems form, not all relationships are positive, and negative encounters can disrupt students' trajectories (e.g., Wofford & Blaney, 2021). Collectively, applications of graduate socialization theory document the role of advisors, peers, and labmates as key socialization agents.

Other research highlights the role of identities, particularly gender, race, and first-generation college status (e.g., Sallee, 2011; Wofford et al., 2021). Notably, inequities prior to graduate training, such as discrepant rates of access to undergraduate research training, can lead to a cumulative advantage and increased opportunities for students from more privileged backgrounds (Gardner & Holley, 2011; Gopaul, 2019). During graduate training, racial microaggressions and discrimination in advising can create additional challenges as Students of Color work toward attaining their degrees (Hayes & Bigler, 2013). Further, early career scholars from historically minoritized groups often report disadvantages in their efforts to access professionally beneficial social networks (Winkle-Wagner & McCoy, 2016; Xu & Martin, 2011). This may partially explain why Gibbs et al. (2014) found that women and students from Black, Latina/o/x, and Indigenous groups in biomedical sciences

were more likely than other students to lose interest in academic careers over the course of their doctoral training. In light of this, it is important for research on graduate student trajectories to consider students' social identities and larger systems of inequity.

Possible selves as a reflection of students' doctoral experiences and academic structures

While we began our work with a socialization framing, we looked to Markus and Nurius's (1986) concept of possible selves, which offered a unified way to explore how one's self-knowledge of past behaviors and new possibilities are carried forward into future decisions. As Markus and Nurius put it, "possible selves have the potential to reveal the inventive and constructive nature of the self," while also revealing how "the self is socially determined and constrained" (p. 954). While socialization theory frames the anticipatory stage as the primary locus of envisioning potential future engagement with scholarly activity, the concept of possible selves emphasizes the importance of recognizing ongoing and dynamic construction of future pursuits. Accordingly, students' experiences and interactions with their training environments can fundamentally shape their understandings of who they are and aspire to be.

Understanding possible selves as they develop within larger societal structures is vital, as environments may not always support one's imagined possible selves. Most critically, we recognize that systems of power (e.g., racism, sexism, classism) often influence students' beliefs about their (im)possible paths in higher education. Further, the imposition of problematic academic structures and violations of trust can hinder doctoral students from successfully envisioning their future selves in academia (Williams et al., 2018). For example, unjust academic labor practices common in STEM doctoral training can shape students' visions of possible selves and the extent to which they can see themselves pursuing academic careers (Cantwell, 2015; Wofford & Blaney, 2021).

Positionality

Before presenting our research design, it is crucial to discuss how our positionalities shape the current study in ways that we may or may not be aware. Collectively, the authors include two white women, two Women of Color, and a white man. The authors have expertise in higher education, educational psychology, and learning sciences and occupy varied roles in terms of rank and positionality at our respective institutions, ranging from postdoctoral scholar to assistant and full professor. This is relevant to our focus on graduate student trajectories, as we each participate in graduate training in different ways. All authors are disciplinary outsiders to the biological sciences, which may have

shaped the nature of participants' stories during interviews. As the team member with primary responsibility for the integration of codes into themes, the first author's perspectives and experiences may be particularly salient to the research. Having completed her Ph.D. in 2018 and currently serving as an assistant professor, she has recently navigated student, postdoctoral, and faculty roles, which have sensitized her to how facets of her doctoral training have both expanded and constrained conceptions of her own possible selves.

Research design

We sought to explore how doctoral students understand their academic and professional trajectories. To that end, we engaged a general qualitative design (Percy et al., 2015; Saldaña, 2016), in which we employed a phased analytical approach using semi-structured interviews. We were guided by a critical constructivist approach (Kincheloe, 2005), which informed our focus on doctoral students' constructed understandings of their trajectories and allowed us to engage with the interplay between students' experiences, their social identities, and systems of power. This perspective guided our focus on individual agency within a broader understanding of doctoral socialization and systems of power in academia and society. Additionally, our critical constructivist approach informed how we engaged our positionalities as researchers, our data collection and analytical approach, and the presentation of findings.

Sample

We selected participants for this study from a larger survey sample of 336 doctoral students in the biological sciences, using maximum variation sampling to capture heterogeneity in terms of gender, race/ethnicity, and first-generation college status (Maxwell, 2013). Participants self-reported these characteristics on the surveys, and groups that were underrepresented in the survey sample (i.e., Black, Latina/o/x, Indigenous, and first-generation students) were oversampled to increase their representation among interview participants. This resulted in an analytic sample of $N = 66$ doctoral students across 20 institutions, each of whom began Ph.D. programs in 2014 and were interviewed annually for the first four years of their programs. Among those in the analytic sample, 74% identified as white; 18% as Black or African American; 15% as Latina/o/x; 3% as Asian; 3% as Native American, Pacific Islander, or Alaska Native; and 3% as an "other" racial/ethnic identity.[1] Seventy percent were women and 30% were men.[2] Sixty-four percent self-reported that they were first-generation to college.

Interview data

Annual semi-structured, hour-long interviews included questions asking students to reflect upon their experiences in each year of their doctoral program, particularly in relation to their skill development, professional intentions, and salient experiences within and beyond their programs. We focused our analyses on data from interviews conducted at the end of students' fourth year in their doctoral program, where they reflected upon their graduate training experience over time. Interviews conducted in earlier years were referenced to provide additional context for how we understood fourth year interviews. Notably, the fourth-year protocol included a question asking students to select a word to describe each year of their program before describing why each word was selected. Guided by socialization theory, probing questions asked about advisors, peers, and other labmates.

Analytical procedures

Data were analyzed thematically to identify patterns in how students described their training experiences and trajectories (see Figure 1). In the first phase of analysis, two members of the research team used open coding (Saldaña, 2016) to inductively construct themes, relying on a subsample of 15 randomly selected participants. The research team met to discuss emergent findings and interpretations, and we developed a codebook of themes, definitions, and example codes, carefully attending to themes related to socializing agents, social identities, meaning making, and power dynamics. Next, two members of the research team used the codebook to independently code data from an additional subset of seven participants before meeting to confirm acceptable levels of agreement and make minor clarifications to the codebook. In the last phase, the authors divided and deductively coded remaining data using the

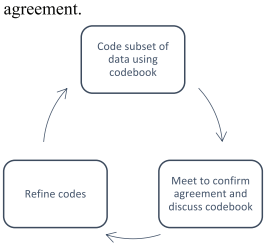
Phase One		Phase Two	
Step 1: Inductively Code Subset of Data	**Step 2: Establish Trustworthiness of Codebook**	**Step 3: Deductively Code Remaining Data**	**Step 4: Review All Coded Data**
Two researchers independently coded a subset (*n*=15) of participant data to identify emergent themes and corresponding definitions and sample codes.	Two researchers used codebook to independently code an additional subset (*n*=7) of participant data before meeting to confirm agreement. 	Remaining data were divided among researchers and deductively analyzed, guided by the codebook.	The first author reviewed all coded data to identify larger patterns in how themes emerged and co-occurred among all *N*=66 participants. Key quotes exemplifying emergent themes were identified.

Figure 1. Overview of data analysis process.

codebook. The first author then reviewed all coded excerpts of the interviews to provide a richer interpretation of each theme. Finally, participant quotations that exemplified the themes were organized and selected for inclusion in this paper. To add precision to the presentation of results, we share the number and/or proportion of students who expressed each theme, though this information should not be used to draw inferences about the importance of themes. To further ensure trustworthiness, we offer counter-examples to themes as they emerged in our data.

In our analysis, possible selves informed our understanding of how themes co-occurred and were mutually reinforcing. More specifically, we applied a lens of possible selves to understand ways in which participants with clearly defined possible selves may have been less likely to change their career goals due to roadblocks encountered during graduate training (see Pizzolato, 2007). Conversely, the extent to which students' ultimate career plans and trajectories were impacted by turbulence in their programs may be informed by the (im)possible selves that they brought to their programs. Thus, possible selves provided a useful tool for examining how themes related to perceived trajectories and doctoral training experiences co-occurred for individual participants. Further, we would expect that the backgrounds and social identities that students bring to doctoral study would be tied to their incoming possible selves (Markus & Nurius, 1986; Pizzolato, 2007). Therefore, possible selves guided our analysis and interrogation of social identities, which we discuss as part of each theme.

Findings

We present themes for each research question before introducing two larger meta-themes related to 1) how participants valued and understood autonomy and 2) how inequities by gender, race/ethnicity, and first-generation college status shaped participants' experiences. We include information about students' social identities to contextualize findings, noting how certain themes occurred for women, Students of Color, and first-generation college students; these details provide only a first look into inequities in training experiences. While we present each theme separately, possible selves and socialization theory guided our interest in the larger ways that students made meaning of their experiences. This is captured, in part, by Table 1, which summarizes patterns in how themes co-occurred for selected participants quoted in the findings that follow.

Table 1. Profiles of participants quoted in findings.

Name	Academic Trajectory	Professional Trajectory	Autonomy	Influences	Race	Gender	FG Status
Aaron	Linear	Unchanging	High	Support from advisor and other faculty	White	Man	No
Evan	Linear	Unchanging	High	Support from faculty; external opportunities; parents are scientists	White	Man	No
Amelia	Linear	Unchanging	High	Support from advisor, other faculty, and peers; "privileged upbringing"	White	Woman	No
Lorenzo	Linear	Unchanging	N/A	Support from advisor and peers	Latino	Man	No
Marie	Linear	Unchanging	Moderate	Support from advisor, other faculty, and peers; external opportunities	White	Woman	No
Brayden	Linear	Changing	High	Support from advisor, other faculty, and peers; external opportunities	White	Man	No
Anthony	Linear	Changing	High	Support from advisor	White	Man	No
Colt	Linear	Changing	High	Support from faculty; external opportunities	White	Man	No
Aaliyah	Linear	Changing	High	Support from advisor	Latina	Woman	Yes
Adrian	Non-linear	Unchanging	High	Challenging but supportive advisor; external opportunities	Other	Man	Yes
Addison	Non-linear	Unchanging	High	Support from advisor, other faculty, and peers	White	Woman	Yes
Ana	Non-linear	Changing	High	Support from advisor and from "female friends"	Latina/White	Woman	No
Jane	Non-linear	Changing	High	Support from advisor and other faculty	Black	Woman	No
Aiden	Non-linear	Changing	High	Support from advisor, other faculty, and peers; "socioeconomic privilege"	White	Man	No
Elaine	Non-linear	Changing	N/A	Support from advisor and peers	Black/White	Woman	Yes
Ava	Non-linear	Changing	Low	Discrimination from advisor; very supportive peers	Indigenous/White	Woman	Yes
Antonia	Non-linear	Changing	Low	Hostile experiences with advisor	Latina/White	Woman	No

FG = first-generation college student. Perceived autonomy refers to students' perception of themselves as autonomous in their fourth year in the program. N/A indicates that the student did not discuss corresponding theme. This table includes the 17 participants who were quoted in the findings presented in this paper. All 66 interview participants remain in the analysis.

Research question one: Variation in perceived trajectories

The first research question concerned how doctoral students understood their trajectories. We found wide variation in the nature of how students described their experiences, particularly in terms of the extent to which they viewed their development as (non)linear and career interests as (un)changing. We discuss themes that capture this variation, focusing on skill development and professional trajectories. Finally, we discuss how students frequently viewed their trajectories as atypical.

Perceived turbulence in skill development

Nearly half of participants described a developmental trajectory characterized by challenges and obstacles (n = 31).[3] The nature of this perceived turbulence varied widely, with students who experienced interpersonal conflicts with advisors typically expressing the most distress. For example, Ava, a first-generation college student and multiracial Woman of Color, described how, beginning in her second year, she became increasingly frustrated with her advisor's criticism, explaining how he "was critical without being constructive . . . he made me postpone my oral defense another couple of months." For Ava, postponing her defense created a sense that she had regressed in her program. Later, she experienced increased turbulence when she unsuccessfully tried to change labs, before eventually mending the relationship with her advisor. While Ava's experience may seem particularly tumultuous, it is representative of many students who described challenges due to poor relationships with their advisors.

Other students describing non-linear trajectories felt that their development "stalled" for a year or more. Sometimes this was due to specific challenges in the lab that led students to feel like they were "spinning wheels," as Aiden, a white man with college-educated parents, put it. Other times, students simply felt that their day-to-day experiences had become "tedious." This was true for Jane, a Black woman with college-educated parents, who described her fourth year:

> Things are much the same, day in and day out, and there's a little bit less variety or change in the day to day as there might have been back in the third or certainly first years . . . I'm just sort of technically competent in the things that I'm working on . . . it feels like a plateau.

For Jane, the first few years of her program were characterized by increasingly gaining skills and proficiency. However, by the time her fourth year came, she felt that she had "plateaued" and had few opportunities to make autonomous choices in the lab. Similar to Jane, many other participants valued autonomy and independence, something that emerged more clearly among students who described linear pathways below.

Perceived linear developmental pathways

Some students (n = 26) described a linear developmental trajectory, in which they gained skills with each passing year. These students tended to focus on how the first year was characterized by "learning and coursework" and the "adjustment" to graduate school. The second year was characterized by further "exploration of interests." In contrast, these students typically described their third year as the time they began "focusing" or "narrowing" their interests. Finally, year four was when they began identifying as an "independent scientist." As Aaron, a white man with college-educated parents, explained of his fourth year:

> I was able to . . . come up with my own projects that worked out, that were not things that my boss asked me to work on . . . they were my own independent ideas . . . It was like, "Okay. Well how can I contribute in a way that only I can?"

Aaron's perceptions of his development were largely defined in terms of his ability to gain autonomy, learning how to make unique contributions in a collaborative environment—something that was made possible by the privileges he brought with him (e.g., access to knowledge about graduate training, a high level of confidence in his academic abilities and potential), coupled with a particularly positive relationship with his advisor. This is consistent with some other students, such as Anthony, another white man with college-educated parents, who characterized his first year by his transition and adjustment to the program, his second year as "honing" his research interests, and his third and fourth years by "independence" and "productivity," respectively. It is important to note that men disproportionately described their experience as linear and focused their narratives largely around their emerging identity as an "independent" scientist.

These linear pathways manifested somewhat differently for women. When asked to provide a word or phrase to describe each year in her program, Marie, a white woman with college-educated parents, described her trajectory:

> It's kind of hard to describe the second year, because that was really the first year in my lab full time and just kind of making some headway with my projects . . . my third, I would say is more making progress . . . Then, I would say for this year, my fourth year, I would say "data." I guess because I finally have been getting some really good data, starting to think of how we're going to put that into my first-author paper.

Throughout her interview, Marie described a linear pathway where she felt increasingly confident in her ability to be productive in her lab. However, in contrast to Aaron and Anthony, Marie focused her discussion more closely around her work, using the word "data" to describe her fourth year. In comparison, men tended to use words like "independent" to describe

themselves as they progressed in their programs. While similar patterns were not apparent by race/ethnicity or first-generation status, this could be due to the lack of diversity in our sample.

Changing career plans

Approximately two-thirds of doctoral students (n = 41) had evolving career interests, to varying degrees. Some entered the program uncertain of their career goals, making it difficult to identify professional development opportunities that would be worthwhile. Aaliyah—a Latina first-generation college student who later developed tentative plans to become a faculty member—described her uncertainty, saying "when I decided to do my Ph.D., it wasn't because I knew I wanted to be a PI or I knew I wanted to go to industry. I just knew I loved science." Aaliyah went on to explain how she would complete a postdoc, so that she had more time to make decisions about her career. Aaliyah's decision to pursue a postdoc to provide additional time to refine her plans was largely representative of other participants with changing or uncertain career interests.

Other students entered their programs with clear career objectives, but those plans changed over time. Typically, students became deterred from academia after learning more about what academic careers entailed, in terms of work-life balance and an increasingly competitive job market. Ana, a Latina student with college-educated parents, explained how she had "seen a lot of postdocs go into the job markets, from labs around here, and just hearing their stories about interviews, and watching them go through the application process, has been really tough. It looks really miserable."

Changing career goals were also connected to students' perceived autonomy and the extent to which they viewed themselves as making progress toward becoming an "independent scientist." As Antonia, a Latina student with college-educated parents, explained:

> I'm not allowed to pursue [this project] anymore . . . It's like I don't want to have my name on a paper that has done a poor job. It kind of feels like I'm compromising my integrity a little as a scientist, and I guess that's not the way I wanted to start a career . . . if this is the way I have to do science, I just don't want to do science anymore.

Here, Antonia described how her advisor told her that she could not continue a collaborative study and had to write up results based on current findings, despite her feelings that more inquiry was needed. As illustrated by Antonia's comments, students who felt that they had limited autonomy in their research projects tended to feel apathy about their work and were sometimes discouraged from continuing in their program or onto an academic career. This is consistent with prior scholarship on how hostile interactions within academic structures can limit students' ability to view themselves as academics (see Williams et al., 2018).

While changing career interests are not necessarily negative, students who had uncertain and/or changing career interests throughout their program struggled to identify professional development activities and measure their progress, given their uncertain or changing goals. Further, because advisors tended to have expertise exclusively in university settings, students who were deterred from academic careers had an especially difficult time understanding the extent to which they might be prepared for careers in industry. As Colt, a white man with college-educated parents, put it, "professors tend to be biased [against industry careers] and advise you into what works for them." This bias created additional uncertainty on the part of students who were unsure of how to prepare for careers beyond academia.

Unchanging career plans

Nearly one-third of students (n = 21) entered their program with clear career objectives that remained stable over time, which provided a number of privileges. Having unchanging career interests allowed students to be intentional about identifying professional development activities, illustrated by Evan, a white man with college-educated parents, who stated:

> I came in with a pretty clear idea of what I wanted out of grad school and the core experimental lab work is a minority of that experience . . . I knew before I entered grad school that I was interested in . . . industry, so I never had an interest in being an academic scientist.

Evan further explained how he was able to identify career-relevant professional development activities from the start of his program. Early professional development allowed him to connect with more advanced students in his program who were similarly "very focused on a career path outside of academia and having that from an early enough stage [enabled us to] actually be taking actions towards that goal in the middle of grad school."

Fewer students described unchanging career interests in academia. This was true of Lorenzo, a Latino man with college-educated parents, who stated, "I'm still on the same trajectory in my career I started on. I'd like to aim for a tenure-track faculty position [at an] R1." Lorenzo went on to explain how he felt "pretty good about [his] job prospects," having a clear sense of his next steps to advance his career, as well as how many publications he needed before and during his postdoc position in order to be successful on the faculty market. For Lorenzo and others, entering with a clearly defined trajectory and vision for their future served as a source of motivation and informed ongoing meaning-making around their academic and career progress, which aligns with prior literature applying possible selves (see Pizzolato, 2007).

Perceptions of trajectories as atypical

Regardless of how students characterized their trajectories, over half of participants (n = 35) perceived their experience as atypical when asked about the extent to which they felt their experience was similar to that of other students. Amelia, a white woman with college-educated parents, described how her experience was uniquely positive, saying that "a lot of my peers are very jaded . . . I wouldn't say they're as happy as I am. I feel like I have had a more positive experience than most people I'm around." In contrast, others described what they perceived to be unique challenges. For example, Elaine, a multiracial Woman of Color and first-generation college student, explained how she faced challenges due to her advisor being a new faculty member, saying that "across labs, there aren't many friends I know who are also with young PIs" and how, within her lab, she felt that "there might be some more pressure" to be successful and productive. Lorenzo described a similar experience; when discussing how his experience might compare to that of other students, he explained, "They're different. Frankly because I am . . . the first person [my PI] trained. We're learning together . . . The majority of the graduate students are with older PIs." It is notable that many students constructed and made meaning of their graduate school experience as atypical, even when their experiences were largely consistent with other participants in the present study. Notably, each of the participants quoted here holds one or more minoritized identities and may, in part, perceive their experiences as atypical due to the ways in which doctoral education upholds individualism, meritocracy, and other oppressive structures (see Gildersleeve et al., 2011).

Research question two: Identified experiences shaping students' perceived trajectories

The second research question focuses on the experiences that shaped students' trajectories, with findings highlighting the important role of relationships, including advisors, other faculty, peers, and labmates. Additionally, we discuss the role of external experiences and the privilege that students bring with them to their doctoral programs. As we present these findings, we pay careful attention to how students' gender, race/ethnicity, and first-generation status may have shaped the nature of relationships and opportunities.

The importance of advisors

The nature of how students characterized their graduate training experience was largely a product of experiences with their advisors. In some way, all participants discussed the important role of advisor interactions, with experiences ranging from supportive to quite hostile. Many students in our sample

($n = 53$) described support from their advisors, while just over a third ($n = 23$) described negative advisor experiences. Importantly, positive and negative advisor experiences were not mutually exclusive, with 10 students describing both support and hostility, either due the nature of their relationship changing or the actual advisor changing. On the positive end of the spectrum, Anthony, a white man with college-educated parents who described a linear trajectory and unchanging career intentions, explained how his advisor provided him with increasing responsibilities each year:

> I'm the most senior graduate student, and so I know that [my advisor] defers to me, if he wants to discuss plans with someone, or if there's just general things in a lab that need to be taken care of, undergrads to be trained. I think our relationship has developed both professionally and personally over time.

Here, Anthony described taking on increased autonomy and credited his supportive and increasingly collaborative relationship with his advisor as key to his overall development. Some other students described similar relationships with their advisors, though Anthony's experience represents one of the most positive experiences among participants.

While advisors had the ability to affirm students' career interests and provide them with increasing opportunities to develop their skills, other advisors acted as gatekeepers. For example, Antonia—a Latina student with college-educated parents who described a turbulent trajectory, characterized by a lack of autonomy over her work—discussed tense interactions with her advisor:

> I'm having a lot of issues with [my advisor] recently, and he's forcing me to stop working on projects that I thought really had potential. Now he wants to revise this project that my committee decided I should not be working on. I've just had a lot of issues with him lately and I just . . . want to do what it takes to graduate now.

Antonia explained how these negative experiences with her advisor influenced her career interests over time. She was initially motivated by this negative experience with her advisor, saying "just seeing the way he treated people makes me want to become a PI to do it better." Ultimately, however, she was deterred from pursuing an academic career in favor of industry, where she felt that she would be able to find a more supportive work environment. In terms of how she perceived her overall skill development, these tense experiences with her advisor provided her with few opportunities to take on increased leadership in her lab, making her feel "resigned" in her program and her development. Antonia's experience was largely representative of other students who had hostile interactions with their advisors and limited opportunities for development, as a result.

It is important to note that 15% (n = 10) of students in our sample described explicitly discriminatory advising relationships. Ava, a first-generation college student and multiracial Woman of Color, explained how she experienced overt discrimination from her advisor and other faculty, making it difficult to find a mentor. She went on to explain how she needed "to find a mentor who will actually mentor me instead of just condescend to me. There were other things where he showed favoritism, and sexism, and things like that. And I felt like I needed a more positive mentor relationship." While Ava ultimately began to feel "much more confident in [herself] as a scientist and as a leader" over time, she described the path to getting there as tumultuous, as was the case for others who described similar discrimination.

Support from other faculty

Two-thirds of students in the sample (n = 44) described mentoring relationships with faculty beyond their advisor, which shaped their perceived success and trajectories. Sometimes, supportive mentoring relationships with other faculty helped to mitigate negative experiences with advisors. However, it was more frequently the case that students who described support from other faculty received a great deal of support from their advisors. As Aaron, a white man with college-educated parents, explained:

> One of the professors on my committee . . . he's offered me opportunities to work on processing data for some of their results because of things that he thinks I would be helpful with . . . He made recommendations about people to go to. Again, the same thing my boss was doing, and said, "If I need to make a phone call or whatever . . . " He's just been very positive.

Despite having a close and supportive relationship with his own advisor, Aaron received opportunities and sponsorship from other faculty members, particularly one member of his dissertation committee. Again, most students who described support from program faculty members also had particularly supportive advisors. Perhaps having the support of one's advisor made it easier to gain respect and support from other faculty as well. Together, feeling supported by both one's advisor and program faculty made students feel affirmed in their skill development and professional pathways, further enhancing their ability to view themselves as academics.

Support from peers and lab members

In addition to discussions of faculty, most participants (n = 48) discussed the importance of support from peers, postdocs, and other labmates. For example, Ana, a Latina student with college-educated parents who described her academic trajectory as highly turbulent, had "strong female friends, who are two years above me in my program. Most of them just graduated. They've been really important, as a support network for me. There are also a number of

postdocs that have been really helpful . . . " Ana and others noted the importance of looking to peers and more senior students as a way to understand their own experiences, progress, and success in their programs. The ways in which students looked to others to understand their own experience and trajectory is largely consistent with the concept of possible selves, which emphasizes self-conceptions as inherently social (Markus & Nurius, 1986). For example, Ava explained how she and a group of cohort-mates would exchange drafts, which was helpful in building her confidence that she was on track in her program:

> We would exchange our written proposals . . . we were all at the same stage, so it just helped, having different perspectives. And reading those, I felt very confident that . . . I was doing pretty well . . . And so, I felt extremely confident that I was well prepared.

Somewhat similarly, Adrian, a first-generation man[4] who noted that "peers do make or break the experience," explained how social comparisons were helpful in understanding his progress but also led to some distress:

> Recently, I went on a little emotional roller coaster ride with one of my friends. He surprisingly decided that mastering out was in his best interest . . . It makes you kind of question like . . . "why do I still think this is a good opportunity?" I don't know. It just makes you have existential questions, and you always have to back up and be like, "Stop comparing yourself, and stop running the race against anyone else . . . " There's also graduations, which are the normal way to get out, and those give you hope . . . you can make it out of this hell hole.

Here, Adrian described the "existential questions" that arose when he compared his progress to that of other students, particularly students leaving the program. At the same time, watching peers successfully graduate provided another point of reference, as he understood his own trajectory in the program. While most other students did not as explicitly discuss social comparisons, the idea of looking to others to assess their own progress was common.

In particular, senior labmates were important in shaping students' career interests and trajectories. As Addison, a white, first-generation college woman, explained, "watching senior grad students go through the motions and getting jobs and having their advice . . . has been very helpful." These findings are largely consistent with other emerging research on the important role senior labmates play in teaching day-to-day research skills and serving as career role models (see Feldon et al., 2019).

Early advantages shaped access

Though not always acknowledged by participants, over one-third of students (n = 23) described bringing a great deal of privilege with them to their program, which made it easier for them to gain access to opportunities and develop supportive relationships with their advisors—ultimately leading them

to adopt linear narratives to describe their development. The majority of students describing these privileges were white with college-educated parents, and these discussions usually centered around family characteristics. For example, Evan, a white man with college-educated parents, explained:

> I grew up in a household where this type of science was the dinner table conversation . . . My dad is a scientist . . . in the same areas that I'm sort of interested in entering. So that kind of made the career path very familiar, and I knew what an industry-focused career path looked like . . . a lot earlier than most people.

Among other things, Evan and other systemically privileged students were able to seek out opportunities that were not available or visible to other students in their program. Evan explained, "I don't think any of the things I'm talking about are really things that a program can really hand to a grad student . . . I sought out each of those opportunities." Importantly, this experience of having to *seek out* key developmental opportunities may exacerbate inequities in graduate school experiences, as only some students knew to seek out certain opportunities. For Evan, following his father's career path gave him access to professional development resources not available to students with less privileged backgrounds. Further, we know that perceptions of one's possible selves are strongly informed by family background and privilege (Markus & Nurius, 1986). In addition to increased access to opportunities, the early advantages and privileges that students brought with them may also inform how students perceived their trajectories and future careers (Markus & Nurius, 1986; Pizzolato, 2007). Ultimately, the benefits of holding such privileges illuminate one way that doctoral education reproduces social stratification (Posselt & Grodsky, 2017).

External professional development opportunities

Just under a third of students (n = 20) described how some of the most influential training experiences were external to their programs, including activities like internships, extracurricular involvement at their institution, and engagement with national societies. Students who entered knowing exactly what they wanted to pursue as a career were disproportionately advantaged in that they could seek out meaningful opportunities beyond their formal graduate training experiences, as were students whose parents had STEM careers (see Evan's comments). The importance of such external opportunities was further described by Brayden, a white man with college-educated parents:

> I feel like [doing an internship] was incredibly helpful. I think it really, you know, was really good for kind of my long-term career plans . . . I made a lot of great connections and learned a lot about what it's like working for a company in the day-to-day.

As suggested by Brayden, external professional development opportunities were especially critical to the development of students who had career interests beyond academia. As Colt, another white man with college-educated parents, explained:

> I did an internship between my second and third year, [which] kind of was cool, because I'd never seen industry before. Professors tend to be biased. They tend to advise you into what works for them, and most of them are all academic. Seeing industry with industry people and seeing the culture and breaking down the misconceptions that it's all about money . . . was really nice.

The fact that many students emphasized the importance of external opportunities as most critical to their development may be one way that inequities are exacerbated in doctoral programs. This may be especially problematic, given that Evan, Colt, and others emphasized the importance of these external experiences in shaping their development and preparation for (presumably) high-paying industry careers.

Synthesis of findings and meta-themes

Autonomy shaped meaning making

In relation to both research questions, it is important to acknowledge how students' descriptions of their pathways centered on the extent to which they perceived themselves as "autonomous" in their programs, with just under half of students (n = 31) explaining how they had become highly autonomous by their fourth year. A smaller number of students (n = 7) described ending their fourth year of their doctoral programs with persistent concerns that they lacked autonomy in their day-to-day lab work, leading to the perception that they had "plateaued" in their skill development and may be unprepared for an academic career. Regardless of the extent to which students perceived themselves as having autonomy, the *value* students placed on it speaks to the importance of possible selves. Students perceived autonomy and agency as ideal characteristics of scientific development, and the value that they placed on these (sometimes absent) qualities shaped their understanding of potential growth or constraints related to their possible trajectories.

Structural inequities shaped access and experience

While we examined how students constructed meaning of their experiences to envision their trajectories, we did not assume that all influences would necessarily be immediately perceived by participants. Thus, our critical constructivist approach positioned us to connect participant perceptions to larger structural inequities that shaped both access to opportunities and participants' abilities to perceive them. Consistently within our data, gender and racial/ethnic differences emerged, as well as differences by first-generation college status to a lesser extent. Here, we present some of these patterns, recognizing that differences in how frequently themes emerged by gender, race, and college generation status alone do not capture the depth of the troubling structural inequities in graduate training experiences. Still, it is notable that 60% of men (n = 12) described linear skill trajectories, relative to just 30% of women

(n = 14). While such stark differences did not emerge by first-generation status or race/ethnicity, more complex patterns were evident. Among the 14 women who described linear pathways, 10 of them were white, while just four were Women of Color (this equated to a third of white women describing linear trajectories, relative to a quarter of Women of Color). These findings are somewhat unsurprising, as we would expect that the trajectories students view as (im)possible would be informed by the level of privilege they carry into their programs (Pizzolato, 2007).

A closer look at participants' stories revealed that the most hostile and turbulent experiences tended to be described by Women of Color, like Ava and Antonia, who had particularly negative encounters with their advisors. At the same time, participants who were white, men, and had college-educated parents more often described smooth trajectories and ready access to resources that informed their career paths. When difficulties were articulated by members of the latter groups, they were reported as substantially less turbulent than those experienced by Women of Color.

Limitations

Before further interpreting the findings, it is important to recognize several limitations. First, this study focused on students from research-intensive biological sciences programs. Therefore, findings may not be applicable to training experiences across different disciplinary and institutional contexts. Future studies would also benefit from more racially and ethnically diverse samples, as white students made up three-quarters of our sample. This is particularly important in light of our findings and extensive literature documenting discriminatory advisor experiences, which may have played a larger role had our sample been more diverse. Additionally, we used longitudinal data from a larger study that had some participant attrition (i.e., 143 students were interviewed in the first year, but only 66 completed all four interviews and thus remain in our analyses). Because we relied on interview data from a larger study that utilized socialization theory, our interview protocol was not informed by literature on possible selves. Future studies would benefit from developing new interview questions designed to directly capture aspects of possible selves.

Discussion

The present study explores doctoral students' perceived trajectories in the biological sciences, with findings providing new insights into STEM doctoral training and faculty career intentions by considering broader academic and professional trajectories and the metaphorical "branching career pipeline" (Fuhrmann et al., 2011, p. 240). We capture wide variation in how students

understood their trajectories as they reflected evolving visions of their possible selves. Given the dearth of knowledge about how STEM doctoral students make meaning of their developmental trajectories (Mantai, 2017), these findings are critical to advancing the conversation about how students perceive their skill-based learning and career-related opportunities in scientific doctoral programs.

Our focus on *perceived* trajectories in a STEM field that relies on laboratory settings is crucial, given the ways that possible selves are constructed through social comparisons (Markus & Nurius, 1986). Attending to students' perceptions of their training experiences allowed us to see how faculty, peers, and labmates informed students' understandings of their own trajectories. Further, one overarching way that students made meaning of their experiences was by focusing on the extent to which they perceived themselves as autonomous in their labs, often through a social evaluation of the lab context. Finally, the current study contributes to knowledge about systemic inequity in STEM doctoral training, documenting disparities in access to key knowledge and experiences and discriminatory practices within labs and programs.

Individual narratives of academic and professional trajectories

Consistent with emerging literature on doctoral student skill development (Feldon et al., 2019), fewer than half of participants described a linear academic trajectory along which they increasingly gained skills with each passing year. Among students who described their development nonlinearly, many discussed challenging circumstances (e.g., disagreements with advisors) that disrupted their paths. Despite results illustrating how nonlinear trajectories are common in doctoral training, many participants viewed their training as unique, leading them to believe that their challenges were individualized, when they may have been byproducts of systemic issues in STEM doctoral education (Gildersleeve et al., 2011).

In perceiving professional trajectories, some students in this study described unchanging career interests and intentions over time, while others described how they navigated uncertainty and/or changing professional plans. Evolving interests are not inherently negative, as doctoral student development is complex and dynamic (Austin et al., 2009). Still, students with more stable career plans were able to seek out professional development opportunities intentionally from the beginning of their programs. Further, professional and academic trajectories were mutually reinforcing. That is, students who perceived linear trajectories in their skills felt affirmed in their initial career intentions, though linear pathways did not always constrain changing visions of their possible selves.

Autonomy as a driver of students' meaning making

Many participants shared stories in which they perceived themselves as having "autonomy in the lab" by their fourth year in the program. In light of how participants ascribed positive value to autonomy and agency, their perceptions of autonomy are a reflection of the ways that they perceived fulfilling their possible selves (or not). Indeed, it was clear that autonomy is a highly valued part of lab environments, particularly in more advanced stages of doctoral training, reflecting the ways that possible selves are socially constructed within disciplinary norms. Our central finding about students' autonomy adds to research that has discussed the agency of STEM doctoral students in their career development (Jaeger et al., 2017). In our study, women and men both expressed consistent value for becoming autonomous, though men more frequently used the term "independence." Importantly, prior research on gender and masculinity in STEM doctoral programs may provide insight into these findings. For example, Sallee (2011) identified ways in which masculinized STEM disciplines place value on "independent discovery," which may explain students' consistent focus on autonomy as a way to understand their experiences and successes. This concept may also relate to the importance of external opportunities, which some students claimed to have sought out independently. However, those opportunities were primarily only accessible "independently" to students who brought significant systemic privilege to their doctoral programs.

Key socialization agents

Our findings about the role of advisors are consistent with prior research (e.g., Lindholm, 2004), with the longitudinal scope of our study providing new insights into how advising relationships evolve over time and inform students' perceived trajectories. Whether positive or negative, all participants discussed their advisor interactions as salient. Further, advisor support provided indirect benefits that were inequitably accessible. Participants described incoming advantages that helped them develop positive advisor relationships, in turn allowing them access to additional opportunities (e.g., support from other faculty). This process underscores the important role advisors can play as facilitators or gatekeepers of opportunity (Gopaul, 2019; Johnson, 2015). Further, in the biological sciences, advisors function as principal investigators, meaning that they exert substantial control over lab environments and activities, shaping students' interactions with labmates and their abilities to take on increasing research autonomy. Students also emphasized the importance of interactions with peers and senior labmates, including advanced

students and postdocs, which is consistent with other emerging research indicating that the engagement of postdocs in one's lab predicts skill development (Feldon et al., 2019).

Students' experiences varied by gender, race/ethnicity, and first-generation college status, which were particularly visible when students described their relationships to advisors and other key socialization agents. White men with college-educated parents often described especially positive relationships with advisors and other program faculty, revealing how the most privileged students receive unique access to mentorship and opportunities. Further, while Women of Color's experiences varied widely in our study, with some describing positive experiences, they were typically the ones to describe the most hostile and discriminatory interactions within their labs and with their advisors. This is consistent with prior literature on discrimination experienced by Women of Color in doctoral programs (e.g., Harris et al., 2015). To be clear, some men in our sample were also impacted by hostile training environments. For example, while Adrian did not indicate his race, as a first-generation college student, he emphasized the uncertainty and tumultuous nature of his graduate program, which he described as a "hell hole."

Privileges and opportunities

More than program experiences alone, perceived academic and professional trajectories were largely shaped by the systemic privileges and background knowledge students brought to the program, which may inform both access to opportunities and meaning making around (im)possible trajectories (see Markus & Nurius, 1986; Pizzolato, 2007). This is consistent with socialization's emphasis on how social identities, prior experiences, and background environments may impact professional trajectories and career decision-making (Gibbs et al., 2014), as well as how social inequities shape doctoral students' development of professorial intentions (Burt, 2019). In the present study, some students (disproportionately white men with college-educated parents) described how key advantages—particularly those associated with family and financial resources—shaped the linear nature of their trajectories and stable visions of possible selves over time. Some participants noted that incoming privileges enabled them to identify professional development opportunities and find supportive advisors early in their program. Notably, students sometimes perceived that the experiences and opportunities most important to their development were external to their program and needed to be discovered "independently" by the student. We posit that this may be one way that programs exacerbate inequities associated with students' privileges and prior knowledge, speaking to the ways that external opportunities may be a mechanism of cumulative advantage (Feldon et al., 2016).

Implications for practice

Our findings illustrate opportunities to add structure to doctoral programs to more equitably distribute information about training opportunities, within and beyond one's program. For example, given our findings related to the identified value of external professional development opportunities (e.g., internships), it is incumbent on doctoral programs to ensure that such opportunities are equitably accessible to all students. As a first step, program administrators and faculty could collaborate with external partners to advertise opportunities via online job boards or recruitment events on campus, where all students can have access. Faculty and administrators can also look to existing infrastructure on how to actively support students' professional development. That is, a range of structured programs—both external professional development programs and models of internal professional development programming specific to graduate students—already exist and can be adapted to become an integrated component of doctoral training (see Austin, 2010). For example, institutions can look to NSF's Alliances for Graduate Education and the Professoriate (AGEP, 2021), which has emerged as a collaborative leadership group dedicated to sharing resources that may enhance equitable opportunities for STEM doctoral students.

Findings related to mentorship highlight the importance of interrogating inequitable structures, including access to mentors, mentoring expectations, and organizational support for mentors (Griffin, 2020) as essential tools for broadening the range of recognized possible selves. In addition, results point to the need for faculty development activities and resources aimed at preparing STEM faculty for the management and leadership roles they play when running research labs, particularly as this relates to faculty awareness of their own social identities and those of their doctoral students. Faculty may benefit from receiving guidance on how they can structure labs so students increasingly gain autonomy and leadership opportunities, as well as opportunities for positive collaborations with other students, senior labmates, and program faculty. These suggestions are consistent with prior scholars' arguments on the merits of training mentors (Pfund et al., 2006). To hold faculty accountable for equitable mentoring practices, such expectations could be built into larger reward structures for faculty (e.g., tenure and promotion). Additionally, program administrators and university-level graduate student support services should provide resources for students who are experiencing hostility within advising relationships, opportunities to confidentially report hostile lab environments, and protection for students who choose to access these resources.

Conclusion

This study provides new insights into how doctoral students understand their academic and professional trajectories, revealing wide variation in how students experience their doctoral programs and construct visions of their possible selves. We also document the role of privilege in shaping students' perceived trajectories, both before and during doctoral training through inequitable availability of knowledge related to opportunities and resources, lab environments, advisor interactions, and external professional development. Finally, we highlight implications for practitioners seeking to advance equity in STEM doctoral training by expanding access to key opportunities and experiences that empower doctoral students to envision and pursue the broadest range of their possible selves.

Notes

1. Percentages add to more than 100% because students could indicate more than one racial/ethnic identity.
2. Students self-reported their gender from the following options: woman, man, non-binary identity. None of the participants selected a non-binary identity.
3. We report frequencies throughout our findings with the goal of adding specificity, transparency, and trustworthiness. In keeping with our critical constructivist worldview, frequencies should only be used for these purposes and should not be used to infer meaning about the value of each theme.
4. Adrian did not indicate his race on the survey.

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