

The Value of a STEM PhD

by

Elizabeth Garbee

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Graduate Supervisory Committee:

Andrew Maynard, Chair
Jameson Wetmore
Derrick Anderson

ARIZONA STATE UNIVERSITY

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ABSTRACT

The quality and quantity of talented members of the US STEM workforce has been a subject of great interest to policy and decision makers for the past 40 years. Recent research indicates that while there exist specific shortages in specific disciplines and areas of expertise in the private sector and the federal government, there is no noticeable shortage in any STEM academic discipline, but rather a surplus of PhDs vying for increasingly scarce tenure track positions. Despite the seeming availability of industry and private sector jobs, recent PhDs still struggle to find employment in those areas. I argue that the decades old narrative suggesting a shortage of STEM PhDs in the US poses a threat to the value of the natural science PhD, and that this narrative contributes significantly to why so many PhDs struggle to find career employment in their fields. This study aims to address the following question: what is the value of a STEM PhD outside academia? I begin with a critical review of existing literature, and then analyze programmatic documents for STEM PhD programs at ASU, interviews with industry employers, and an examination the public face of value for these degrees. I then uncover the nature of the value alignment, value disconnect, and value erosion in the ecosystem which produces and then employs STEM PhDs, concluding with specific areas which merit special consideration in an effort to increase the value of these degrees for all stakeholders involved.

To my family, who have always taken my dreams seriously. To my advisor, who has always been in my corner. To my coders, the real MVPs of these data sets - top corgi. And finally, to my 21 year old self who took a huge risk and decided to jump off a cliff, somehow trusting me to catch her on the way down. Look at what we did together!

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PREFACE

July 4, 2013. The day I knew I didn't *actually* want to get a PhD in astrophysics.

I was a junior (soon to be senior) at a small liberal arts college in the Northeast, and it was once again application season. At my school, we were notorious for treating graduate degrees as a fallback position, and also had a relatively well deserved reputation for never actually re-engaging with “the real world” once we left college, instead recreating our school in small pockets around the country and the world. But that wasn't the case for me. I always knew I wanted to get a PhD, probably since the moment I knew what it was: grad school was plan A. In all my favorite TV shows and movies growing up, the PhDs were the ones the other characters went to for advice and expertise - it wasn't that these people knew more, but they somehow knew differently. I think I wanted that perspective more than anything, a knowing which went straight to the heart of things. But I didn't quite know what I wanted a PhD *in*.

In high school, I was one of those kids who was above average at a lot of things, but didn't have one clear passion - and so when well meaning adults gave the advice to just “follow your passion” in college, it left me feeling even more confused. If I had a passion, wouldn't I already be following it? When I got to college and it came time to choose majors, I chose not to choose - instead double majoring in astrophysics and classical civilizations. Again, I was above average at both but exceptional at neither, and I always had the impression that to get into graduate school you had to be truly talented in your field. Classics (and Greek specifically) seemed like the sort of thing you might have for a hobby as an eccentric, interesting older person, so I thought making my living as an astrophysicist made more sense. That was, until I started

researching astrophysics PhD programs that Fourth of July in 2013 while my friends went to the amusement park.

Earlier that summer, my father and I were nearly trapped in a forest fire. One of the most devastating in Colorado history, it started next door and swept through my town, claiming more than 500 homes (including our own) and two human lives. While Dad was loading the heavy stuff into the Suburban, it was my job to run through the house and grab “everything else.” We had lived in that house my whole life, and besides obvious things like photo albums and my brother’s guitar, there was very little to help me in those moments, flames in full view, to understand what we would wish we still had years in the future. Yet in the days and weeks that followed, I began to realize that perhaps the most invaluable thing that came out of the fire wasn’t actually in that car. It may sound horribly cliché, but the fire was a wake-up call, reminding me that change, no matter the magnitude, can happen in an instant: and if such a dramatic change in my life could be caused by an accident, just imagine the sort of change I could bring about on purpose. I didn’t yet know what I wanted to do with this newfound resolve, but I knew whatever it was, I wanted to make it count. I’d walked out of something that by all rights could have killed me, and I felt strangely brave and unstoppable.

I don’t have clear memories from that afternoon in July between when I started my astrophysics graduate program search and when my friends came back later that night; but I do know it involved six straight hours of the TV show *How I Met Your Mother*, a box of Triscuits, and curling up in the fetal position on my bed. I had a visceral, physical reaction to the idea of doing a PhD in astrophysics, despite absolutely loving my physics program at college, my colleagues, friends, and professors. I mean, I was the kid who asked special permission to stay up late when I was little to watch *Cosmos* re-runs with Dad after dinner. I had been preparing for this moment

for three years, maybe even my entire educational career, and when it finally came, I had a full blown panic attack. My body just shut down. When I finally came out of it, I knew one thing for sure: there was no way I was applying to any of these programs. I couldn't face spending the next seven years of my life in the basement of a windowless physics building somewhere or alone in a telescope observation room, doing work maybe eight people in the world cared about, five of whom only paid attention to see if I cited them or not. I couldn't stomach the thought of wasting this second chance. That realization threatened to shake everything I thought I wanted from my future career, and my identity as a scientist. And in that void, there was only one remaining question echoing in my ears.

Now what?

This research is, in part, the result of what happened next. But in many ways, and arguably the most important, this study has nothing to do with my story. It's an effort to shed light on a phenomenon that I would have faced were I to have pursued a PhD in astrophysics, a hypothetical road less traveled if you will, and one which some of my dear friends and colleagues from college see taking shape on their horizon. It's in reaction to story after story of incredibly gifted and talented students graduating with a PhD in some seemingly valuable STEM field only to find it impossible to land something other than a series of post-docs, and who finally take an adjunct professorship at a school in a state they can't stand because they don't think they can find anything better.

The U.S. scientific enterprise is grounded in the assumption that a terminal STEM degree has considerable personal, societal, and economic value. Yet, the evidence to indicate the nature and magnitude of this "value" to different stakeholders remains

largely anecdotal. At the same time, there is increasing concern in some quarters that there are serious disconnects between the claimed value of a terminal STEM degree, and the workplace expectations and varied career pathways confronting new and future graduates. There are also growing indications that some STEM PhD graduates are finding it hard to use their degree in their subsequent career; that issues around gender, race, socioeconomic, and even political diversity are undermining the potential personal and societal value of a STEM PhD; and that an increasing number of young people are intentionally not pursuing a PhD in STEM because they cannot see the value of doing so. Many of these indications remain anecdotal. Yet if they are correct, there is a substantial risk that current policies and programs supporting STEM PhDs are not effectively supporting U.S. social and economic development.

Effective STEM policies and programs rely on value alignment between different stakeholders. Without alignment, their effectiveness is potentially threatened by invalid assumptions of value, uncertainty over the nature and magnitude of that value, and disconnects between perceived value to each stakeholder group. Lack of value alignment at the terminal degree level has far reaching implications through the educational ecosystem, in which promises and expectations articulated in STEM degree programs may not match the realities facing students. This study begins to address this plausible risk by studying the perceived value of a STEM PhD to students and their future employers, using a novel approach based in understanding risk as a threat to value across and within multiple constituencies.

I joke that this work is fueled in large part by righteous indignation at these students' situations, but that's not far from the truth. Our politicians and village elders keep telling us year after year that America's future is its children, specifically its graduate-level-educated-in-STEM children - but if the system which produces this human capital fails to give them the opportunity for fulfilling employment options at

the other end, something is clearly and fundamentally broken. In other words, what is the value of a STEM PhD outside of academia?

Chapter 1

INTRODUCTION

1.0.1 The Value Gap

The argument which forms the foundation of this research posits that we assume continued and increasing risk as a culture, society, and country if we continue with our current system of training STEM PhDs. At the outset, I hypothesized that there existed a disconnect between what we privilege and prioritize in academia in terms of education and training, and the skills and abilities sought after by non-academic employers. I based this hypothesis on the mountains of anecdotal evidence available about highly qualified STEM PhDs still unable to land a permanent position years after graduation ¹, and also more traditional forms of data such as the National Science Foundation's (NSF) Survey of Earned Doctorates (SED) and Survey of Doctoral Recipients (SDR).

Every year, the NSF releases a report on science and engineering employment characteristics and outcomes. Conducted since the middle of the 20th century, the Survey of Earned Doctorates and Survey of Doctoral Recipients surveys students who finished their PhDs the previous academic year in an identified science, engineering, or health (SEH) discipline ². The results of this survey are used by academics and practitioners alike in their efforts to analyze and predict demographic and employment trends in these various STEM (science, technology, engineering, and math) fields. For

¹A good example of this evidence is the proliferation of closed groups on Facebook and LinkedIn which serve as support networks for such people, whose main topic of discussion concerns individuals' experiences trying to get a job after graduation.

²National Science Foundation Survey of Earned Doctorates: <https://www.nsf.gov/statistics/srvydoctorates/> (Accessed March 1, 2018)

the first time in 2015, the SED was able to provide discipline specific employment characteristics by more than doubling its sample size (National Science Foundation, 2017). According to this latest report, 87% of new PhDs living in the United States (US) were employed at the time they took the survey, 76% of whom were employed full time (National Science Foundation, 2017). Analysis indicated, “the proportion of 2014 doctorate recipients who reported definite commitments for employment or a post-doc position was at or near the lowest level of the past 15 years” (National Science Foundation, 2015). The NSF also conducts the annual Survey of Doctoral Recipients (SDR) ³, aimed at new graduates. During the past decade, the SDR cited much lower unemployment rates than the SED, staying squarely in the single digits even at its recent peak of 3.4 percent in 2013. The picture of STEM PhD unemployment looks quite different depending on which survey data are being used, and when. These surveys, like many conducted on large populations by high profile organizations, receive significant criticism due to the perception of a self selecting population, incomplete sampling, the timing of the survey compared to a student’s employment cycle (when they filled out the survey as opposed to when they signed an employment contract, for example) and other drawbacks. Despite that criticism, however, the SED and the SDR remain the most complete account researchers have of employment outcomes for recent STEM PhD graduates - a fact which contributes to the difficulty of determining the state of STEM PhD employment in general at any given time.

While perhaps shocking to some, these new numbers reflect a trend observed since the late 1970s by scholars and practitioners alike. By and large, researchers and employers argue as to whether new STEM PhDs are finding satisfying employment

³National Science Foundation Survey of Doctorate Recipients: <https://www.nsf.gov/statistics/srvydoctoratework/> (Accessed March 1, 2018)

at the rate that might be expected, or in anticipated sectors or careers (Xue and Larson, 2015). This phenomenon takes a slightly different shape depending on who’s talking: either we’re experiencing a shortage of quality STEM human capital, we’re producing more STEM PhDs than we can reasonably employ, or they just aren’t graduating with skills that make them marketable across multiple sectors of the 21st century economy. Despite a new SED and SDR every year, the numbers on STEM PhD employment are often incomplete or murky at best, and they fail to tell us *how* students are using their PhD training in the employment they do eventually find. Put simply, these credentials are generally assumed to be valuable, but it seems that students, academics, and employers often disagree about the nature and degree of that value.

Before we go too much farther, it’s worth pausing to briefly discuss STEM, the now ubiquitous acronym often used interchangeably with S&T (Science & Technology) to describe the disciplines and areas of study traditionally associated with the natural and physical sciences. Judith A. Ramaley, formerly the assistant director of education and human resources at the National Science Foundation (NSF), first coined the term in 2001 while she and her team developed curricula for “enhanc[ing] education in science, mathematics, engineering and technology” (Christenson, 2011). In one of her publications the following year, Ramaley used the STEM acronym to describe efforts underway at the NSF to support greater STEM literacy in the general educational system in order to support American economic competitiveness (Ramaley, 2002). Since then, the term has entered the mainstream and has become a rallying point for federal funding for education in the 21st century (National Academy of Sciences, 2005; Oleson *et al.*, 2014). However, there are those who claim this convenient acronym isn’t very helpful, and can sometimes do more harm than good when it comes to helping students find employment after graduation (Base *et al.*, 2012;

Oleson *et al.*, 2014). A large portion of the criticism focuses on the inconsistency of the disciplines and specialties grouped under “STEM” depending on who uses it, and the degree to which these varying definitions make it increasingly difficult for students and employers to understand which jobs require which qualifications (Charette, 2013; Rosenblum and Spence, 2015). In fact, according to researchers at the University of Wisconsin-Madison, “estimates of STEM jobs in the US vary from 5.4 million to 26 million, depending on which occupations are included”; and many analysts “overlook blue-collar occupations which require STEM knowledge, which results in (a) under-counting the number of STEM-related jobs, (b) inflating wage estimates for the STEM job category, and (c) under-estimating the value of non-bacheloreate postsecondary education” (Oleson *et al.*, 2014, pg. 2).

The STEM umbrella, so to speak, often leads policymakers and analysts to conflate occupations with industries, and blur the lines between skills required and tasks performed (Oleson *et al.*, 2014). In the minds of some, these kinds of findings raise yet another question - do you need a STEM degree to get a STEM job? (Charette, 2013; Oleson *et al.*, 2014). Maybe not: “For STEM jobs alone ... 92 percent will require some postsecondary education, but about 20 percent of those jobs in 2018 will only require some college or an associate degree, which reflects a substantial number of jobs that do not require a bachelors, masters, or doctoral degree” (Oleson *et al.*, 2014, pg. 21). Additionally, research suggests that students more closely identify with their subject or particular specialty than with STEM (Mellors-Bourne *et al.*, 2010), raising further questions about its utility in terms of helping students find jobs. ⁴

⁴With that in mind, I will continue to use STEM throughout this chapter, and the rest of this study, because this is the language used by academics and practitioners when discussing the kinds of education and careers we will examine. I do this in full knowledge of the complexities associated with the term, and my usage of it should not in any way be taken as evidence of my disregarding the issues at stake. For the purposes of this study, I choose to define STEM disciplines the same

This relatively new acronym, however, describes a group of fields and disciplines which have featured prominently in the U.S. political imaginary since the 20th century. The frequency with which they're mentioned by lawmakers may lead some to conclude that these disciplines enjoy special attention - and sometimes they do, especially when mentioned in the same breath as national security, for example (National Research Council *et al.*, 2012). But they belong to a much broader lineage of educational efforts sponsored in part by the federal government, sponsorship hard won and often contested in a country with such a complex relationship to federally funded education to begin with. I cover this historical aspect of the issue much more thoroughly in Chapter 2.

1.0.2 Value Disconnect

As non-compulsory degrees, individuals pursue a PhD with the understanding that this degree can do something for them that no other degree can. For many, it can offer the opportunity to further explore an area of research they find fulfilling; others appreciate the ability to specialize before they hit the job market. Underpinning all of these various motivations, also explored more thoroughly in Chapter 2, lies a basic assumption which holds for all of higher education: these degrees are valuable, and not just for the students, but for all stakeholders involved in their production. The magnitude and nature of that value necessarily vary according to each person's needs and goals, the aims and objectives of the granting institution, and many other complex factors. One aspect of that value which features heavily in the anecdotal evidence discussed earlier and the purpose of surveys like the SED and SDR concerns the further assumption that the value of a PhD lies, at least in part, in the ability

way the NSF does (mathematics, natural sciences, engineering, computer and information sciences), but will differ from the NSF in that I will not include social and behavioral sciences.

of the degree-holder to find a job after graduation with the skills and experience earned in the pursuit of that degree. When I use the term “value disconnect” in this research, I’m pointing to the apparent mismatch (according to anecdotal and employment outcome data) between the value of these degrees in terms of leading to rewarding and fulfilling employment for the people who complete them, and the increasing trend of unemployment among this population. Something’s missing in the translation of value of these degrees from before to after graduation. This research aims to begin to uncover the nature and magnitude of this value disconnect, in order to uncover areas of possible development in the system which produces and hires these PhDs to improve their employment outcomes.

The mobilization of a STEM PhD educated workforce cuts across multiple sectors of expertise, the study of which engages not only the fields of policy making and science and technology studies, but also labor economics, mentoring, human resources, and organizational behavior, to name a few. For labor economists, the value of a STEM PhD is often operationalized as an individual’s or group’s financial contributions to the economy as an effect of their education and training, whether they are naturalized citizens or here on a visa (Peri *et al.*, 2015; Kerr, 2013). The economics perspective also contributes substantially to the narrative discussed more thoroughly in the next section concerning labor market parity and the shortage or surplus of available scientists and engineers (Langdon *et al.*, 2011; Metcalf, 2010; Rothwell, 2013). Additionally, experts in the field of effective mentoring for STEM higher education have spent the past few decades investigating the effect of mentoring on recruitment and retention of students into STEM graduate programs, (Crisp *et al.*, 2017; Crisp and Cruz, 2009) often arguing that the skills acquired by students as a consequence of mentoring increases their value as human capital (Wilson *et al.*, 2012; Taherian and Shekarchian, 2008; Latham *et al.*, 2008).

When it comes to employing STEM PhDs, human resource management literature can offer insights into how to sustainably increase and a diverse workforce (Robinson and Dechant, 1997), as well as perspectives on managing international employees (Dowling, 2008) (both issues of continued importance in sectors concerned with STEM human capital). And experts in organizational behavior can provide key insights as to the social values and culture of higher education writ large, the behavior of individuals within that culture, and the degree to which organizations are not inherently adaptive, but inertial (Cohen and March, 1986; Hannan and Freeman, 1989; Dowling and Pfeffer, 1975), all factors which heavily influence the value of a STEM PhD. As such a cross-cutting issue, this study argues that the discrete measures of value for a STEM PhD from the perspective of non-academic employers could have both relevance and implications for those fields listed above, and more besides.

1.0.3 *The Lens of Risk Innovation*

Investigating the possibility of value disconnect in the STEM ecosystem requires a framework which provides a way to explore the risk incurred as a consequence of continuing with the current system of producing those degrees. The fields of risk perception, analysis, risk management are replete with such frameworks, each with strengths and weaknesses for this particular study, beginning with the definition of a risk in the first place. For example, the Social Amplification of Risk Framework (SARF) works under the assertion that risk is “a situation or event where something of human value (including humans themselves) is at stake and where the outcome is uncertain” (Pidgeon *et al.*, 2003, pg. 56). One of the seminal texts in the field of risk management, Beck’s *Risk Society*, defines risk as “a systematic way of dealing with hazards and insecurities induced and introduced by modernization itself” (Beck, 1992, pg. 21). There are those, Jasanoff and others, who argue strenuously on the

purser side of social constructivism, asserting that risks do not exist independently of our perception of them (Jasanoff, 1993); and those more aligned with Kaspersen, Ostrom and Wilhelmsen, Sunstein, and Ropeik (among others) who clearly delineate a valuable distinction between a hazard and a risk (Kunreuther *et al.*, 1996; Ostrom and Wilhelmsen, 2012; Sunstein, 2002; Ropeik, 2010). Additionally, Slovic (Slovic and Peters, 2006; Slovic, 1993) and Gilovich *et. al.* highlight research suggesting that “people judge a risk not only by what they think about it, but how they feel about it” (Gilovich *et al.*, 2002, pg. 410). That feeling involves a complex cocktail of components, including (but not limited to) the level of trust in the source of the risk analysis, the degree to which one has to mobilize their conscious and subconscious processes in order to engage with the threat, and the heuristics and biases at work in every choice we face and how those factor into our ultimate decisions (Kahneman, 2011).

This incredibly brief survey reveals a bounty of frameworks to choose from when approaching the central curiosity of this study, namely the risks present in the ecosystem of the production of STEM PhDs which may rest on undiscovered fundamental value disconnects. Legitimate judgments of value can often lead regulators and policymakers to be primarily (or at worst, exclusively) concerned with statistics, whether or not the risks are hard to avoid, painful, or unevenly distributed (Sunstein, 2002). That perspective often ignores or eschews attempts to include these varying assertions of value in risk assessments or risk management due to their resistance to similar simplification. In order to steer clear of those pitfalls, for the purposes of this research I will be using the comparatively new framework of risk innovation, which simply defines risk as a threat to existing or future value, a definition purposefully broad so as to encourage experimentation and multiple perspectives (Maynard, 2015). More specifically, risk innovation offers a way of surveying the landscape of a certain risk

or threat which provides the practitioner the space and permission to not only think outside the box, but dismantle the box if necessary. It “gives license to what might be described as risk entrepreneurship, where the ultimate measure of an idea’s worth is whether it has an impact, not whether it adheres to convention” (Maynard, 2015). There is no one toolkit or formulaic analysis for risk innovation - its strength lies in its ability to invite individuals to evaluate a risk from the perspective which provides the most useful insight, regardless of where that perspective originally came from. Existing institutional activities and frameworks may indeed be enough to mitigate short term risks, but longer term threats may require true institutional and procedural innovation across the ecosystem.

In the case of this study, formulating the current system by which we produce STEM PhDs as a threat to the value of these degrees for all stakeholders involved lends itself to a stakeholder centered analysis, something which is often missing in discussions of employment outcomes for degree holders. I structured my research so as to investigate the articulated and assumed value of these degrees for two of those stakeholder groups which also get comparatively less attention in the existing literature: the individual departments at higher education institutions, and non-academic employers who hire STEM PhDs. This approach results naturally in two sets of questions for both academic units and future employers: what is the articulated value of a STEM PhD from their perspective, as evidenced by their communication of that value to students? And how do those articulations of value align with or differ from one another, and in some cases work against each other?

1.0.4 The Data

The first part of this study looks at the value of a STEM PhD from the institutional perspective, specifically the articulations of value offered to students by individual

academic units. In examining what departments tell their students these degrees are *for*, I arrive at some sense of what specifically these units think makes each degree program valuable. These articulations of value come from documents produced by the programs and distributed to students either during their application process or their first year during orientation, both recruitment and process oriented documents.

A systematic review of all such documents for all U.S. graduate programs offering STEM PhDs was way beyond the scope of this research, so instead I chose to focus my efforts on my home institution of Arizona State University (ASU). The largest public university in the country, ASU serves students from all across the country and the world. In its standing as one of the top research universities in the country, ASU also offers a selection of PhD programs which represent a breadth of possible future employment and career options for students. And while ASU is perhaps unique in its organizational design from other public universities across the country, it provides an ideal test case from which to begin to uncover the articulated value of STEM PhD programs from the perspective of academic units themselves.

The second part of this study generates new data on the value of a STEM PhD from the employer perspective, through a series of interviews I conducted with HR managers, researchers, vice presidents, and research directors at some of the biggest companies and organizations who hire people with a STEM PhD. This kind of data exists for other kinds of degrees, but is an area of relatively untapped exploration for STEM PhDs in particular. I framed these interviews in terms of value to these individuals, asking about things that really excited them when they saw it on a STEM PhD's resume, for example. The analysis of this rich interview data involved the creation of a standard thematic codebook based on my interviewees' responses, which was then applied to each interview in order to draw out broad themes in the data.

The final piece of this research was the bringing of these two data sets and analyses together, in order to map out the areas of value alignment, value disconnect, and value erosion discussed above. Some of the resulting findings are amplifications of echoes in the existing literature, while some present new challenges and opportunities. This resulted in cross-cutting themes which I discuss in depth, as well as specific areas which merit special attention from those who hope to increase the value of these degrees across the ecosystem.

1.0.5 *What's Ahead*

To paraphrase one of my mentors, the ambition of the following study in general and the next few chapters in particular is to help make the wicked into something merely difficult (Hodge *et al.*, 2010). To that end, the next chapter provides a historical background to science education as it relates to higher education and public policy in general, as well as a survey of the work that has already been done to address issues surrounding the question of the value of a STEM PhD. Chapter 3 is an exploration of the assumed value of the STEM PhD at Arizona State University, through an analysis of program requirements, plans of study, and student handbooks for every PhD program in a self identified STEM field across the university. This is an effort to understand some of the messaging students receive about the value of these degrees from the departments themselves, and in turn, to uncover the core competencies faculty and program administrators believe each degree confers. Chapter 4 shifts focus from the student to the employer, as I present data I collected and analyzed from interviews with individuals across multiple sectors, companies, and organizations who ultimately hire these PhD students when they graduate. This is a crucial gap in the data available in the literature, and that chapter is the beginnings of my effort to contribute to filling that gap. The subsequent chapter brings both data

sets together, as I work to identify the areas of value alignment, value disconnect, and value erosion in the ecosystem which values a STEM PhD. And lastly, Chapters 6 and 7 look towards the future and suggest possible areas of examination for academics, professionals, and civic leaders in terms of increasing the value of these degrees for all stakeholders involved.

Chapter 2

SKILLS, SHORTAGE, AND SURPLUS

2.0.1 Brief History of S&T Education in the U.S.

American democracy has always had a fraught relationship with the role of public education, stemming from a fundamental tension between the demands of capitalism, the “appropriate” role of the federal government, and the articulated value of a democratically educated citizenry (Chomsky, 1995, pg. 5). Education is never explicitly mentioned in the Constitution, but not as the result of a lack of dialogue among the founding parents on its role in their new society. On the contrary, many heated debates during the first Continental Congress concerned the value of creating a “national university” and its implications for the role of the federal government in education. Their interest in such an institution reflected their Enlightenment intellectual heritage, most notably a strong conviction in the value of education for education’s sake. More practically, the founding parents believed that this new grand experiment’s success rested in large part in an educated citizenry, partly through raising the overall level of higher education in their fledgling nation (Castel, 1964). In the minds of its proponents, the idea of a National University reinforced the value of scientific education and training, something on which they could all agree despite their many other partisan differences (Dupree, 1986).

Around the same time, Thomas Jefferson created the United States Military Academy, more commonly known as West Point, through the Military Peace Establishment Act of 1802 (Ambrose, 1966; McDonald, 2004), as part of his vision for a national defense program. The establishment of West Point provided a counter-

point for discussions about the National University, a plan Jefferson heavily favored (McDonald, 2004). Jefferson interpreted the training of future military officers as well within the powers of the national government as outlined in the Constitution. The second superintendent of the Academy, Colonel Sylvanus Thayer, redesigned the curriculum around civil engineering because he perceived a lack of engineers among the ranks of educated citizens in this new country (Ambrose, 1966). Indeed, up until the middle of the 19th century, West Point cadets built most of the nation's bridges, roads, harbors, and railways (Ambrose, 1966).

And while the National University as originally envisioned never made it off the drawing board, this vision for the role of education in a democracy persisted. Until the late 19th century, institutions of higher education in the United States sought to replicate the English model of 'liberal education,' with a heavier focus on teaching than research (Haverhals, 2007, pg. 427). However, as the needs of American society evolved following the Civil War, universities moved away from the European tradition and searched for an alternative to the German model.¹ They did so by focusing on "professionalism" and orienting the new universities towards practical teaching and learning, which they thought was perhaps better suited to the American temperament (Haverhals, 2007, pg. 427).

This reorientation also saw such legislative activities as the Morrill Land Grant Act and the Allison Commission, both of which affirmed the worth of government science and the university's role in furthering that research. The wave of progressivism that led the U.S. into the 20th century further solidified science's place in policymaking with the assertion that scientifically based decision-making was itself in the public interest (Dupree, 1986). One of the great changes with Progressive

¹Wilhelm von Humboldt re-imagined the German university alongside the development of the new 19th century nation-state, complete with 'enlightened citizens' (Bildung) and an academic environment of scholarship (Wissenschaftlichkeit) (Biesta, 2007, pg. 469).

leadership was a wider appreciation for science in the mind of the public, and the act for a new Bureau of Standards demonstrated a new ability for Congress to legislate scientific activities directly, for example by mandating standardization of weights and measures, in addition to serving as the nation's first national laboratory. The U.S. clearly has a long standing tradition of supporting S&T education in the name of an informed citizenry, despite a sometimes contentious relationship with the idea of federally funded education in general. This is largely due to the ways in which policymakers link S&T education to broad national themes like “informed democracy,” “national security,” and “economic competitiveness.”

Mid-way through the 20th century, policymakers began to link S&T education not only to economic progress and an informed democracy, but also to the national security of the U.S. itself, with the passing of the National Defense of Education Act (NDEA) of 1958 (Harris and Miller, 2005). The scope and mission of the bill depended heavily on the contemporary context of the launch of Sputnik one year earlier and its impact on national policy. The failure of the Naval Research Laboratory to launch one of its Vanguard rockets not two months later fueled additional questions of American dominance in the emerging arena of post war science and technology. Seen as an “educational emergency bill” by the legislative branch, the NDEA was the flag bearer of the Eisenhower administration's assertion that education was America's greatest weapon in the fight against communism (Harris and Miller, 2005), and education was now an integral part of the national security conversation. This bill also reflected the longer standing debate concerning the appropriate role for federal involvement in education. Signed by Eisenhower on September 2, 1958,² (and followed by the establishment of the National Aeronautics and Space Administration (NASA) a

²National Defense Education Act: <https://www.britannica.com/topic/National-Defense-Education-Act> (Accessed March 1, 2018)

month later) the bill authorized one billion dollars in federal aid for a dozen separate educational programs governed under its ten titles. Though this was not the first time the federal government acted explicitly in the sphere of education, nor would it be the last, this piece of legislation “demonstrated one of the most extensive and multifaceted attempts of the government to underwrite the education of its citizenry.” (Strain, 2005, pg. 513).

In addition to the argument linking S&T education to an informed citizenry and increased national security, stakeholders across multiple sectors continue to link graduate education to American economic competitiveness and prosperity (Stewart, 2010; National Academy of Sciences, 2005; National Science Board, 2015; Dasgupta and David, 1994; Olson and Riordan, 2012). According to the National Science Board, for example, “To ensure continued U.S. competitiveness and prosperity, our Nation must foster a strong, STEM-capable workforce” (National Science Board, 2015, pg. 10). In fact, some argue that science (and by extension, science education) and the national economy have been inextricably linked since the early 20th century (Dupree, 1986). Hoover went so far as to equate scientific research with the prosperity of the 1920s, “relying on research as a long-run answer to the fall in productivity that accompanied the depression.” (Dupree, 1986, pg. 246). Besides the financial recovery from the Great Depression, 1935 also marks a shift in emphasis and procedure reflecting the theme of “research, a national resource” (Dupree, 1986). Little more than a decade later, Vannevar Bush described his and others’ hopes for the permanence of the temporary relationship the military established with public and private labs during war time as “The Endless Frontier” in a now-infamous letter written to President Truman. The relationship between S&T sectors and the economy continues to grow, serving as a cornerstone of the economic policy efforts of many presidents since Truman (Clinton *et al.*, 1993; Olson and Riordan, 2012), and a feature of the

discourse surrounding the development of STEM human capital.

When academics talk about human capital, they generally mean productive wealth embodied in labor, skills, and knowledge (Tan, 2014; Schultz, 1961). Human capital theory research indicates that not only does education “increas(e) the productivity and earnings of individuals” (Tan, 2014, pg. 2), but that “the complementarity with firms and schools depends in part on the amount of formalized knowledge available” (Becker, 1962, pg. 18). Economists stress the uncertainty involved in any estimation or assessment of the returns on investment in human capital (Becker, 1962), but can often overlook “the simple truth that people invest in themselves and that these investments are very large” (Schultz, 1961, pg. 5). Such is frequently the case in discussions of the skills mismatch issue with STEM human capital. If the narratives of an educated citizenry, national security, and economic competitiveness marshall our prevailing conversations with respect to the value of STEM higher education, then the human capital comprising a talented STEM PhD workforce are their footsoldiers.

Towards the end of the 20th century, Congress passed legislation that changed the trajectory of intellectual property and technology development at the nation’s universities, and which further enabled new relationships between academia and industry. The Bayh-Dole Act of 1980 was one of the biggest drivers behind increased patenting at universities, building on decades of federally funded R&D at these institutions (Sampat, 2006; Mowery *et al.*, 2001). Before the passage of this legislation, many schools feared criticism that patenting and licensing their discoveries would compromise their commitment to scientific research and education (Sampat, 2006). Additionally, up until Bayh-Dole, most university patents were for technology developed without the use of federal funding, rather supported by private institutions and state or local governments (Sampat, 2006). Senators Birch Bayh and Bob Dole addressed this last concern in their legislation (Pub. L. 96-517, December 12, 1980) by

allowing a university, small business, or non-profit to patent technologies developed through federal funding, decentralizing federally funded technological innovation in favor of turning that responsibility over to the institution responsible for the discovery.³ Institutions who sought to patent federally funded invention through this new act would have certain responsibilities to the government depending on the nature of the technology and the licensing options that institution preferred. The intention was to create the means for “technology transfer” and more evenly distributed societal gains from university research (Sampat, 2006). And while not solely responsible for the growth of “technology transfer” operations in the U.S. since the 1980s, this aspect of academic knowledge production, utilization, and dissemination has continued to build relationships between academia, industry, and the federal government (Bozeman, 2000).

2.0.2 STEM Shortage vs Surplus

As such, the quality and quantity of talented members of the U.S. STEM workforce has been a subject of great interest to policy and decision makers for the past 40 years. This discussion tends to fall into two narratives which govern and shape the relationship between the government and S&T education. Either the U.S. is experiencing, and will continue to experience, a shortage of STEM workforce talent unless policy makers intervene; or there is no shortage of talent, but rather a shortage of career employment opportunities or a mismatch of skills for our existing STEM talent (National Research Council *et al.*, 2012; National Academy of Sciences, 2005; Stewart, 2010; Lowell and Salzman, 2007; Mervis, 2003; Metcalf, 2010; Oleson *et al.*, 2014; National Academies of Sciences, 2017; Mervis, 1992). While presenting vastly

³35 U.S. Code Chapter 18 - PATENT RIGHTS IN INVENTIONS MADE WITH FEDERAL ASSISTANCE. (Accessed March 1, 2018)

differing views of the state of STEM human capital in the U.S., each argument has merit depending on which degree level, which occupations, and which individuals fall under the STEM umbrella at the time (Carnevale *et al.*, 2011). The question of whether we have too many or too few STEM workers also depends largely on the degree to which the conversation focuses on STEM R&D activities, regarded by many as the portion of the STEM sector which drives innovation (Carnevale *et al.*, 2011). In fact, according to the newest SED numbers, “Of doctorate holders residing in the United States, 41 percent were performing research and development (R&D) as their primary work activity. When R&D was reported as either a primary or secondary work activity, the rate increased to 63 percent” (National Science Foundation, 2017).

Let’s take a step back for a moment to talk about some possible origins of this type of STEM jobs uncertainty. However you construe that uncertainty, whatever form it takes in the literature and in practice, studies suggest it is largely the result of structural forces in the U.S. economy and the narratives linked to U.S. S&T superiority. Additionally, growing numbers of PhDs and increasingly few tenure lines present the U.S. with a serious challenge in the coming years when it comes to more traditional academic STEM human capital. To further compound the issue, the market for new PhDs lags their production, further exacerbating a structural and stubborn imbalance. Demand is often fixed by demographic trends (Atkinson, 1976; Alberty, 1970), with too few senior scientists in faculty positions who have reached retirement age in time to open those spots to younger, more freshly minted PhDs (Atkinson, 1976).

People who study this issue tend to characterize the underlying cause(s) of this crisis as either one of a shortage or surplus of qualified, talented, and eligible STEM workers. The STEM *shortage* conversation tends to rely heavily on the economic competitiveness narrative in terms of sustaining American leadership in science and technology innovation in an increasingly integrated global market (Carnevale *et al.*,

2011; Teitelbaum, 2003). This often materializes in arguments regarding sheer numbers of STEM graduates produced, the number of STEM jobs available to them, and the perception that we have a sufficient supply of neither. For example, we more often see shortages in specific sectors, and research suggests that these shortages are due in part to diversion of STEM-capable workers into non-STEM careers (Carnevale *et al.*, 2011, pg 12).

Many trace this scarcity narrative to the late 1980s, when the National Science Foundation (NSF) leadership warned Congress that we would be short more than 675,000 scientists and engineers by 2006 using what is now called the “pipeline model” to predict the number of future STEM professionals based on contemporary trends (Charette, 2016). According to economists Daniel Goroff and Richard Freeman, “the NSF constructed its ‘bogus claims’ on ‘extrapolations that were not based on any remotely plausible assessment of the labor market’” (Charette, 2016, pg. 1). Rather, some economists and others argue that these numbers came from data manipulation (Greenberg, 2001), and a desire to “induce more young Americans into science and engineering to lower the cost of scientists and engineers to large firms” (Charette, 2016, pg. 1). In fact, in 1985, the Office of Technology Assessment concluded that, “Given the problems with forecasting supply and demand for scientists and engineers, predictions of shortages based on such forecasts should be treated with skepticism” (Greenberg, 2001, pg 95). A few years later, after several academics and engineers publicly testified to such skepticism, Congress called a hearing into the shortfall predictions, during which several members of the committee accused the NSF of “faking a crisis to boost its budget” (Greenberg, 2001, pg. 136). During the hearing, witnesses testified to suppressing reports, under then-director Bloch’s direction, which refuted the results of the “pipeline model” - and the Government Accountability Office (GAO) confirmed the lack of peer review on the initial report. This whole ordeal

highlights the tension between the science community’s impulse to enlarge its ranks and sensitivity to the trust and goodwill of its federal funders. And while largely debunked based on the above, the scarcity narrative furthered by the “pipeline model” had entered the mainstream and had already begun to significantly shape the U.S. STEM human capital conversation.

In addition to an assessment of the relative faults and strengths of any boots-on-the-ground argument inspired by the pipeline model, significant research in the past few years points to a rise of certifications, certificates, and two year degrees, all of which represent increased demand for STEM “competencies” (Carnevale *et al.*, 2011). This concerns not just those skills and capabilities in the current workforce, but a response to a fear that future workers won’t graduate their preparatory degrees with the qualifications necessary to contribute to the 21st century workforce. To address this shortage, researchers suggest we will need “creative and flexible policy solutions” as opposed to “scar[ing] students into liking science or boosting it at the expense of other fields,” a suggestion which criticizes previous efforts at addressing the shortage (Carnevale *et al.*, 2011, pg. 77). Such solutions include focusing more on understanding student work and career interests rather than assuming students will pursue a career in STEM simply because they’re capable (Carnevale *et al.*, 2011); teaching math and science at a higher standard nation-wide, while increasing its target audience in a more “discipline-relevant, accessible way” (Carnevale *et al.*, 2011, pg. 77); a curriculum which embraces and targets diverse learning styles of students (Carnevale *et al.*, 2011, pg. 78); and technical and career preparation in high school, in service of providing increased opportunity to those who choose not to pursue post-secondary education (Carnevale *et al.*, 2011, pg. 78). Some academics and practitioners refute altogether the assertion that we are currently experiencing a widespread STEM human capital shortage, both in terms of skills, talent, and jobs available (Cyranoski

et al., 2011; Mathews, 2000; Berghel, 2015; Goodstein, 1993). Many cite the inherent difficulties with characterizing the phenomenon in purely boots-on-the-ground terms. For example, while overall job growth between 2008 and 2018 in the U.S. is projected at a 10% growth rate, the number of STEM jobs surpasses that average rate at 17%, a sector second only to Healthcare in terms of projected growth (Carnevale *et al.*, 2011, pg. 22).⁴ Additionally, experts predict a wave of job openings due to imminent baby-boomer retirements, some even projecting 2.4 million such available positions between 2008 and 2018 (Carnevale *et al.*, 2011, pg. 23). Unemployment numbers, however, don't tell us anything about *how* STEM PhDs use their training, further complicating the issue (Mathews, 2011). This muddy empirical evidence for a lack of STEM graduates or shortage of qualified workers leads some to speculate that those who further the shortage and scarcity narrative benefit from doing so, “tak[ing] the Rumsfeldian view that we'll be better off pretending that it does exist” (Berghel, 2015, pg 75).

2.0.3 *The Skills Gap*

The second overarching narrative insists the more pressing problem is not one of scarcity or surplus, but rather a mismatch between the skills students learn in school and the ones which make them valuable in the 21st century workforce (Charette, 2016; Carnevale *et al.*, 2010). This narrative persists in part because it's a relatively easy and familiar story to tell, and one which rings true for people who have been told they're not qualified for a job opening or can't get hired themselves (Kiviat, 2012). A disconnect between available jobs and people qualified to fill them “neatly serves many ideological masters,” and as a consequence offers something for everyone politically

⁴Critics are quick to point out, as we've seen before, that what counts as a “STEM job” largely determines the validity and accuracy of these projections.

(Kiviat, 2012). There is, of course, a difference between a skills shortage and a difficulty finding human capital at a price employers are willing to pay (Benderly, 2015).

Regardless of which estimate you use to calculate the number of STEM jobs likely to be available in the next 10-15 years, and even putting aside which jobs get to count as STEM, scholars and practitioners agree that employers filling these jobs will “overwhelmingly ... require college degrees or other post-secondary preparation ... [which is] quickly becoming the only viable path to the American middle class” (Carnevale *et al.*, 2010; Rosenblum and Spence, 2015, pg. 109). The nature of this kind of education and training will no doubt change with the economy, likely focusing on broader general education and skills instead of specific and narrowly defined qualifications (Carnevale *et al.*, 2010; Rosenblum and Spence, 2015). Indeed, the successful future in the U.S. of employment in general, and STEM employment in particular, “will require post-secondary education in one form or another” (Carnevale *et al.*, 2010, pg. 110). As a consequence of this, some suggest a shift in future worker conceptions of value in their own post-secondary preparation, more closely identifying with “the occupations they will be filling than to the specialized industries in which they work” (Carnevale *et al.*, 2011, pg. 111). When it comes to academia, jobs are often directly related to the subject of students’ doctoral theses (Auriol, 2010; Millar, 2013). However, employment in industry or as an entrepreneur may greatly depend on a student’s characteristics, as opposed to their actual degree (Fritsch and Krabel, 2012). These findings have significant implications for the skills and training students get as they move through their STEM PhD programs. Career goals for graduate students change over time (Helm *et al.*, 2012), skills training for both academic and government or industry jobs continues to fall short of employment in many ways (Helm *et al.*, 2012), and in many cases professional development or career advising

services are simply lacking or unavailable for these students (Helm *et al.*, 2012).

The Department of Defense (DoD) has a slightly different perspective on the STEM skills mismatch narrative than academia or industry. DoD may be facing a labor shortage of their own in the next 10-15 years due to baby boomer retirements (Base *et al.*, 2012; National Research Council *et al.*, 2012). In this case, however, the creation of an oversupply of scientists and engineers isn't actually a desirable outcome (Base *et al.*, 2012). Overwhelmingly, DoD depends on on-the-job skills training, *growing* rather than *graduating* engineers, for example (Base *et al.*, 2012). The percentage of foreign nationals entering the U.S. STEM workforce does nothing to address DoD's looming shortage, because those individuals largely aren't eligible for security clearances (Base *et al.*, 2012). Researchers and practitioners suggest that DoD might be well served by developing a strategy that builds in the uncertainty with respect to supply and demand for these jobs (Base *et al.*, 2012; National Research Council *et al.*, 2012; National Science Board, 2015).

An important caveat or qualification to this discussion is the research suggesting that even for those who do pursue STEM degrees, many won't work in those fields when they graduate (Charette, 2013; Oleson *et al.*, 2014; Lowell and Salzman, 2007). This causes some to wonder why we continue to push more students to pursue STEM as a degree path (Charette, 2013). Research suggests we do sometimes see shortages for certain specialists, but neither students nor career advisors can plan for those (Charette, 2013; Lowell and Salzman, 2007). Companies benefit from having a large labor pool, and the link in the U.S. between STEM higher education human capital and innovation, national defense, and economic competitiveness already generates an abundance of scientists and engineers (Charette, 2013; National Research Council *et al.*, 2012). The STEM crisis narrative also benefits higher education because universities can easily expand their enrollments when taxpayers continue to subsidize

STEM education (Charette, 2013). This leads some to suggest we would better served by creating more enduring and fulfilling STEM jobs (Charette, 2013; Oleson *et al.*, 2014).

2.0.4 *The Pursuit of a STEM PhD*

This, then, is the backdrop which frames the decisions real students have to make every day about what their post-graduate careers will look like. What do we know about why some students choose to pursue a STEM PhD and how this choice shapes the career options available to them in the future? Some STEM students perceive a PhD as necessary for career mobility (Gibbs and Griffin, 2013; National Association of Graduate-Professional Students (NAGPS), 2001). Diversion from a STEM career is mostly voluntary, and students' inability to find a job reflects both on the job and the candidate (Carnevale *et al.*, 2011). Student career paths are less simple and predictable than we might have previously thought (Mellors-Bourne *et al.*, 2010; Gibbs and Griffin, 2013). Several studies highlight the rationales either given by students themselves or gleaned from trends in the data. Perhaps most importantly, STEM majors overwhelmingly pursue PhDs largely for the love of research, not because they have specific career goals (Nyquist *et al.*, 1999; Blume-Kohout and Clack, 2013; Mellors-Bourne *et al.*, 2010; Gibbs and Griffin, 2013; Anonymous, 2010; Jones, 2003; Kolata, 2016). This has an even more significant set of consequences because career goals form the bulk of the conversations economists have about STEM human capital. Furthermore, some research suggests that when choosing a STEM PhD, students are poorly informed about future job prospects (Blume-Kohout and Clack, 2013; McAleavy, 2004; National Association of Graduate-Professional Students (NAGPS), 2001; Hartle and Galloway, 1996). As a result, some suggest we involve grad students in decisions that affect their education and career options (National Association of

Graduate-Professional Students (NAGPS), 2001; Hartle and Galloway, 1996; Austin *et al.*, 2009) and help inform career expectations of students and their faculty mentors simultaneously, so they can work together to help students make a post-secondary career choice that fits their values, expectations, and visions for themselves (Di Pierro, 2007; Hawthorne and Fyfe, 2015).

This post-secondary education decision has a whole host of job and career implications, as one can well imagine, but often those implications aren't well understood or communicated for a number of reasons. A significant contributor to uncertainty in this area has to do with the perception that the length of time it takes to finish a PhD makes it nearly impossible to keep up with the changing labor market. There are also significant incentives in place to keep training students even if the job market doesn't look good - labs still need research assistants, graduate programs still need students (Jones, 2003). This effect is further compounded by the research suggesting the number of years between a job seeker and completion of their degree is related to their eventual employment outcomes (Clark and Centra, 1985). An increase in the number of years spent in a PhD program may even lead to a decrease in a person's starting salary and long term earning potential (Potvin and Tai, 2012). In fact, for some specialities, the job market is more favorable and accessible for masters degree holders than for those people with a PhD. Data suggests, for example, that graduates of the NSF funded Professional Science Masters programs fill a gap in the workforce and are in high demand (Rogers, 2013). Furthermore, half of all STEM jobs require only an associates degree (Rothwell, 2013; OECD, 2015; Oleson *et al.*, 2014). These figures seem to contradict the assumption that a STEM PhD is the most practically valuable degree in a given STEM field.

Another major factor in the difficulty of communicating the career implications of post-secondary education decisions comes from the research suggesting that students

sometimes feel that the structures, policies, and practices in their degree programs threaten the value of their PhD once they leave (Nyquist *et al.*, 1999). For example, increases in university R& D funding incentivizes the admission of students on the margins, students who are less likely to finish their degrees (Blume-Kohout and Clack, 2013; Charette, 2013). Some scholars even suggest that the structure of U.S. graduate training in general creates a “culture of dependency” among students, in which they “are made economically or psychologically dependent on their professors and departments” (Kennedy, 2000, pg. 6). Furthermore, the argument continues, the culture of academia in the U.S. creates a sense of entitlement to an academic job for those who pursue a PhD; and yet those job seekers are expected “to make significant sacrifices in the pursuit of academic employment” (Kennedy, 2000, pg. 6). Additionally, students get mixed messages about priorities in the academy (Nyquist *et al.*, 1999). For example, students perceive that research is more important than teaching (Bergner *et al.*, 2015), but get paid either through research or teaching - and while they sometimes get instruction on how to conduct research (depending on their advisors), they rarely ever receive instruction or guidance on how to develop their teaching skills (Cassuto, 2016). Despite all this, students also indicate that they want balance in their personal and professional lives, but get the sense that balance is difficult with a faculty job (Mason *et al.*, 2009). Students still overwhelmingly get messaging that academia is the preferred career path (Sauermann and Roach, 2012; Conti and Visentin, 2015).

Often we don’t have to wait until students start job hunting to see how those degree programs shape their experience of their chosen field or their productivity as a scholar. Students are mostly satisfied with their PhD programs but are unclear on their own success or performance day to day (Golde and Dore, 2001). Students also want a broad range of skills and training (Golde and Dore, 2001; Nyquist and Woodford, 2000),

including teaching prep, management and communication skills, and help writing proposals, just to name a few (Nyquist and Woodford, 2000; Campbell *et al.*, 2005; Helm *et al.*, 2012). Additionally, and crucially important to our broader discussion, STEM PhD students report a relative scarcity of career awareness and development opportunities (Golde and Dore, 2001) and often don't take advantage of the few resources that are available (Helm *et al.*, 2012). The specialization necessary to earn a PhD makes it difficult for career offices to help place students (Anonymous, 2010; Jones, 2003). And yet we know that a little career development can significantly increase student success in the job market (Austin *et al.*, 2009); not only that, but it has also been demonstrated to improve student research quality (Trautmann and Krasny, 2006). With respect to teaching specifically, students overwhelmingly report feeling unprepared to teach (Golde and Dore, 2001; Baldwin, 1977; Austin *et al.*, 2009). And for those who are primarily considering research careers without teaching responsibilities, students feel well prepared for research, though not all aspects (Golde and Dore, 2001) and are wary of the academic fast track's reputation for overwork (Mason *et al.*, 2009).

2.0.5 *Employment after Graduation*

Those students who do earn a STEM PhD again find themselves at a crossroads as they try to navigate life (and employment) beyond school. In general, recent STEM graduates report still having optimism for their futures, whether in the academy or elsewhere (Golde and Dore, 2001; Pratt *et al.*, 2010). Students want their work to matter outside the lab and feel like academic research gives them freedom in deciding in which arenas to make their contributions (Gibbs and Griffin, 2013). Tenured professorships are an obvious first choice for those contributions, and a large number of students really do want faculty positions and think it's possible (Golde and Dore,

2001; Nyquist *et al.*, 1999).

Those who choose to seriously pursue professorships or academic careers often have to first pass through the gates of post-doc purgatory, a sometimes hazardous liminal space between schooling and profession. Firstly, we suspect ⁵ that there are more post-docs than faculty (Auriol, 2010; Blume-Kohout and Clack, 2013) and some even go so far as to characterize students who take successive post-doctoral appointments as a form of underemployment (Greenberg, 2001). Additionally, the number of students without post-grad commitments is rising, and the number of available post-docs hasn't kept up with increased production (Benderly, 2014). These positions are often regarded as cheap labor for labs (especially in the cases when professors and mentors don't treat post-docs as time-limited career development opportunities), and labs are just getting bigger, very likely increasing demand for post-docs (Stephan, 2012). And more time as a post-doc doesn't actually equal an increase in research productivity (Webber and Yang, 2015). Students often take these temporary postings partly because they don't think anything else is available (Jones, 2003), with some continuing to wonder if they'll ever get a permanent position (Carr, 2013). Many scholars and practitioners conclude that post-docs can be beneficial for an academic career, as long as those positions are relatively short and incredibly productive (Benderly, 2015).

When it comes to those elusive faculty positions, the oversupply of post-docs and newly minted PhDs is thrown into stark relief. The current faculty job market for new PhDs is extremely competitive (Barkume, 1997; Matthews, 2011), and some see this as an “unintended consequence of responding to specific societal needs” (Nyquist and Woodford, 2000). For example, data indicates the number of PhDs granted has tripled from 1964-1994, due in no small part to an increased proportion of women

⁵Since the definition of a post-doc changes from institution to institution, all the statistics for this phenomenon and somewhat problematic and incomplete when taken individually.

(Barkume, 1997). And in 1993, less than half of PhD level scientists and engineers worked in academic positions at educational institutions (Barkume, 1997). And sadly, faculty employment of STEM PhDs is low even with an outstanding research record (Aylesworth, 2008; McAleavy, 2004; Watson and Audrey, 2017; Maisel and Gaddy, 1997). Some are quick to point out that even if we employed every STEM PhD in a faculty position when they graduated, that doesn't mean that these problems in academic production are automatically solved, such as how much our systemically problematic employment data continues to shape the conversation about whether these students are getting the right kind of education for the careers to which they aspire (McDowell, 2016).

For those who choose to go outside academia when they graduate, the waters get murky quickly. The information concerning what industry employers look for in their STEM PhD employees is incredibly sparse to non-existent. However, in general, future industry employers look for advanced general education and skills rather than specialization (Carnevale *et al.*, 2010) but put a premium on demonstrated ability to think broadly and critically (Carr, 2013), creativity (Lee *et al.*, 2013), leadership (Anonymous, 2007; Nyquist and Woodford, 2000), teamwork, relationships, networking (Lee *et al.*, 2013), written and oral communication skills (Anonymous, 2007; Carr, 2013; G. Jensen and Pm, 0400; Lee *et al.*, 2013; Pratt *et al.*, 2010), and a working knowledge of marketing, economics, business (Anonymous, 2007) among others. Industry employers more recently highly value interdisciplinary scientists (Lucena, 2005), and students want to do interdisciplinary work (Golde and Dore, 2001), but many in industry warn that the “research output of doctoral researchers ... [is] seen as irrelevant by business” (Boddy, 2007). A number of universities and industries have partnered up to build stronger relationships in knowledge production and dissemination, and those efforts tend to center around graduate students (Thune, 2009).

PhD students who are central to these partnerships receive significantly different research training than those students not involved in such projects, and their work environments and culture are much more heterogeneous, leading some to conclude that these students are more attractive to industry employers (Garcia-Quevedo *et al.*, 2012) and that more students ought to have the opportunity to benefit from these kinds of opportunities (Thune, 2009).

2.0.6 *Mitigating Factors*

I've talked briefly about the complicated relationship we have in the United States between higher education and the imperatives of an educated citizenry, economic superiority, and national security. That frames the subsequent discussions of how real people interact with and experience the ecosystem which produces STEM PhDs in this country. Lots of smart people in many different sectors and branches of government have done important and transformative work to try and make these degrees valuable for everyone involved. Suffice it to say that the study presented in the following chapters is not the first, nor will it be the last word on this issue. If these degrees are as valuable, in demand, and desperately needed as our popular culture since World War II has led us to believe, why are newly minted STEM PhDs having such a hard time finding jobs when they graduate? Recent studies and research suggest that there are significant institutional and structural obstacles in the paths of recent graduates, and that those in power in these settings often have very little incentive to change their norms and practices.

First and foremost is a widespread culture of competition in academia which often gets more pronounced the further along someone is in their graduate studies. The competitive, sometimes cutthroat atmosphere has reached the level of cliché and meme, as evidenced by popular comic strips, twitter hashtags, and internet tropes

detailing the experience of many graduate students ⁶ . While often shared in good fun, do these kinds of jokes point to an attitude that tough experiences in grad school are an unfortunate but necessary component of making it in academia? Do we, as students, colleagues, mentors, and administrators actually think that the kind of uncertainty and struggle described in previous sections makes students stronger, or weeds out the ones too weak to survive? As one researcher points out, “After all, we made it through” (Nyquist *et al.*, 1999, pg. 10).

Perhaps a more charitable observation is that administrators and faculty struggle to see ways to actually change the structure of STEM graduate education fast enough to keep up with the shifting job market, which in turn makes it incredibly difficult to make academia a welcoming or supportive working environment. In many cases, maintaining a status quo with respect to the structure of these graduate programs is not only easier but more economical for universities and colleges. The linking of U.S. STEM Higher Education to the narratives of “informed democracy,” “national security,” and “economic competitiveness” created enormous demand for research and teaching assistants, and continued funding in many labs and departments depends on the “quality of research rather than the quality of graduate training” (Nyquist and Woodford, 2000, pg. 6). In fact, research universities have adapted themselves to the subsidized education of PhDs “as a byproduct of publicly funded research” (Dasgupta and David, 1994, pg. 25). This arrangement is plausible and works largely due to an incentive structure which doesn’t reward assistants for higher quality performance with higher pay (Dasgupta and David, 1994). Universities have no incentives to reduce their enrollments (Barkume, 1997) and an increase in funding for STEM PhD programs may actually worsen students’ job prospects (Massy and Goldman, 1995).

⁶<https://legogradstudent.tumblr.com/> , <http://phdcomics.com/> , to name a scant few (Accessed March 1, 2018)

The aforementioned original report presenting the pipeline model feeds directly into the scarcity and shortage narrative by predicting a drastic shortage of STEM PhD human capital and linking that phenomenon directly to our ability to protect our national interests and compete in the 21st century economy (Greenberg, 2001; Lucena, 2005; Lieff Benderly, 2012; Hartle and Galloway, 1996). An oversupply of scientists and engineers is viewed by policymakers and higher education institutions as important to our economy and national security (Charette, 2013; Anonymous, 2010).

2.0.7 Threat to Value

We will never have a complete accounting of the many ways in which students use their STEM PhD training, nor will we ever know for sure where every U.S. STEM PhD student goes to work after completing their degree, no matter how large the SED or SDR sample sizes get. We will never have a clear winner between the shortage and surplus narratives, nor will we ever have a complete list of all the skills and competencies students could possibly need in the workforce. These risks are not new, nor are their many contributing causes - and indeed, in the short term, we have somehow managed to create a system which has produced some of the most highly talented, innovative, and influential scientists and engineers of the past century. The ecosystem of STEM PhD production and employment as it stands thus poses a threat to the value of these degrees for the degree holders. These findings, and others beyond the scope of this chapter, strongly suggest a disconnect between what students are taught and how they are evaluated as they receive their advanced degrees, and what employers from all sectors are actively seeking and often failing to find in their STEM human capital recruitment efforts. I argue that these disconnects in terms of perceived and articulated value, and sometimes even areas of value erosion are actually risks present in and furthered by this ecosystem. These risks take the shape of threats

to value from the student perspective, from that of their future employers, and from that of the institutional frameworks which support and guide STEM PhD training in the U.S. Differing articulations of value also pose a risk to these degrees, not just in terms of their economic or personal value, but in their relationship with the guiding narratives of an informed citizenry, economic competitiveness, and national security with which we began this chapter.

Chapter 3

ASSUMED VALUE: ASU STEM PHD PROGRAM REQUIREMENTS AND STUDENT HANDBOOKS

Regardless of what scholars and academics may say on the subject, students ultimately pursue a PhD because they think it will be worth something to them in the future, either personally or professionally. They believe that the experiences that they gain in the process of earning this degree will qualify them for the next stage of their career in ways that none of their previous degrees have, or could. By the same token, institutions of higher education offer these degrees because they perceive a demand for which they can create a supply; they also use PhDs as a way of investing in the future, not just of their own organization but in their local communities. This chapter will build on the theoretical framework of threat to value introduced in Chapter 1, and the historical context provided in Chapter 2, in an effort to begin to understand the value of a STEM PhD from the perspective of the degree-granting institutions, before a student even enrolls in a specific program. Put quite simply, what do these colleges and universities think these degrees are *for*?

Due to the limited scope of this study, I focused this aspect of the research on one university's suite of STEM PhD programs, those of my home institution. The largest public university in the country, the mission of Arizona State University (ASU) is "To provide outstanding programs of undergraduate and graduate education, cutting-edge research, and public service for the citizens of the State of Arizona with special emphasis on the Phoenix metropolitan area."¹ With over 13,000 graduate students

¹Arizona State University Charter: <https://president.asu.edu/about/asucharter> (Accessed March 1, 2018)

(nearly 4,000 of whom are pursuing PhDs) and ranked in the top ten higher education institutions by research expenditures,² ASU provides an ideal setting in which to examine the value of a STEM PhD from the perspective of one of the premier academic institutions that produces individuals with such degrees.

In the past decade, ASU has restructured its traditional academic units and disciplines into schools of shared purpose, as opposed to traditional academic disciplines. For example, my own school brings together scientists, policy analysts, ethnographers, historians, futurists, and many others to envision ways in which we as a society might build a technological future that serves everyone, with a keen awareness of all the uncertainty and hazards involved in doing so. We're called the School for the Future of Innovation in Society, unique not only in its membership but in its structure and educational offerings. But as strange as that sounds, we're not unique among academic units at ASU writ large. You won't find a straightforward anthropology or ecology department here, but you might find both anthropologists and human ecologists in the School for Human Evolution and Social Change, for example.

While widely touted as one of the keys to our success as a school in recent years (and a large contributor to our continued ranking as Number One in Innovation according to U.S. News and World Report), the transdisciplinary nature of programs at ASU has a very practical consequence for this study. While certainly valued by those outside ASU (as evidenced by data presented and analyzed in future chapters), efforts at inter- and transdisciplinarity are more prevalent here than they are in the outside world. You would be hard pressed to find a single degree program at ASU which doesn't talk about interdisciplinarity at some point, or which doesn't actively seek out transdisciplinary partnerships across the university. This presents the biggest

²All of these facts and figures can be found at the University Office of Integrity Assurance website, which provides the most up-to-date statistics on student enrollment and university expenditures.

source of selection bias in using ASU as a case study for research investigating the value of any kind of degree program. In the following sections, I discuss the ways in which inter- and transdisciplinarity manifest as values in STEM PhD programs at ASU - but the frequency with which that organizational structure and aspiration are mentioned should not to be taken as evidence of greater importance compared with all the other things that this institution thinks makes these degrees valuable.

Individuals (in our case, students) are products of their position within an institution, and accomplish what they do based on the authority and resources granted by their organization (Wilson, 1989). There are crucial differences between how any organization operates and its structure, and both cannot function without coordination (Wilson, 1989). The artifacts of that coordination can tell us volumes about both the operation and structure of an institution, and also thereby how the organization conceptualizes the value of the products it produces. In the case of this study, the artifacts each department produces in their effort to recruit students to their various STEM PhD programs can tell us what the departments expect students to gain from the experience. From the outside, it is unclear who contributes to these documents, who reviews them, and the degree to which they guide faculty teaching practices or lesson planning. However, as often the first descriptions of these programs seen by students, they represent how each unit chooses to present itself to individuals interested in their degree program - and thus can tell us something about each unit's priorities when marketing themselves. In short, what each program *says* it's for.

When a student begins investigating possible degree options here at ASU, they are quickly directed to the online directory which contains all of the plans of study (POS) for each program. These documents contain the nuts and bolts of the application process, courses required as pre-requisites, and the necessary criteria for graduation. However, a POS also includes a program description written by the academic unit

offering the degree. These descriptions range from a few sentences to a full page, and are often one of the first things a prospective student sees as they evaluate their interest in the program. As such, this is a goldmine of information as to what the administrators and faculty of each program think a student will gain by participation and the expectations they might have for what possible future careers these degrees could enable.

Additionally, each degree program or academic unit produces a handbook each year, a guide and roadmap for current students as they navigate the sometimes treacherous waters towards graduation. Some are even publicly available on a program's website for people to browse through. Handbooks offer a wealth of practical information for students, but also provide a great indicator of what program directors think ought to matter to students as they move through their requirements. Taken in combination with the plans of study, this collection of documents paints a pretty complete picture of what the system values which produces these degrees, and what administration and faculty think they are for. Plans of study and student handbooks cannot, of course, tell us much of anything about whether or not an individual department achieved its self-defined metrics of success, i.e. whether the students got what they were meant to out of their PhD experience. However, as the first wave of documents and materials given to students as they enter each program, plans of study and handbooks can tell us a great deal about a department's expectations, priorities, and aspects of the structured experience more heavily valued than others.

This analysis includes POS documents for every PhD program at ASU which self-identifies as STEM (not including health sciences), coming to 34 in total. I excluded health sciences since they are more hapazardly considered as STEM in the literature and by higher education institutions in general (often depending on whether a college or univeristy has a medical school). The program handbooks for these degrees, while

not as numerous, span the breadth of STEM PhD offerings available at ASU. Some units produce one handbook for an entire school, such as the School of Earth and Space Exploration, despite the fact that they offer many individual PhD programs; other units, such as the Fulton Schools of Engineering, tend to produce unique handbooks for each degree. In addition to specific information about class registration and thesis deadlines, these documents include program descriptions, departmental priorities, explicit and implicit expectations of students: all of which, taken together, begin to frame the value of these degrees to students from the perspective of the academic unit. Specifically, this analysis focused on indications of value beginning with phrases like “as a student, you’ll develop ...” or “preparing students to ...” or “our program provides ...”, for example. Additionally, I included any mention of careers made possible by these degrees, jobs which the authors of such descriptions anticipated might value a particular degree, and priorities as laid out by the department. In the following sections, I begin by describing each aspect of value as evidenced by the POS documents, in addition to two cross-cutting themes which emerged from that data as a whole. The subsequent section details the articulations of value evidenced by student handbooks and how they either contrast or compliment the findings from the plans of study. Lastly, the chapter ends with a brief discussion about further influences on the nature and direction of these STEM PhD programs, and indeed graduate education as a whole, as a consequence of ASU’s status as a public university.

3.0.1 Plans of Study

By and large, departments at ASU indicate through the documents meant for prospective and new students that these degrees will prepare them for desirable future careers in academia, government, or industry; that they will receive research

training pertinent to those careers, in addition to necessary research experience and training on how to work on interdisciplinary teams; and that these degrees will provide them the opportunity to make a difference in their communities and in the world. Different programs emphasize and articulate each of these aspects differently, providing clues as to their perception of these degrees' value to students. As evidenced by these data, administrators, staff, and faculty attribute the value of a STEM PhD according to the following categories, also shown in Figure 3.1 at the end of the chapter.

Career Preparation

12 out of the 34 programs I evaluated put career preparation front and center in their description of what these degrees are for and what they expect students to get out of the degree experience. We might stereotypically assume that the majority of those 12 programs are some sort of engineering, as it is widely accepted that at least at the undergraduate level, engineers receive training and instruction more obviously directed at industry or government employment. However, at least at ASU, that assumption appears misguided. Not only do engineering programs represent less than half of this category of career preparation (including mechanical and aerospace engineering), but engineering is neatly distributed across nearly all the following categories of value ascribed to a STEM PhD. The rest of the programs that emphasize career preparation above other indicators of value include (but are not limited to) statistics, microbiology, and geological sciences. The mathematics programs cite demand for talented individuals in possible future careers: “More and more data is generated from Internet searching and the use of smartphones, causing projected demand for statisticians to increase 34 percent in the next 10 years. Your statistics PhD degree will train you to analyze this data ...” and “Demand for mathematicians is projected to grow 21 percent during the next 10 years.” Other programs tell students that these PhDs will

prepare them for “professional careers” in and across various disciplines, while others list the possible sectors of future employment. In the case of the latter, the list often has the same order of academia followed by government and then industry, indicating a possible ranked order of preference. PhD Biology (Science and Society) presents a slightly different list of career sectors: “Graduates choose careers in higher education, research, administration, policy and science communication.” What unites all these various programs, however, is the clear focus on career preparation in the articulation of value for these degrees.

Career and Research Training

This second category represents those few STEM PhD programs which emphasize career preparation and research training equally in their program descriptions. This is, of course, not to suggest that those in the previous section don’t care about research training. Rather, it suggests to me that in this limited advertising space, some programs expect students to be drawn to the degree due to different factors. The chemistry and physics PhD both describe their programs as producing independent scientists who will then have the right preparation to enter into a successful career. Here the emphasis is on independent research as a prerequisite for future employment. Perhaps as an artifact of a degree program at ASU, both chemistry and physics also cite the opportunity to be part of interdisciplinary research teams as a possible draw, but that aspect receives much less emphasis and relative importance. When mentioned, transdisciplinary work receives a brief mention of broader significance: for example, the last line of the physics PhD asserts “Transdisciplinary expertise of this nature is increasingly vital to modern science and technology.” This category clearly places slightly more value on training independent scientists, since they believe that will lead to rewarding employment for students.

Inter- or Transdisciplinary Experience

The next theme of value attributed to a STEM PhD from the student perspective involves a predominant emphasis on the opportunity to participate in world class inter- or transdisciplinary research. One of the major benefits of these programs, according to those who wrote these descriptions, includes the ability to tailor your degree program to meet “your own professional goals.” Rather than prescribe professional goals, programs in this category assert that inter- or transdisciplinary training is valuable in itself. Like the previous section, these programs also place value on creating “independent scientists.” For example, “The PhD program in biochemistry provides students with the training to be successful independent scientists who can contribute to current challenging societal issues.” This last sentiment reflects another feature of this group, namely the presentation of transdisciplinary research as a way to bridge science and society, work on the bench with real world solutions. To achieve this kind of connection, these degrees boast that they train students to think in an interdisciplinary way and to effectively collaborate across specialties. The fundamental assertion here is that interdisciplinary equals effective and relevant.

Research Experience

This next group places the most value on creating students trained in “leadership and excellence in research.” When careers are mentioned in these descriptions, it’s in terms of a career in research, without any mention of specific sectors or focuses. One engineering program in this category even has a program description mostly comprised of a list of areas of research emphasis. Additionally, a few cite creative scholarship as a valuable characteristic of their particular degree program, in addition to independent research (as with some discussed above), and the flexibility to design one’s own research program (again, echoed above). Very simply, the STEM PhDs in this category advertise themselves to students predominantly according to their ability to confer valuable research experience.

Research and Transdisciplinary Training

Programs in this next group place nearly equal emphasis on research skills and transdisciplinary work, merging the two previous groups in terms of value to students. Like the first group, some of these programs cite a high demand for scientists and researchers as a contributor of value. However, degrees in this group also seem to describe (either implicitly or explicitly) training a “new kind of scientist,” one with preeminent research skills but also the ability to contribute to social and global problems through a fluency with transdisciplinary work. For example, the human systems engineering PhD program asserts “Employers have an ever-increasing demand for personnel who can bridge the gap between rigorous science and solutions to real-world problems.” As such, these program descriptions place heavy emphasis on the opportunity to work on interdisciplinary research teams as part of the degree experience. The sustainable energy PhD says that pretty explicitly when they advertise that this degree “is designed to train students who can see beyond the boundaries of traditional methodologies and disciplinary viewpoints.”

Opportunity for Impact

Finally, the last category in the list of articulations of value according to plan of study program descriptions demonstrates heavy emphasis on the ability to make an impact. The degrees in this group all, in one way or another, describe their value in terms of teaching students how to solve complex real world problems. The sustainability PhD program says this most succinctly when it describes its students as “seeking solutions to a broad array of critical issues facing our society today.” It bears repeating that this categorization by no means suggests that career and research training aren’t important to the sustainability PhD, for example, but rather that their primary emphasis in their advertising to students rests on an opportunity to “make a difference.” As a corollary to impact, some of these programs describe passionate

students who want to generate knowledge directed specifically at addressing societal needs. The applied math PhD program makes this quite explicit by beginning their description with a question directed at the prospective student: “Are you passionate about making a difference in the world?” Regardless of other competencies valued by the degrees in this category, they place the most emphasis on their graduates’ ability to take their training into the world to solve problems not just after graduation, but in the very pursuit of their degree.

3.1 Plans of Study: Cross-Cutting Themes

In addition to the specific emphasis on career and research training, interdisciplinary work, and the opportunity for impact, some of the ASU STEM PhD plans of study documents indicate that departments value communication / professionalism and independence. And while this by no means suggests that these two aspects of graduate education don’t matter to those who don’t explicitly mention it in their student-facing documentation, they do merit special consideration in this analysis. Communication / professionalism and independence make another appearance in the data presented in Chapter 4, so what follows is an introduction to these themes from the institutional perspective, not the last word on the subject.

Communication and Professionalism

In the 34 self-identified STEM PhD programs offered at ASU, only two explicitly mention “communication” and “professionalism” as values in their student facing messaging on the POS. Both of these degrees operate out of the School for Engineering of Matter, Transport and Energy (SEMTE). Intrigued by this, I went to my personal and professional network to find someone who had done a PhD in either of those programs to ask about communication and professionalism: were these officially

incorporated into the curriculum? Explicitly mentioned by staff or faculty as major focuses of energy and effort in the department? After a few informal conversations, I learned that this emphasis is much more implicit than explicit in the graduate level training offered at SEMTE. Undergrads do take a course called “Engineering Profession,” described by one of my contacts as focused on “soft skills” usually ignored in school: communication with other disciplines, presentations, how to work effectively on teams, business acumen, and ethics. However, at the graduate level, things like communication and professionalism are much more a part of the culture than they are a part of the curriculum. Another contact reminded me that these (and all undergrad engineering) programs go through yearly ABET accreditation, which involves soliciting feedback from industry on how well students are meeting the objectives of the program. This includes both technical skills and ethics, awareness of how engineering relates to current social issues, etc. These factors begin to explain, in my view, why these values receive special treatment and explicit mention in the program descriptions for PhD programs in SEMTE.

“Independent”

I want to call attention to one more broad theme which manifested across several of the value categories, that of producing “independent” scientists or scholars. More than half of the STEM PhD programs offered at ASU seem to take pride in providing a set of classes and experiences which ultimately create independent PhDs. This is subtle and nuanced enough to defy a clear cause and effect explanation, so I’ll instead suggest that independence may perhaps be a trait to which scientists and engineers aspire, maybe due to their portrayal in popular culture or the nature of solitary lab work. Regardless, I believe it merits brief yet special attention in this section, especially in light of findings from subsequent chapters in this book. Accordingly, I’ll return to “independence” later in this study.

3.1.1 *Student Handbooks*

After finishing the analysis of STEM PhD program descriptions, in order to understand what the administration thinks is valuable about each of these degrees to students, I moved to the student and TA/RA handbooks which were publicly available for those same programs. These documents are meant to be a one-stop-shop of resources for students as they navigate course requirements, qualifying exams, publications, and dissertation defenses. While all handbooks have the same basic structure and categories of information, subtle differences between handbooks across these various programs at ASU add nuance and complexity to the program descriptions of the previous section.

One of the first sections a student comes across in these handbooks has to do with how their admission application will be evaluated by the admission committee. This includes a student's GPA, their major, their previous institutional affiliation, standardized test scores, and course performance - all ostensibly measures of a student's intellectual ability and their academic lineage. Students are also uniformly expected to submit a personal statement and letters of recommendation as part of their application. Some programs give explicit guidance as to what they expect to see in a personal statement. For example, the Industrial Engineering PhD handbook requires a student's statement to include professional goals, a description of past research experience, current research interests, and to identify specific faculty members the student would prefer to work with if accepted to the program. It's clear from this listing that the committee expects a student's letters of recommendation to provide some color to the student's resume and transcript, as is usually the case with such letters.

What about expectations of the student once they enter the program? The School

of Electrical, Computer, and Energy Engineering begins that section of their PhD handbook by clearly stating that “Academic excellence is expected of graduate students.” As evidenced by the contents of what follows, they take academic excellence to mean grade performance in graduate courses. For their students, the School of Earth and Space Exploration (SESE) builds on that sentiment by adding to the expectation of excellence by “demonstrat[ing] the capacity for independent, original research.” That section goes on to say that “Students are encouraged to begin their professional careers in science early by preparing their PhD research for publication in refereed journals.” Here we have a slight window into yet another category of institutional expectation, that of the direction of a student’s career once they graduate. SESE’s prescription is a subtle indicator that they expect students in their programs to pursue a career in the kind of environment which values peer reviewed journal articles. This is not to suggest that a refereed journal article is without value, far from it - but rather an acknowledgement that different employers in different sectors may look for other indicators of career readiness, an idea investigated much more thoroughly in Chapter 4.

The later sections in the handbooks available for STEM PhD programs at ASU focus more on specific requirements for passing one’s dissertation defense, followed by a laundry list of information and expectations which don’t fit neatly earlier in the document. For example, some provide a list of student organizations or a link to that information on the website. Here we see some of the themes from the individual program descriptions reinforced, most notably those of transdisciplinarity and professionalism. Turning again once more to the SESE handbook, I noticed an interesting complement to the kind of breadth of experience advertised in their graduate program POS documents. On one of the last content pages, the author says “Given the broad range of expertise necessary for the diverse research topics under study in

SESE, no single prescription for achievement of breadth from SESE can be defined. Therefore, the onus is on the advisor, as well as the student, to ensure that not only the specific knowledge and skills necessary for the degree are gained, but also that the value of educational and experiential breadth in the longer term interest of the student is considered.” This suggests that the administration in the school see it as their responsibility to provide the opportunities from which an interdisciplinary research experience could be derived, rather than charting a discrete course for a student to follow from admission to graduation. As the handbook says, this places enormous responsibility for success on the student and their advisor, a relationship echoed by other handbooks which stress the importance of a student choosing the “right advisor.” It’s unclear from these documents how a student might know whether their chosen faculty advisor is the “right” one for them, or how they might come to understand if their advisor can adequately help them construct a program which provides the “specific knowledge and skills necessary” in the context of their longer term interest. This is made especially difficult, of course, if a student has any uncertainty about their future career or research aspirations.

A few of these handbooks also have separate sections for professional conduct expected of their graduate students. These come mostly from the Fulton Schools of Engineering and the School of Engineering of Matter, Transport, and Energy, and appear in a paragraph titled “Renege.” It states (in slight variation across specific handbooks), “It is unethical for students to continue to seek or consider other employment opportunities once an offer has been accepted. [We] expect students to honor an acceptance and withdraw from all employment seeking activities.” It then goes on to list a series of punishments if a student fails to do so. In my estimation, this is the kind of admonition which usually makes its way into official documents because the administration has been negatively affected by examples of this kind of behavior on

the part of students. And while I'm certain that administration and faculty consider all the various aspects of what it means to be ethical and professional in a workplace environment, this paragraph stands out as a partial explanation for how they define professional behavior as indicated in the PhD program description. It's also notable that this paragraph doesn't appear in handbooks for programs more traditionally labeled as natural sciences.

3.1.2 *Great(er) Expectations*

Of course, as a public university, ASU is not solely responsible for its curriculum - it answers to the Arizona Board of Regents (ABOR), who set the strategic vision and programmatic aspirations for all public universities in Arizona. What, then, does ABOR expect of these STEM PhD programs, and graduate education at ASU in general? The most recent strategic vision document for ABOR³ describes their overall mission as one of "Impact[ing] Arizona." They split "impact" into four categories of goals, namely Educate, Achieve, Discover, and Impact. This first goal, Educate, speaks most directly to what they intend for students to get out of their degrees. Under Objectives, ABOR lists aspirations for increased diversity among the student body, quality and innovative learning experiences, a respectful atmosphere, all laudable and quite standard expectations for a public university. But they go on to say that they also want to "encourage public service, research experience, internships, clinical placements and other types of professional engagement as an integral part of the overall student experience; equip graduates with 21-st century communication, analytical and problem solving skills; produce graduates who are thoughtful, intellectually well-rounded and have an appreciation for lifelong learning." These as-

³Arizona Board of Regents 2018 Strategic Plan: <https://www.azregents.edu/impact-arizona/abor-strategic-plan> (Accessed January 1, 2018)

pirations are not STEM specific, of course, as they encompass the vision the Board has for their universities in general. But interestingly, here we see a couple of the themes from the documents analyzed in earlier sections of this chapter, most notably that of research experience, communication, and relevant training or skills. However, some of these other aspects, such as public service, and intellectually well-rounded don't feature in the explicit messaging about what administrators and faculty believe students ought to get out of their STEM PhD experience. Perhaps this is because they believe a student develops those competencies elsewhere in the university or in their private lives, or maybe they don't consider those traits and qualities as meriting special attention in the development of their PhD students.

From an analysis of the student-facing documents for each of the STEM PhD programs at ASU, as well as a brief look at the strategic vision for the student experience as a whole, we can begin to understand what ASU thinks these degrees are for. From the perspective of the institution, an ASU STEM PhD provides career and research preparatory training, inter- and trans-disciplinary research experience, and an opportunity to make an impact. Additionally, some of these degrees emphasize the development of communication / professionalism and individuality. A university's first responsibility is to its students, creating and supporting environments of growth and learning. And in the case of STEM PhDs at ASU, departments see the value of these degrees to students in terms of the skills and experiences described in these documents.

As valuable and instructive as these kinds of documents and guidance are to beginning to understand the value of a STEM PhD from the institutional perspective, they can only tell us so much about value to the ecosystem as a whole. There is, of course, an entire other group of stakeholders in this ecosystem who are just as heavily invested in producing this kind of high quality human capital, a group which goes

largely unheard in the academic literature on the subject. In the next chapter, we move from thinking about the value of a STEM PhD from the perspective of the students and their academic institutions to actually asking about that value of those who may ultimately hire them in the future.

Figure 3.1: STEM PhD Programs Offered at ASU, Organized Thematically by Primary Assertions of Value to Student.

Career Preparation	<ul style="list-style-type: none"> • Geological Sciences • Molecular and Cellular Biology • Biology (Biology and Society) • Microbiology • Speech and Hearing Science • Statistics • Materials Science and Engineering • Industrial Engineering • Aerospace Engineering • Mechanical Engineering • Engineering Education Systems and Design
Career and Research Training	<ul style="list-style-type: none"> • Astrophysics • Chemistry • Physics
Inter/ Transdisciplinary	<ul style="list-style-type: none"> • Evolutionary Biology • Systems Engineering • Human Systems Engineering • Sustainable Energy • Neuroscience • Environmental Life Sciences • Mathematics Education
Research	<ul style="list-style-type: none"> • Biology • Biomedical Informatics • Chemical Engineering • Electrical Engineering
Research and Inter/ Transdisciplinary	<ul style="list-style-type: none"> • Exploration Systems and Design • Applied Mathematics for the Life and Social Sciences • Biological Design • Civil, Environmental, and Sustainable Engineering
Impact	<ul style="list-style-type: none"> • Sustainability • Biochemistry • Applied Mathematics • Environmental Social Science • Electrical Engineering (Arts, Media, and Engineering)

Chapter 4

VALUE AND VALUES IN THE PRIVATE SECTOR

In the previous chapters, I've highlighted the context and academic arguments surrounding the employability of STEM PhDs, and the value that's assigned to STEM PhD programs as they are presented to students in their recruitment and program documents. I'd like to turn now to the individuals and organizations who ultimately hire these students when they graduate. For the purpose of this study, I have chosen to exclude the academic positions for which STEM PhDs may be eligible. This is a crucial area of investigation, but that path has already been well worn by others before me (Carnevale *et al.*, 2011; Teitelbaum, 2014; National Research Council Staff, 2000). Instead, this chapter will focus on the traditionally less discussed “non-academic” career options for students who choose not to pursue a faculty or university research position. So where do these people go if not into academia? According to the NSF Survey of Doctoral Recipients, more than half of the surveyed doctoral scientists and engineers reported employment with private, not-for-profit or for-profit organizations, in addition to local, state, and federal governmental institutions.¹ And while of course this survey is not a full accounting of the various jobs and careers individuals pursue after they earn a STEM PhD, this data does suggest that a large number of those students choose non-academic career paths. This chapter focuses on beginning to understand the value of a STEM PhD to those non-academic employers who represent such a large slice of what individuals choose to pursue after they earn their doctorate.

¹NSF Survey of Doctoral Recipients. (2013). Table 42: Employed doctoral scientists and engineers, by occupation and sector of employment: 2013. (Accessed January 1, 2018)

We could easily imagine the pros and cons of working outside academia, based on our own experience or those of our friends and colleagues, but one of the biggest overall advantages as described by one of my contacts at a large multinational tech company involved access to resources which enabled cutting edge innovation;

“It doesn’t exist in universities, like maybe there are research chips that are done and stuff like that, but as far as figuring out how the actual bleeding edge stuff is being made and what’s available, no university has a tenth or a hundredth of the money necessary to even explore that. So it only happens in industry, in companies that have huge bankrolls. And it only happens by people who have been there doing that before, which means the only way to get that kind of training is to actually be in industry.”

Of course, some university, government, and industry partners have begun ventures like technology transfer as a mechanism for distributing the intellectual and practical heavy lifting necessary to take an innovation off the drawing board and into the market (Krugman, 1979; Bozeman, 2000). As mentioned in a previous chapter, the 1980 Bayh-Dole Act helped to codify and incentivize this kind of relationship by giving universities, among others, the ability to retain the intellectual property they create in partnership with the federal government.² But those partnerships, and others created between individual companies and university departments, don’t always translate into the kind of experiences for students which might help them understand not only what working in industry is “actually” like, but also clue them into the multitude of jobs and careers that may be available to them outside academia once they graduate. We know from the literature that some industry employers seem to be experiencing a skills mismatch between what they’re looking for in their STEM human capital and the capabilities offered by the people who apply to those open positions (Charette, 2016; Carnevale *et al.*, 2010; Rosenblum and Spence, 2015); we also know that certain sectors feel as though there is a shortage of interested and avail-

²Code of Federal Regulations 37 C.F.R. 401 and 35 U.S.C. 200-212. (Accessed March 1, 2018)

able talent to draw upon (Teitelbaum, 2003; Base *et al.*, 2012). And yet, the Survey of Earned Doctorate statistics for the most recent year, as discussed in Chapter 2, show record underemployment for people graduating with STEM PhDs in the U.S.³ So what's the disconnect? Are there invisible roadblocks or missing qualifications keeping these highly talented individuals from filling the needs of these industry and government employers? I wanted to find out.

4.0.1 What does industry say they value in their technical human capital?

This chapter describes the generation of new data on the value of a STEM PhD from the employer perspective, through a series of interviews I conducted with HR managers, researchers, vice presidents, and research directors at some of the biggest companies and organizations who hire people with a STEM PhD. This kind of data exists for other kinds of degrees, but is an area of relatively untapped exploration for STEM PhDs in particular. The analysis of this rich interview data involved the creation of a standard thematic codebook based on my interviewees' responses, which was then applied to each interview in order to draw out broad themes in the data. I go into a more detailed explanation of the method by which this codebook was created later in this section.

We can have all the academic arguments we want about “where the jobs are” or where we draw the line in the sand between academia and the private / public sectors - but when it comes time for a PhD student to start looking for their first job after graduation, what matters to them in that moment is which companies and organizations have job openings that match the student's search terms. To identify prospective interviewees, I created a database of search terms which closely aligned with the STEM PhDs offered at ASU, programs which feature in the previous chapter.

³NSF Survey of Earned Doctorates. (2016). (Accessed Jan 1, 2018)

I then fed these terms to job-hosting sites such as Indeed.com, LinkedIn, and USA Jobs, and from that generated a list of companies and organizations with job openings that matched the search terms. My final list comprised 86 organizations, companies, and departments spanning multiple sectors and varieties of job descriptions (this list is included as an appendix). While by no means an exhaustive representation of “where the jobs are,” it provides a representative snapshot of companies and organizations outside of academia currently seeking individuals with a STEM PhD qualification.

With this list, I used a combination of snowball sampling to identify target interviewees at as many of these companies or organizations for which I had personal and professional contacts. I was most interested in speaking with hiring / recruitment managers or individuals who drove the research vision of their respective organizations. All told, I interviewed 17 people representing experiences and viewpoints from multiple sectors and various levels of participation in their own organizations. 70 percent of my interviewees chose to remain anonymous, so I’ve chosen to attribute all of my quoted data with broad and general descriptions of what they do and what kind of employer they work for, in order to avoid spotlighting a handful of names in a sea of generalizations.

I built this approach around the perspective of the student as they search for jobs following graduation, and its power lies in that student perspective and the new insights it brought to this question of the value of a STEM PhD. It had practical advantages but also a few notable drawbacks. Firstly, more jobs exist for individuals with a STEM PhD than are advertised on these kinds of websites. This means that I have a source of selection bias at the beginning of this process. It also represents the landscape of available positions at a moment in time, and with the availability and ease of posting job opportunities online, this landscape shifts by the hour. And of course, there are employers who hire individuals with a STEM PhD for positions

that wouldn't match any of the search terms I generated, so that places a further limit on the interview data I ultimately collected.

Interviewees were given the opportunity to participate anonymously, or attributed by whatever combination of name and affiliation best met their needs and those of their organization's communications department and legal teams. This, in combination with the fact that I recorded these interviews for transcription later, did prevent a few individuals from consenting to be interviewed - specifically, either because they held an active Top Secret clearance and required prior approval to be recorded in any setting, or because their company's legal teams advised them against participating.

Very practically, I wanted to interview people who had seen enough STEM PhD resumes and job applications to give me a sense of general themes and trends in terms of what they selected for. I also wanted to get a sense for what they themselves valued about their own work experience, and any advice they might have for their past selves or students just beginning to search for jobs. I began these interviews by asking how he or she first came to work at their present job, including their educational background and what drew them to their organization. While some of this information could be found on their resume, I was interested in how they described these data and the articulations of value that came from explaining why they chose which job (as opposed to the simple fact of their employment). The interviews moved to what they valued most about working where they do, a question which surprised some people but yielded some incredibly rich responses. Next we discussed specific skills or abilities they have that help them the most in their work, including classes/workshops they were particularly grateful they took in school or those they wish in hindsight that they had taken. I was hoping that this set of questions might result in direct and specific insight into areas of possible value disconnect between the way we train STEM PhDs and what they might ultimately find useful in their future employment.

After that set of introductory questions (which took anywhere from five minutes to fifteen depending on the person), the interview moved to skills or abilities they specifically looked for when hiring STEM PhDs out of graduate school. This included questions about what might disqualify someone from working with them and what really excited them when they saw it on a resume. I also asked if they had noticed any trends in the STEM PhDs who had been applying to work with them recently, and if the STEM PhDs they themselves worked with had any traits or characteristics in common. I designed this set of questions to get some clarity on how the value of STEM PhD human capital is operationalized at these various organizations and in these sectors - that is to say, if these people could build their ideal STEM PhD-qualified employee, what would he or she look like? Since students are future employees, this was all in an effort to shine some light on areas of possible value alignment, value disconnect, and value erosion in terms of what an ideal STEM PhD employee vs student might look like. Are there things we could do while students are still in school to better set them up for that transition, or give them access to more future career options?

I then concluded my interviews by asking a couple of questions designed to get my interviewees to do some metacognition about their employment experience as a whole: knowing what you know now, what advice would you give your former self as he or she applied to their first job? What advice might you have for a STEM PhD who wanted to work at your company? While each person's responses were of course tailored to their own experience, the advice given coalesced around a handful of themes both personal and professional (the interview protocol is included as an appendix).

These interviews yielded a rich dataset which I then inductively coded with the assistance of a masters student. Here, "coding" means classifying interviewees' re-

sponses according to categories and themes which emerge from the data. I chose this approach because I wanted to generate findings which emerged from the data as opposed to testing a hypothesis, in order to make generalizations about the value of a STEM PhD based on my interviewees' specific responses (Saldana, 2015).

To start, I transcribed all of the interviews and then made notes for each as to general themes and observations I pulled from reading them for the first time since conducting the interview. My second coder and I then cycled between inductively coding one or two interviews separately, coming together to discuss our codes and their application, reaching a consensus, and then using those new consensus-driven codes on another interview (Saldana, 2015; Auerbach and Silverstein, 2003). We repeated this process until we no longer felt we had to make changes to the collection of codes, or codebook, in order to capture the valuable aspects of each interview and how they related to the research questions. I also calculated Cohen's Kappa values for a few of our codes in an effort to gauge the degree to which my coder and I agreed (Blackman Nicole J.-M. and Koval John J., 2000; Hsu and Field, 2003), but found that metric rather unhelpful for this particular analysis. The unit of coding was a sentence, and due to the semi-structured and informal nature of the interviews, several sentences had more than one code applied to them. Additionally, since each interview was at least a half hour long, each was regularly upwards of 100 sentences. Due to the math involved in calculating Cohen's Kappa, the large number of total possible coded sentences strongly outweighed the handful of times my coder and I would use each code, thus giving the illusion of near perfect agreement every time. As a consequence, I will not be presenting kappa values for each of the codes in the book, but rather describing each code's application. After my second coder and I finished the codebook, I recruited one more outside coder to ensure the integrity of the analysis. Both my second and third coders volunteered to participate in this research and were compensated for their

time. Once the entire data set was fully coded, I organized similarly grouped coded data into categories of shared characteristics. This classification revealed patterns of value in the data which pertain to basic qualifications and perspectives, the nuts and bolts of the hiring process, and intangible characteristics these employers look for in potential employees.

4.0.2 *PART ONE: The Basics*

In this first section, I want to focus on what my interviewees suggested were pre-requisites when considering STEM PhD job candidates. These include things like high academic achievement, their publication record, and their intellectual lineage (who their advisor was, which program at which school they went to, etc). As discussed above, I also very explicitly asked what they valued the most about working where they did, and if there was anything that got my respondents really excited when they saw it on a resume, which surprisingly coalesced into a few discrete categories of skills, experience, or observations which I'll discuss in this section as well.

Academic achievement, publications, intellectual lineage

The people I spoke with certainly placed value in these more traditional and tangible markers of talent and ability, but discussed them in terms of being a pre-requisite for consideration in the company / organization. For example, an acting deputy division director at a federal agency told me “when I look at a resume I am first of all looking at the courses that the candidate has taken and you know, certainly their grades are important because I think that reflects overall their aptitude.” A hiring manager at a multinational tech company described a very similar process when she said “as we look for PhD students, we do pay attention to what kinds of publications they have, who their professor is, which school they go to, which department, advi-

sor's history, whatnot." Academic achievement, publications, and intellectual lineage clearly matter at an early level in a job application with these kinds of companies and organizations - they're looking for the best talent available to them, and these kinds of metrics are a quick and easy way to establish "best" among a pool of applicants. This was a sentiment expanded upon by a director at a national lab when he told me "It's not just collecting merit badges and gold stars, it's given you're gonna apply to a job at a place like [my lab] that you've achieved some level of performance that's been graded." I had a number of people at various organizations describe variations on this theme - not so much dismissive of these merit badges and gold stars, but rather an assertion that we wouldn't get to talking about the candidate seriously if these things were absent on a resume. These are first order considerations almost discussed as "givens," the mere presence of which was unremarkable. It seemed to me that the "real value" in these markers was in what each individual candidate did with them. For example, a vice president at a multinational tech company told me "I like to see the projects they've done because you know, the degrees and all that are very good and are fine. If you've gone through a PhD, you're obviously a good student and know what the work is. But I try to look at what kind of work they've done, how they've applied their knowledge."

"the process"

A majority of my interviewees discussed the value of the PhD credential in terms of skills and abilities students gained during "the process" of completing their degrees. These include both very practical skills of research design, management, and problem formulation (among others), but also traits students developed along the way, such as grit and persistence. A few of my interviewees had STEM PhDs themselves, and one such software engineer at a multinational technology company expressed this idea

the most clearly when he said “I guess in a lot of ways, the useful incidental skills I learned to be a PhD student were the things that were the most directly applicable to industry.” A director of a university affiliated research center (UARC) built on this idea when he said,

“it’s the process for what you have to do to have a thesis issued. You get to get the credential. The process of knowing that I can take somebody and plug them in and they know how to do original work, they know how to do that research, they know the process. They have the energy and thirst and motivations and all that to do it. It might not necessarily mean they’re gonna leverage their thesis work in the process, it means they know how to do it as if it were a thesis with fresh material.”

This emphasis on “the process” ran through more than half of my interviews, and experience with this kind of process emerged in the data as a basic aspect of what distinguished the value of someone with a STEM PhD. A few people were careful to clarify that these kinds of skills were not necessarily exclusive to a STEM PhD - for example, I had someone tell me that in his experience, “having the degree is a good indicator for that expertise, not having the degree is not an indicator for not having that expertise.” While “the process” meant slightly different things to different interviewees, often according to whether or not they had direct experience in or with a PhD program, the employers I spoke with seemed to value the ability to successfully undertake a research project of one’s own design, almost regardless of the specific focus of the project. This demonstrated to them that the individual in question would be able to replicate that process for them, the employer, as opposed to an individual with a different kind of degree or credential.

Knowledge generation, knowledge implementation, execution

This observation goes hand in hand with other skills highly prized by the people I talked with, including “knowledge generation,” “knowledge implementation,” and “execution.” Different people at different organizations had varying interpretations

of whether a PhD demonstrated the ability to generate knowledge or implement it. For example, a director at a national lab had a very instrumental view of what it meant to do a PhD: “So I mean, stripped down completely, it’s not necessarily about intellect as much as it is about due diligence, understanding what the rules are, and having enough intellect to follow those rules and to do what you’re told well.” This was how he viewed the value of a PhD as opposed to some other kind of degree, and an ability that he witnessed in his colleagues who themselves had STEM PhDs. On the one hand, the more academic work environments (national labs, research labs associated with universities, etc) also seemed to see someone with a PhD as someone who generates new knowledge, who advances the state of the art: a manager at a federally funded research and development center (FFRDC) expressed this quite succinctly when he said “I like a person who can write a new book more than I like the person who can learn everything in a book.” Private sector companies and multinational corporations, on the other hand, seemed to perceive a PhD as someone who was able to take knowledge generated by themselves or others and implement it in new and transformative ways. A vice president at a multinational corporation told me he saw value in a PhD because of “the analytical process, the creative thinking, interaction with people are the ones that can solve the problem. Rather than ‘I know what my field is and I can do it.’” Whether they saw the value in a PhD in terms of knowledge generation or implementation, a substantial number of my interviewees described follow-through or commitment as something they viewed very positively, something I’m terming “execution.” For example, an engineer at a large tech company told me that sometimes in his experience (as someone with a STEM PhD himself) “the project may not be fully fleshed out, they’re just telling you to fix something. They don’t have any clue what a fixed project looks like at the end of the day, they may not understand the problem. You’re the one responsible at the end of

the day.” If you managed to earn a PhD, that showed employers that you had the ability to design and execute a complex project, an ability they valued.

Skills match

It seems to matter a great deal to employers that candidates for a position have the right set of skills for the open position in question. This observation borders on the obvious, but informed the ways in which my interviewees described how they determined if someone was a good “skills match.” One of the people I talked to (who himself has a STEM PhD) vividly remembers how he tried to demonstrate he was a good skills match for his current position when he applied, “sell[ing] the problem solving skill set that I have and obviously the technical side of it is in my background, so I’ll just tell them how I solve problems and why I’m a decent fit for what they do.” The recruitment managers I talked with spoke a great deal about scanning for “keywords” which they used as a first order screening mechanism, especially when they themselves didn’t have a background in the field represented by the job opening.

“Basically when I scan resumes I’m like a machine in terms of scanning the keywords. Because unfortunately as a recruiter, there might be, there are recruiters who have computer science and electrical engineering backgrounds who can really understand what they see on the resume. But there are other people like me who didn’t have any engineering education and I’m at a recruiter job to sort and screen engineering students. So without a lot of deep understanding, the first thing to do is to really look for the keywords that the hiring managers share with me.”

She didn’t feel like she had the expertise to read between the lines in someone’s resume and understand what various experiences meant, so she relied on keywords as a proxy for expertise in the area. Often these keywords would come from the managers or individuals in the departments that were hiring. Most of the people I talked with had a good idea of what a good “skills match” would look like for them. A director of a UARC told me “So there has to be a skill set that has a technical component that is a reasonably good match. So they can make contributions to the statement of work

accordingly.” One of my interviewees, himself with a STEM PhD, who was recently hired by a large multinational tech company reflected on this process when he said “I have since been on the other side of the interview table many many times because we are growing a lot, and there were definitely some times where somebody bombed the technical problem even though they seem like a great person, they just did not demonstrate that they had any of the expertise that we needed.” In this case, the lack of a skills match was a more important decision-making factor than whether the candidate “seemed like a great person” - amiability is not enough. A hiring manager at a multinational tech company put a finer point on this observation, since in her own experience “the only thing I can think of [that would disqualify someone from working there] would be if they’re truly looking for maybe a niche technical skill and or approach to problem solving and someone has something kinda opposite that would say ok, this person would probably steer in this direction and we want someone to steer in this other direction.”

Additionally, a couple of people described a shift during their careers as to which kinds of skills they found more valuable or useful in their work environments, with technical acumen as highly prized as they first started, followed by interpersonal and relational skills meaning more as they climbed the corporate ladder and their responsibilities shifted. The most articulate expression of this observation came from a retired fellow at a multinational defense contractor:

“When I first worked for [a national lab] and [a defense contractor], the skills that mattered the most were my technical skills. That was definitely true through the time I was in my late 40s. But then in the second half of my career, as I took on more technical leadership responsibilities rather than just to solve problems, the skill sets changed. And I felt that I was very blessed at that time to have gotten my undergrad degree at a four year liberal arts school. Because even though I was a physics major, there was a greater emphasis on a more well rounded development of person and the communication skills I learned, the interpersonal relationship skills I learned ... Those skills turned out in the end to be the ones that were the most significant. I had to have the technical background and the union card I guess that comes with having a PhD. But that was kinda

the foundation. These other skills ended up being much more important in the latter part of my career.”

So not only do the employers I spoke with value a technical skills match with their STEM PhD human capital, they also observed that there were other skills which added value to their company or organization.

Degree focus vs project

Overwhelmingly, my interviewees described in one way or another a value tension I’ll describe as “degree focus vs project.” The specific degree focus matters in that it is another indicator of whether a candidate might be a good “skills match” for the open position, but that seems to matter less to employers than the thesis project which engendered “the process” I described above. For example, a director at a University Affiliated Research Center (UARC) described the advice he gave his own son as he was considering doing an advanced degree, which boiled down to “the thesis topic, whether it’s masters or PhD, may or may not be relevant to what job you take next. The process of actually getting issued your degree meaning that you’ve had enough awareness of what’s required to do original work, and it’s that process to do original work that becomes very important, not the specific work itself.” While closely coupled with “the process,” this deserved its own code because the people I talked with almost always described this sentiment as this kind of juxtaposition, as if they were aware of the degree to which the degree focus matters in the course of the PhD, and how much it matters to the PI or the student getting the degree. A hiring manager at another UARC told me that this trend continues well into some of her colleagues’ employment, since “at least half of our PhDs are working out of field. So they’re not married to their degree focus.” And a vice president at a multinational corporation echoed this when he said “I direct a data science team and I don’t think I’ve hired

a single data scientist. Because it's how you expand your domain of capability onto the job at hand." One of my interviewees who has a STEM PhD himself remembers his own hiring process vividly, and while recounting some of the details to me he remarked that "what I was interviewing for was completely unrelated to my research." But often the tone my respondents used when describing this juxtaposition to me was one of reassurance, almost "we know right now your degree focus really matters, but we want you to know that once you graduate, it matters much less than the thesis project and what you learned doing that project."

Career flexibility, flexibility within organization

Some interviewees expressed the value they placed on being able to move around within their organizations or companies. For example, vice president for a multinational tech company told me that "The good thing about [where I work] is you can do that within the company itself without having to sort of you know, go look for another job as well." As a corollary, many people I spoke with highlighted the new and flexible ways people are getting the kind of skills that make them valuable in the workforce, not just their degrees. A hiring manager at a multinational tech company expressed this when she described how the people she screens seem to be taking advantage of this trend, "you see that much more in the software space, people maybe want to change careers, so coming into an entry level software position and they did a six month or six week coding academy or something like that." Additionally, another hiring manager hearkened back to the conversation about matching skills and degree focus while highlighting career flexibility when she noted "at [the PhD level] it doesn't matter your degree, it's your experience level and if you have those soft skills to kinda transition around."

System

That brings us to a theme which was less discussed than some of the themes discussed above, and which generally came up as people were describing their roles or their organizations to me: “the system.” My conversations with a few individuals included some of what they perceived to be misperceptions about working in industry, including what it was like to be part of a huge company. One hiring manager told me she wished people understood that, “Yeah, ultimately you work with individuals and that big machine, and I dunno, maybe there might be frustrations on the system and how the process gets in the way? But the process is administered by people you work closely with, people in your team, people working closely with your team.” At the end of the day, the system is made of people, and my interviewees who talked about “the system” did so in terms of the people involved.

Community Development

This next code emerged as a theme in the data as I asked people what they got the most excited by when they saw it on a resume, and was one that I was frankly not expecting to be as pervasive as it was. More than half of my interviewees told me that they really liked to see volunteering, team sports, church involvement, fraternities or sororities, etc; the kind of community development activities which signalled curiosity, passion, drive, and leadership. For example, a director of a UARC likes to see “if they have hobbies, if they have lifestyles or whatever, [because] they show genuine curiosity as they’re going through life, that’s always a very good thing for me to see.” One senior fellow at a multinational tech company gave me one more layer of specificity when he said “I look for team sports, what do you do outside your normal day? Do you have activities in your past where you’ve worked together in a team in sports or team group for community development?” And when paging through resumes a vice

president of research at a multinational tech company always asks herself,

“is there something else you’ve done and that something else you’ve been equally successful at? It could be anything, it could be some volunteer activity or could just be a hobby that you have, but because of the hobby you’ve spawned a little business and you were reasonably successful. Those kinds of things are also very interesting and attractive because it shows that if you have passion you will go after it and make it happen.”

Like “keywords,” “community development” seemed to serve as a proxy for some of the more intangible character traits that didn’t make it through on a resume otherwise. A manager at a federal agency told me she gets excited by:

“a well-rounded applicant. I mean some of them can have a very strong technical background and they don’t have policy or other experiences. But leadership too is important. You can pretty much see in the resume if you see an applicant who has done a lot of leadership experience that they would be the person that’s the go-getter. So I think involvement in communities or clubs or whatnot and in leadership roles is really important.”

This is so interesting because of how prevalent this sentiment (and others like it) was across the data set, but also because it’s something that’s actively dissuaded in some cases while students work on their PhDs⁴. Students, STEM PhDs in particular, are often told by professors or advisors that if it doesn’t matter to the dissertation, it isn’t worth doing. Furthermore, community development didn’t feature at all in the program documents or handbooks for STEM PhD programs at ASU, beyond the general assertion that social impact matters. But if those kinds of volunteer or extracurricular activities matter as much to “industry” employers as it did to the individuals I spoke with, dissuasion from such could be doing our students a huge disservice if they’re interested at all in a career outside academia.

⁴This kind of anecdotal evidence features heavily in the advice columns in publications like *Nature* and *The Chronicle of Higher Education*, and in discussions students have in places like *Alternative PhD Careers*, a LinkedIn support group for students trying to figure out what to do with their degree absent a desire to stay in academia

Leadership

I wanted to discuss this code immediately following “community development” because my respondents sometimes described the former as an indicator of the latter. A vice president of a multinational corporation linked these two themes when he said that he didn’t get excited by “one thing, but something that shows the promise and potential, so either folks that have volunteered, served in leadership positions, certainly awards and recognition that these are folks with promise - any exposure to industry, through internships ... You know again, it’s things like leadership positions, it’s folks that have done something different.” But importantly, a good number of people I talked with described “leadership” as a quality they valued in their STEM PhD applicants, and which manifested itself in various ways on the resume and during the interview process. One of my interviewees, a manager at a UARC, said that she was particularly interested in STEM PhD candidates who had leadership experience because she was keeping an eye out for her future replacement:

“And I’m always looking for people who may have leadership skills, because those don’t naturally happen within a lot of the - I shouldn’t say that, it’s stereotyping. But a lot of the folks who have the really deep critical technical interest and skills do not really have an interest or the soft skills to become leaders one day. And they don’t really want to either by the way. In fact I think they would feel like it’s a waste of their time to do that. Time is better spent down in the lab with their sleeves rolled up getting their hands dirty, figuratively ... [but I get excited by leadership] because if they can do both, it’s rare to find but if they can do both, then I have a future replacement for me or one of my assistants from one of my sections.”

Here we start to touch on some of the stereotypes surrounding people who earn these kinds of degrees and spend their careers in research, something that becomes a bit more pronounced later in the chapter. But unlike something like “the process” or a skills match, leadership wasn’t discussed as a pre-requisite for consideration, but rather a cherry on top which made a candidate stand out among the rest. A few of my interviewees even indicated that they viewed leadership as a capability that

someone could grow into once they were hired into an organization - like the manager at a national lab who told me “if someone with a masters comes in I’ll pair them with a principal investigator, someone who has been here for some time and that seems to facilitate that transition into a leader role.” And while leadership experience was something that was relatively obvious on a resume, my respondents also sometimes saw that quality manifest itself in interviews or other sections of the application.

4.0.3 *PART TWO: Nuts and Bolts*

One of the last questions I asked my interviewees concerned advice that they might have for their former selves as he or she entered the workforce for the first time, and advice they would give STEM PhD students who wanted to apply to work for their company. This second section is all about the very practical aspects of what it takes to get a non-academic job according to my interviewees.

Networking / professional connections

Firstly, people told me that students have to do more than just send in an application to even be considered for a position. At a large and prestigious federally funded research and development center (FFRDC), for example, the stack of applicants is so deep that my interviewee said “I’ll be convinced by what’s on their resume. But I’ll never know they exist unless I see their resume.” He went on to tell me that unless a student reaches out to him or a PI, or is someone specifically recommended by a professional contact, that there’s no way that resume will even reach his desk. This would be much easier if “they could be making contacts that would help them when they graduate. They don’t know that they need contacts.” More than half my interviewees emphasized the importance of these kinds of networking and professional connections during the pre-application process. One even told me that she preferred

if students asked to set up a quick phone call to introduce themselves and ask about a position: “emailing is fine, the email could easily be ignored though if it’s from an unknown outside a call is more disruptive, it’s attention getting - you’re gonna remember that call.”

Job research

Secondly, nearly all of the people I talked with told me that they would have suggested to their past selves and would advise current students to do their research on available jobs before they started any applications. For example, a hiring manager at a multinational tech company told me that “I was so focused on the degree itself and getting good grades and that was all that mattered, but now that I think about it I would really learn about different career paths that are available out there and different companies that offer them.” There are too many examples to list here of all the ways in which participants admonished students to do some research as to who might want to hire them, but a director of a UARC put it quite succinctly when he observed that “for investigative minds as we’ve trained them to be, I don’t find them always looking at the marketplace in terms of where their services might be highly appreciated as much as we’d think.”

“the money”

A few of my interviewees also wanted to pass on to students advice about not getting caught up in the dollar value of a paycheck as the primary way of determining whether or not to take a job. A vice president of a multinational tech company recounted advice that she gives her daughter, and that she wishes someone had given her when she was applying to jobs out of grad school: “it’s not always about the money, that’s what I tell my daughter. It’s not always about the money, but if you have a good

degree and you've studied in a STEM field you'll always have a job. But does that job give you real pleasure or joy? Go for that job.”

And lastly, some people I spoke with even had advice for academia writ large - for example, a manager at a federally funded research and development center (FFRDC), who himself has a PhD in physics, suggested “having a service for PhDs to talk to somebody about opportunities after they graduate, I think that basically doesn't exist. Just to help them figure out whether they want to spend five years in a phd program, or help them focus their energies.” This suggestion echoes what some have observed in literature surrounding STEM recruitment and retention at the graduate level, the near lack of useful career development or counseling available to these students.

4.0.4 PART THREE: The Intangibles

When I asked these managers, directors, vice presidents, and scientists what it was that they most valued about where they worked, they often told me specific things about their company or aspects of their job that they most appreciated (some of which came out in Part One). But despite the heterogeneity of the companies, organizations, and industries represented by the people I interviewed, nearly all of them at one point talked about just how much they valued “the people.” This last section is all about the more subtle or intangible traits that not only make someone with a STEM PhD a valuable hire, but that contribute towards making them the kind of people my interviewees love working with.

Attitude

“Attitude” might seem a bit obvious as something that matters when you go to hire someone, but I was surprised at the degree to which my interviewees discussed it

as an indicator of value, or conversely something that might undermine value. For example, one interviewee told me a story of a top flight applicant with an extensive list of publications and quite the academic pedigree, who was ultimately not hired because she didn't like his attitude and the way he was treating her co-workers during his site interviews:

“There are some very outstanding resumes which have been recommended by faculty members that we really respect but when we spoke to the candidate, it was just you know the communication didn't go smoothly, almost - one candidate in particular, he wasn't even interested in telling me what his work was about, he was more interested in asking me questions about how much I knew about his work. And then he was like, 'oh you don't know this part so I don't quite know how to explain this to you.' It was like I wasn't qualified to interview him or something. But you know, unfortunately for him I wasn't the only the person who got that impression, there were 3 or 4 people who agreed. Then it was a clear no because even though he's a star student and professor highly recommended him, we have to pass on the candidate ...”

This was also one of the places in the data where some of the stereotypes about people who get STEM PhDs were reinforced. A director at a national lab told me about his experience with people like the candidate mentioned in the story above, remarking that:

“Once you become isolated you become more and more comfortable being isolated. That enables you to be socially fitting as you get older and older and older and you become more isolated. You can see that anecdotally anywhere you go to like grad school and you look at some of those people who are high performers on paper and you have a conversation with them, it's awkward.”

The socially awkward scientist is such a common TV and movie trope that there are whole shows dedicated to these kinds of characters - a trope which, in my interviewees' experiences, had some solid basis in reality.

Additionally, a couple of people I talked with spoke about how different attitudes were prized in academia as opposed to “industry.” A software engineer at a multinational tech company with a background in physics observed that “physics has a culture that values being right over anything else more or less, and it doesn't really encourage

any of the kind of development and ... I don't know, there's no class you can take for that or that the department could really fix." But physics isn't the only discipline that struggles with this kind of attitude whiplash. One of my interviewees described this kind of attitude expectation in terms of teamwork when he reflected, "you are forced in industry to work together as teams - if you don't, you're out. Whereas at [a national lab], you could have some pretty arrogant and sometimes caustic people and because they have such unique skills and they work within a narrow domain, they're tolerated. They wouldn't be tolerated in the industry workplace." Another person told me that he worried about "excessive career building," the kinds of individualistic activities which told him that an applicant was a primadonna, someone more interested in shining light on themselves than working towards team goals, "looking at the bigger picture."

Maturity

One of the aspects of the interviews proved difficult to code, but was prevalent enough to merit an attempt. It tended to emerge when I asked people if the STEM PhDs they themselves worked with had a trait or a quality in common. Many people I spoke with seemed to describe valuing maturity in their STEM PhD human capital, something tightly coupled with attitude. However, descriptions of what might constitute maturity varied widely across the board. A hiring manager at a multinational tech company used the word outright when describing the STEM PhD interns that she works with: "they are mature, they know what they're doing, they're experts in what they do, it's more sometimes it even feels like we're inviting consultants rather than hiring an intern student to teach." It also came across when a vice president at a multinational corporation described a practice he tried to cultivate in his own team, one of criticizing an idea rather than the person presenting the idea. "They are

accomplished, highly motivated, and really good people,” he said. “Then also they challenge, what we call challenge the work not the person. You care for the person, it’s nothing to do with the problem you’re trying to solve. So if I ask you the right questions in a room, it’s absolutely ok - but discuss directly and openly and clearly not personally toward the person.” Another example of maturity in the interviews came from an observation by the director of a UARC when he spoke about the kinds of “kids” he sees apply for the jobs available at his center, saying:

“You know a lot of times these kids are young. Recognizing they all mature at different rates, some see it better than others. You know typically to some extent focus required to as you say become credentialed with a PhD is a pretty narrow focus and often times can come at the expense of other things. It’s difficult sometimes to see the woods for the trees. So I empathize with young researchers because they don’t necessarily have a broad perspective on things because they’ve been held to certain expectations necessarily focused on singular topics for much of their waking hours.”

With this he tied many of the other themes together from earlier in the chapter as he tried to explain to me what he was noticing about the kinds of people who tend to apply to not only his organization, but research jobs across various industries. Maturity struck me as one of the more intangible of the qualities in this group, but definitely a case of “I’ll know it when I see it - and it matters enough to look.”

Passion

It seems to matter a lot to these employers whether you demonstrate a “passion” for your work, but that demonstration can manifest itself in many different ways. This aspect of value tended to emerge when I asked people if they had any advice for their past selves or PhD students who wanted to work with them. For example, one vice president for research suggested that students:

“Read up on [what we do] and see if it drives your passion - when you come into the interview you can say I’m interested in this area because of this reason etc, and you can use that to drive your story. Based on your

publications, your projects, your internships, and then - sort of be ready to market what you bring to the table. Whether we like it or not, our nation is filled with marketing. We all have to learn how to be good at it.”

Here she suggests that passion not only makes someone more appealing or valuable to a potential future employer, but that it goes a long way towards helping someone tell the story of who they are based on how they represent themselves in the application process. On a similar note, another vice president described how he advised someone to apply passion as they do their job research, recommending “wherever you’re applying, people just think the thing is whatever they have and apply to 55 job applications a month, or something online - whatever. But I would say apply with a passion to work at that particular job, and convey that passion when you interact with the people in that job.” According to my interviewees, it matters not only that you demonstrate passion for the company or organization you’re applying to work for, but also that you feel passionate about the work itself. “What I’ve learned is that we’re all going to live a very long time,” one respondent observed, “so unless we work on things that we’re passionate about, it would be very easy to be bored and disheartened and be miserable if you’re not enjoying what you do. There has to be something in your job that you really like doing.” A few people also suggested that internships and shadowing professionals was another good way of getting a feel for whether you have any passion in that area or not. And lastly, some people I talked to found that at least for themselves, it didn’t matter if that passion was job specific or came from outside projects or hobbies. One of the software engineers I talked to (who himself has a PhD) told me about his recent interview process, and how he was surprised that “the personal projects came up over and over again because the people that I was talking to were super passionate and really enjoyed working on what they were working on, and so was I.” Like some of the earlier themes such as community

development and attitude, the employers I spoke with seemed to respond very positively to someone who really cared about what they did, and who could demonstrate a passion for applying that energy and drive into working at their company or organization - regardless of where that passion may have originally been directed.

Openness

Again, while slightly difficult to code, something else which surprised me in the data was the degree to which people gave advice to students to be open to new opportunities etc, or that openness was something they valued in their STEM PhDs - either personally, in terms of their work, or as an aspect of their company culture. When I asked a vice president of a multinational tech company about the skill or ability she had that helped her the most in her work, she said “I think I’ve always had - when I was a student, I was very much - I just like to get it done and be done with it. The change part I don’t know how it came to me, but I don’t know whether it was a skill I had. But I’ve always been very embracing about change, to look for the positives in the change, and then just to move forward.” In response to that question, another person told me that he valued his physics training in that “if you can do [high level physics] then like that’s a useful skill because it’s actually - if you allow it to, it can sort of free you to think about things in unconventional ways and it seems like you can re-examine things that you sort of at a fundamental level things you thought you knew.” Both of these responses gesture at a flexibility, an openmindedness that has served them well in their industry careers. An engineer at another company was able to distill this trait into a set of behaviors he witnessed in his colleagues that he found immensely valuable. “The ones I work with are actually quite open to new data,” he said, “so they don’t while they certainly have a lot of historical knowledge of the device, when new data gets presented that contradicts what we thought before,

they're very reasonable in adopting the new data. Re-analyzing or reshaping their previous conceptions. They're not stubborn, in a lot of ways they're pretty malleable. I don't see that across the board, so I think that's something unique to them." We then talked about how this was indicative in our minds of the scientific enterprise in general, the aspiration to let conclusions follow from data and not the other way around. I had the opportunity to also speak with his boss, himself with a physics PhD, and he ended our interview by asking me to convey to students the importance in "allow[ing] themselves to continue to learn and experience. There's a lot of things to experience and minimize regret in life. Personal and professional." I was slightly surprised by this response, but as I continued my interviews a handful more said they would tell students to stay open, and stay flexible. And as difficult as this sentiment can be to articulate, it was nevertheless on many of my interviewees' minds.

Impact

As I mentioned previously, when I asked people what they valued the most about their work, answers varied slightly and according to particular industries. Nevertheless, responses coalesced around a few key themes - one of which was "the people," but I had nearly as many participants respond with some variation of "impact," the idea that their work mattered outside the office or the lab. For example, one of the vice presidents I spoke with almost suggested it was a silly question when he responded "Oh it's needless to say I think direct impact to the patients and human health, so really what we do touches almost a billion people, and you know, I could actually see with my own eyes how you could come up with awesome medications and cures for some deadly diseases like cancer, and so on. Really the impact to human health is just tremendous." This theme also emerged as a variation of advice my interviewees would have for students wanting to work at their companies or organizations. A software

engineer was telling me how much he appreciated the research experience he had as a physics undergrad, and not just for the technical skills it gave him: “Go out as an undergrad, get on a research project while you’re being paid, and do it. That real world experience is - it’s really, you’ll absolutely learn something from that. You may learn technical things, but you’ll learn things about yourself and working in the real world.”

Fulfillment

As a corollary to impact, several people I spoke with described feeling like their work or their job was personally fulfilling in some way. For example, one of the senior researchers at a large multinational tech company I spoke with told me “I have a lot of influence on technology that has been released to the marketplace and everyone experiences it that goes to the movies or uses a projector, so it’s a proud moment for me to go to I can honestly say every movie theater on the planet, you watch a movie, I’m inside of that because I invited the tech that’s used in all of them.” He spoke about this as being an incredibly rewarding aspect of his career. This was somewhat tricky to code since so many people described fulfillment in terms of impact, but my additional coders and I decided to split them up because one did not necessarily imply the other. It perhaps just so happens that my respondents tended to find the impact of their work personally fulfilling. Regardless, a number of people indicated that students looking for jobs in industry would do well to find a job in a career that met either or both of those criteria.

Communication Skills and Translation

One of the most prevalent themes in the entire interview dataset was how valuable my respondents found the ability to communicate effectively and for their STEM PhD human capital to be able to translate what they did across disciplinary bound-

aries. One person summed it up quite succinctly when he said “I don’t know which is ultimately more important. Having raw knowledge and ability to persevere to find technical information, or having the ability to communicate ideas and concepts. They’re both very much tied together for success in this kind of environment. You can’t do one successfully without the other.” My respondents suggested that without the ability to take what you do and communicate it to others, especially in a research environment, the entire knowledge enterprise suffers. A director of a national lab described what might happen in such a situation: “Now you have vertical stacks of isolated people, and you’re losing the dynamic symbiotic knowledge exchange that would be there if people had better conversational and interpersonal skills.” This sentiment was echoed by another senior researcher as he and I talked about how he perceived the difference between inter- and multidisciplinary. Unlike some researchers who speak about people having an interdisciplinary background, he saw value in people with STEM PhDs having deep technical knowledge in their field first, and then the ability to translate to other specialties. “We’ve always talked around here that siloed knowledge is important,” he said, “but a higher level knowledge of being able to branch across is where you really get traction.” This is sometimes at odds with the cultures of the disciplines which produce these STEM PhDs, and when our discussions veered into this territory we again saw evidence of the roots of some of the stereotypes surrounding PhD scientists. A software engineer at a multinational tech company, himself with a physics degree, observed that “physics is a place where you can be very socially awkward and totally get away with it, and I feel like a lot of what I learned after college was how to be diplomatic and how to talk to people and connect with people, because that is at least as important as being right.”⁵

⁵It may seem like I’m picking on physics especially in this chapter, but that’s due to the high percentage of my respondents who have personal experience in physics. I was unable to find anyone who would consent to be interviewed in some of the more biologically or chemically inclined

Breadth vs Depth

This is another place in the data where interviewees sometimes disagreed with each other without knowing it. Some saw more value in a depth of knowledge or experience in one specific area - like a manager at an FFRDC expressed, “I’m looking for some of the more intangibles, like their level of interest and experience in the niche of the field that I work in.” And some found immense value in a breadth of knowledge or experience and possible application. As one manager at a national lab told me, “It’s kinda nice to come upon a candidate or resume that has some breadth to it, because in reality at a lab like [ours] we do so many different kinds of things, it’s very rare that a person is going to do one thing for their entire career here. They’re gonna move around a little bit.” Often people described this as another tension, but generally seemed to agree that a combination of both was most desirable - either for themselves, for future employees, or both. A retired senior fellow at a multinational defense contractor observe that “when you get all those [PhDs] together, you find that virtually all of them are subject matter experts, which means they know a lot about their single discipline, very deep in it, but when you move very far out of their discipline they don’t have a lot of knowledge. At the higher levels where you’re interested in technical leadership you need people who are a little bit broader and maybe not as deep. I always characterize it as the difference between technical expertise and domain knowledge.” This was a sentiment echoed by many, for example by a senior researcher in the defense industry: “As great as narrow and deep is, we can’t just have narrow and deep. We need more people who have this breadth and can work across disciplines. And that working across disciplines is not just knowledge, it’s also interpersonal teambuilding skills.” In this case, he was speaking about breadth and

companies and organizations on my list, a definite limitation of this dataset.

depth in terms of not just technical ability, but in the intangible qualities highlighted in this section - things like communication skills, attitude, and openness.

Teamwork

A good number of people talked about “teamwork” in one way or another as being something they valued, but not always in the same way. For example, a manager at a national lab told me that when she looks through applications, “I kinda try to see if I can identify any signs - does this person work well with others.” Another manager at an FFRDC told me “If they’re not crazy about working on their own, then actually they’re a burden to me. I have to tell them what to do all the time.” Some would described valuing “independence” first and then the ability to integrate into a team, some saw “teamwork” as crucial to someone’s successful integration into the company or organization. When I asked about one UARC manager’s own transition from the military to the research setting, she described a stark difference in the degree to which teamwork mattered in the workplace:

“the difference between here and the Navy is here while teamwork and collaboration are important, it’s just as important you’re able to stay on your own two feet and deliver on your own. In the Navy, teamwork is life and death. It’s a little different. Individual strengths are important in the Navy too, but if you can’t function as part of a team, you’re not going to make a career out of that. But here you can get by because of the need for such strong individual contribution.”

Echoing that sentiment to some degree, a vice president at a multinational corporation (himself with considerable experience in academia and a STEM PhD) described his experience with teamwork both in academia and industry. “The ability to work collaboratively with others, it’s critical to success” he said. “I don’t - you know I think in academia also, the best researchers are the ones who are able to do that, but I don’t think it limits you as much in academia, the lack of that skill as it does in industry. I’ve seen PHD scientists struggle in industry when they aren’t able to

make that transition from being a PhD student where it's your research, your name, your paper, to a situation where it's very fluid who's getting credit and who's not, no one person can do it alone ... think again through the program, the experiences, the recognition that it's teamwork that's even more important than what we can achieve individually." This was also sometimes discussed in terms of one's relative "intellectual freedom," often in terms of relative freedom to an academic environment. A senior researcher in the defense industry told me that if you're someone who does work in cyber, or something else highly prized right now, "that's the most critical area, they need the skills, they'll give you considerable freedom to do things that become meaningful for the company." This was in contrast to the experience a software engineer described to me as he transitioned out of grad school and into industry. He loved the ability he had in grad school to spend time reading about new research, but was surprised when he took a job at a multinational tech company at how little emphasis was placed on that kind of activity. "There's huge interest of the people working there in research and everything," he told me, "but there is not huge - it doesn't help you ship so, and it is not necessarily going to correlate with the things that your customers want and they're very focused on customers and the important things as far as customers are concerned."

Potential

"Potential" was something discussed by fewer of my interviewees, and when it was, it seemed to come from people at large multinational corporations and in the context of something that might throw up a red flag in the hiring process. When I asked if there were anything that might disqualify someone from working at his company, a vice president of a multinational corporation surprised me when he started talking about promotions and upward mobility: "Employers are looking more for potential,

the opportunity to learn and grow and folks that we see as having, especially when you're hiring talented entry level positions, you want to be able to see them grow to much higher levels in the organization, you're not going to hire someone if you only feel they can move a step or two early in their career and then go no further." Another vice president took this one step further as he mentioned looking for potential, telling me that "... if somebody has spent - has been working for a number of years and hasn't really advanced or achieved much, then I'd be skeptical that that person is going to be able to come in and really help grow and deliver and out-perform in the role we hire them." This is distinct from a skills match, and not quite leadership, attitude, or any of the other codes in this section. What these people were talking about deals much more explicitly with reading between the lines of a resume to chart a pattern of accomplishment that might begin to hint at that kind of growth in the future. Some even expected applicants to be able to articulate this potential themselves - one vice president described some of the questions he asks people in interviews, including "what do you bring to the table? What do you think you bring to the table? I often think, do you think when I ask you to my team, the strategy for the team goes up, or do you bring clarity, or do you bring energy, or creativity?" This kind of self awareness dovetails slightly with maturity, but seemed to manifest itself differently in these interviews.

“good fit”

A majority of my interviewees discussed something along the lines of trying to understand if a candidate would be a “good fit” or not. “Good fit” of course means very different things to different companies and organizations, but it seems to matter to nearly everyone. There are too many examples from the data set to cite here, but a director at a UARC summed it up nicely when he said “it’s absolutely incumbent on

organizations, including my own here, that when you're hiring you're not just looking for qualified candidates, you're looking for qualified candidates who would resonate with your ecosystem, your environment, your culture." Interviewees described this as another one of those intangibles that is difficult to divine from any single part of a job application, but as something that they endeavored to uncover during an in-person interview process. When one of my participants, recently hired to a multinational tech company, found himself on the other side of the interview table not too long ago, he told me that he did his best to figure out "good fit" even despite what he perceived to be a slightly inefficient and clunky interview process: "if you work well with these people and if they do a good job, which is what you're supposed to look for in the first place. That's what you should be hiring for, and instead we pack it down to these one hour slots and you ask some quiz question that is more or less irrelevant to what you're actually going to be doing in the job." Some indicators of "good fit," as described by my interviewees, are if a candidate is "invigorating" (brings in new ideas and perspectives) and whether or not they take "initiative." For example, one director at a national lab suggested that he screened for a spark of imagination or creativity, because "if someone can create something it doesn't matter really what it is. It shows imagination, and intellect or certification without imagination is a useful person on the team, but perhaps not the person that's ever going to bring anything new to the table." Building on this idea, one of the vice presidents I interviewed spoke about "good fit" in terms of looking for a prospective employee who had shown initiative, who had "done some kind of - especially things that are fairly unique, a summer in DC, working in an institute, learning about policymaking - it's things like that that tell you this is a person who is focused on getting the right experiences to broaden themselves. New perspective that's a little broader than just your average 'I just know about my PhD and my own area of expertise' - there's a lot of learning to

do outside of that. Anybody who has shown me they recognize that and have gone out and have sought out these experiences is usually a big plus.” In this case, he valued a breadth of experience to the degree that it determined someone’s level of fit with his team and his organization. That was not always the case, but more often than not my interviewees seemed to have a good intuitive feel for knowing if someone were a “good fit” - another case of “I’ll know it when I see it.”

Culture

When participants described what it is they valued most about where they work, or how they determined if someone was going to be a “good fit,” they often began to either explicitly or implicitly describe aspects of their work culture, and the degree to which it mattered to them. For example, a vice president of a multinational tech company described to me just how much she appreciated her own company’s culture when it came to women and sexual harassment:

“Sometimes you don’t know how good you have it unless you look elsewhere, I just hear there were like too many of those women not treated appropriately and in fact treated very very badly at tech companies, and that is something which is like unthinkable [here]. Actually, even the other two companies I worked for. That kind of problem I never ran against. There were other issues of course, you have to go the extra mile - but there was never a sexual harassment kind of issue. I never even thought to worry about it. I feel very badly for that young lady and what she had to go through at Uber. Those things would never happen here. I think it’s the culture that also matters.”

Some people I talked with described aspects of their corporate culture without using that word explicitly, and often quite introspectively. When giving advice for students who want to work at his company, a software engineer gave a very egalitarian view of his work environment when he said “By and large at least in my group, we don’t make much of a distinction between PhD and not PhD. People come in and are hired with PhDs and like, that gives them a certain job title off the start. But on the day to day basis we’re all just peers and interact with each other.” This was an aspect

of his work environment he really appreciated because it reminded him of working in his lab in grad school. Later on, I was discussing the issues of recruitment and retention with a director of a UARC when he said “we don’t have balls and shackles on anybody’s ankles. It’s really up to us to establish an environment that is as or more enticing than the next. And if we can’t and we lose people it’s our own fault.” He went on to describe some of the struggles some of the federal agencies he works with are currently experiencing when it comes to their technical workforce, and how sometimes it has nothing to do with the work specifically: “This is a huge problem that NSA and others have, they get these great kids, they give them this tremendous training, and then they get recruited away three years later because their salary is getting doubled and they get to live in the sunshine.” And while culture may be intangible, the people I spoke with indicated these sorts of specific aspects of their work environment that they greatly valued.

Values

Along the same lines, whether explicitly using the language of company or personal values, several respondents described to me trying to establish whether or not a candidate’s values were in alignment with the organization’s. For example, an acting deputy director of a federal agency told me “... that’s fantastic to see a candidate who embodies those values because that’s what we do here, and we want candidates who can come on board and embrace those values and work with us in achieving those goals. So it’s been great to see that there are a lot of candidates out there who are strongly committed to the same values.” This is another aspect of how some people described “good fit,” but stands on its own as something that the employers I spoke with specifically look for in their STEM PhD human capital. In some cases, these company values meant a great deal to not only the person in question, but also her

clients: “So that makes it a unique place, we stand by our values - which is why I think we have that strong reputation with our enterprise clients who have been with us over so many years.” A couple of people also described to me situations in which their own values were not in alignment with their company’s, which prompted them to re-evaluate their employment. One software engineer walked me through his decision to join his current company, citing a disconnect between his personal values and his pervious employer’s. He told me, “Work life balance at [my previous employer] wasn’t very great so I applied [here] and got hired ...” This idea of work life balance came up in multiple interviews, almost always as someone expressed some of their own personal values or an organizational structure which supported such a balance for them. For example, one respondent cited career flexibility as something which helped her find her own work life balance, which manifested itself in an alignment between what mattered to her and what mattered to the company.

4.0.5 So You Want To Work In Industry?

While they represent companies across multiple sectors, industries, and varied dependence on STEM PhDs, my interviewees were able to provide thematically similar, invaluable data on the value of that degree to them and their organizations. This included both concrete and more intangible metrics of value which partially reflected what’s represented in the literature, but which also opened up new avenues of future investigation. And interestingly, nearly every individual I spoke with indicated to me that they would really appreciate seeing the findings of the larger study, since this research represented possible insights they themselves didn’t have but would find incredibly helpful and useful. In the next chapter, I take what I learned from these interviews and expand those findings to the public face of value for these companies and organizations.

Chapter 5

VALUE ALIGNMENT, VALUE DISCONNECT, VALUE EROSION

The previous chapters laid the foundation for an holistic analysis of the value of a STEM PhD from the perspective of academic institutions and non-academic employers, grounded in a review of the literature surrounding the place of these degrees in the national narratives of an educated citizenry, economic competitiveness, and national security. Through the analysis of existing programmatic documents and insights gained from new interviews conducted with individuals who hire people with STEM PhDs outside of academia, the value of these degrees to these various stakeholders has begun to take shape. In this chapter, I draw these analyses together and map out a value landscape according to areas of value alignment, value disconnect, and value erosion revealed by the data. Value alignment refers to areas of agreement between stakeholders as to what matters and what is most valuable or useful in terms of a STEM PhD; value disconnects are places in which the data from different stakeholders disagree, or where the datasets seem to talk past each other; and lastly, areas of value erosion refer to behaviors or attitudes expressed by one stakeholder group which actively erode the value of a STEM PhD from the perspective of another group. By identifying these features of the landscape, we will better understand the contours of the issues facing students and their future employers, and perhaps even begin to chart a path towards increasing the value of this degree for all stakeholders in the ecosystem.

5.0.1 *The Value Landscape*

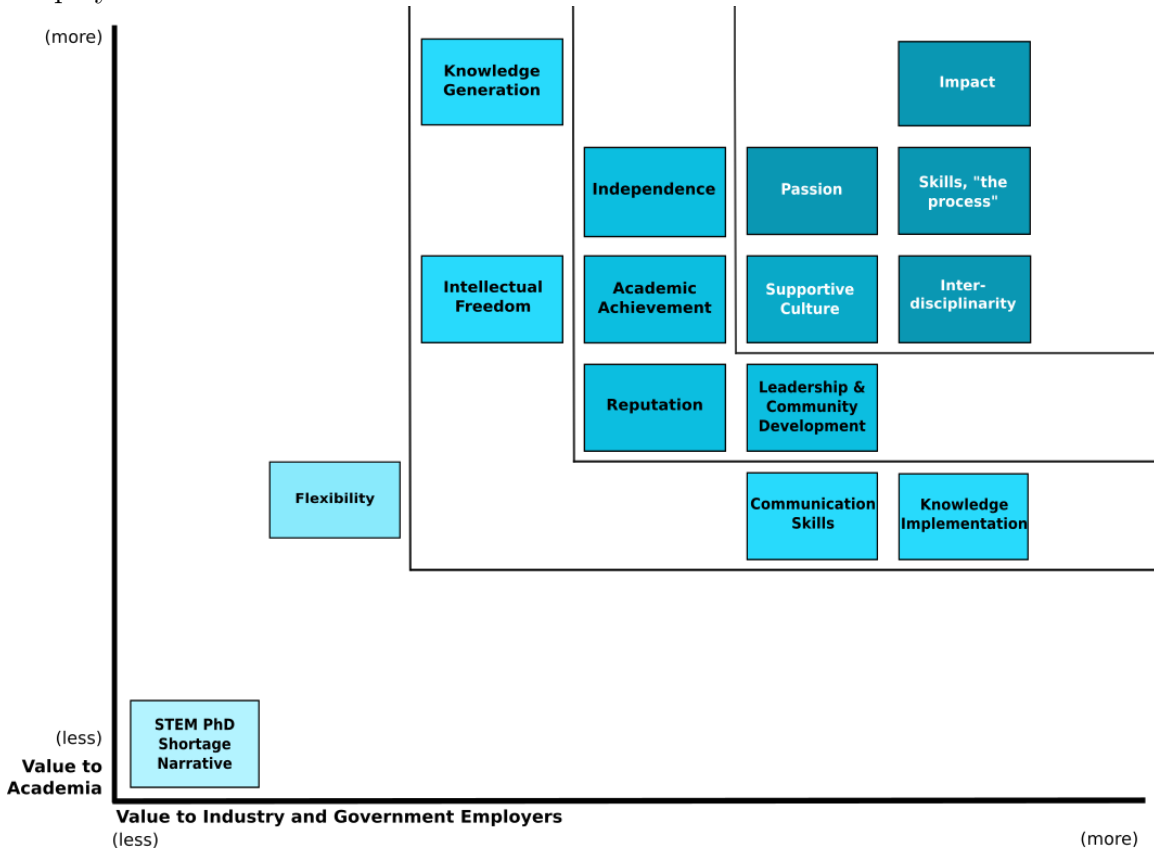
Before we dive into the specific areas of the most prevalent and widespread areas of value alignment, value disconnect, and value erosion revealed by the work described in previous chapters, Figure 6.1 presents a visual representation of that value according to relative importance for each stakeholder represented by the data. I determined the placement of each box according to the degree to which each theme manifested in the data and subsequent analysis. This was not a case of frequency as a proxy for importance, but rather an informed approximation based on a view of the data as a whole. This visualization does not include each theme from every data set, of course: rather it highlights some of the most prevalent and crucial areas of value and situates them among each other. The vertical axis represents the value to academia and higher education institutions, and the horizontal to industry and government employers. The axes go from less to more valuable, a relative and qualitative approximation which is meant not to suggest some absolute value, but rather provide a place to start in terms of talking about the value tension as evidenced by the data. In the following sections, I go into these areas of value more in-depth as I tease out areas of alignment, disconnect, and erosion.

5.0.2 *Value Alignment*

In this section, I describe the areas of value alignment revealed by an analysis of data from previous chapters. The following are observations and themes on which the stakeholders largely agree, and which describe features or behaviors that make a STEM PhD valuable across the board.

These degrees are designed to prepare students for rewarding and ful-

Figure 5.1: STEM PhD Value Landscape, with Themes from the Data Arranged According to Relative Articulated Value of Each to Academia and Non-Academic Employers



filling careers. STEM research and expertise is valuable, and not just for its own sake.

This observation borders on the obvious, but merits explicit recognition in a section about the points of shared value in a STEM PhD among academia and non-academic employers. Like any other degree, these are meant to prepare students to enter the workforce based on a combination of their own career interests, competencies, and expertise provided by their ultimate degree program. As discussed in Chapter 2, the graduate STEM workforce in the U.S. has not only shaped our visions for what an educated citizenry could look like in a democracy, but drives economic competitiveness and bolsters national security in the U.S. Very simply, this means that everyone in-

volved in the STEM PhD ecosystem has a shared core mission. I wanted to highlight this aspect of shared value first because, ultimately, the entire enterprise involved in training and employing these individuals is meaningless without placing students and their needs front and center. Regardless of all the other roles a PhD student plays during the course of their degree, the literature and the data here agree that the value of these degrees rests squarely in a student's ability to parlay that training into a rewarding and fulfilling career.

Interdisciplinarity and translation of expertise across domains really matters.

It can be easy to write off “interdisciplinary” as a buzzword due to sheer overuse in STEM higher education. But in talking to industry and government employers, it was clear that the ability to take one's own domain knowledge and translate it across adjacent disciplines was not only highly prized, but somewhat unique to individuals who had earned a STEM PhD. And while inter- or transdisciplinarity means slightly different things to different people in various settings, both higher education institutions and non-academic employers seem to value STEM human capital that has deep expertise of their own which they can then communicate to others outside their field. This analysis demonstrates that the value in a STEM PhD when it came to interdisciplinarity actually comes from deep disciplinary roots: this is not a shrugging off of traditional expertise, but rather an acknowledgment that such expertise is only made more valuable in translation. The other component of this kind of interdisciplinarity, at least to some of my interviewees, involves the ability to exercise some empathy with the other person, the willingness to try and understand an issue from their perspective if but for a moment. One of my interviewees described this last quality in terms of being able to speak the language of disciplines and specialties related to his,

the ability to function in a team which valued each perspective.

Passion not only makes our work better, but makes it worth doing.

This not only emerged as a theme in my interview data, but also in the STEM PhD program documents from Chapter 3. Passion for one's work is contagious and confers enormous value to any degree, especially a STEM PhD. A majority of my interviewees described a sentiment of curiosity in a prospective employee driven by an infectious passion, many even suggesting that it didn't matter what that passion was directed towards. The fact that someone showed them they really cared about something made them an attractive candidate, because it at least indicated the possibility that they might have the capacity to care that deeply about a potential job. This was reflected in the program documents analyzed in Chapter 3, with one program even beginning their description by offering a student the opportunity to put their passion to use in the course of earning that degree. The verdict is clear: passion adds value.

We do what we do not just because we find it personally fulfilling, but often because we want our work to matter outside the lab.

As briefly discussed in Chapter 2, students indicate that they pursue a STEM PhD for the love of research and what the impacts of that research could do for theirs and future generations. I call this motivation "impact," and it emerged in the program descriptions and advertisements in Chapter 3, in conversation with my interviewees, and in the messaging STEM PhD employers put out to their shareholders about why their work matters. In Chapter 4, we broke impact down into four components: mission, values, culture, and people. Those elements of value were present in every aspect of this study, and it's evident that one of the elements which holds the STEM PhD ecosystem together has a lot to do with what we hope our work could mean for

more people than just ourselves. This aspiration hearkens all the way back to the goal of an educated citizenry articulated by our founding parents, and is still one of the most powerful engines behind the public support of scientific research.

Not all STEM PhD students grow up to be professors.

I was lucky enough to interview a number of people who had themselves pursued a STEM PhD or had chosen otherwise, and perhaps one of the most surprising features of the dataset was the agreement between those individuals and other employers that finding a job after graduation involves a great deal of expectation management. Two different interviewees had very similar stories about their own job search that I want to share together in their entirety: the first by one who completed a PhD, and the second by someone who chose to leave academia after a bachelor's degree.

Interviewee 1: “I was really taken with the idea of becoming a professor. I still am. I knew grad school was a necessity for that. Reality sunk in over the years, I realized I was a much better engineer than researcher. I saw that my publication record was not keeping up with the insane publication records that get you professor jobs. I also realized that my cohort of friends at university, at conferences, some of them were truly truly exceptional individuals and they started having trouble finding professor jobs. And I'm like if I do the delta between myself and these people, and they're having trouble, I don't stand a chance because I now have an understanding of how many of those jobs are available. And the whole adjustment of expectations happened after that.”

And the second,

Interviewee 2: “those people who were clearly at the top and brilliant and just you know, they were just like seemingly effortlessly cranking out pages of thesis just like nailing it. And those folks were definitely on the way to the top and go to some sweet post-doc and get a faculty position. But I also saw there were a lot of smart people working hard and they were like some combination of maybe their advisor or whatever, they were really ... they were smart people who were doing research and they were going to get a PhD, but it wasn't clear that they had a great deal of happiness. I love physics and physics has done a great deal for me even though I chose not to do a PhD. The thing I'm most grateful for is that I got to actually work with people actually doing physics. It's not a slight against physics to say my experience, I decided not to pursue that as a career because I realized I wasn't quite that brilliant and that hard working.”

These individuals' experiences echo what researchers and practitioners have expressed in previous studies, that STEM PhD students still want jobs as professors and what's more, think it's possible. But this data gestures at the second part of that story, in which many students come to realize that a professorship simply isn't an option. This may be due to several factors, a few of which I expanded upon in Chapter 2: but the fact remains that the system which trains these individuals advertises these degrees mainly as preparation for careers in academia, as evidenced by the analysis of program descriptions in Chapter 3. When this issue came up in my interviews with other individuals, themselves further removed from their own job hunt, these employers seemed well aware of not only this phenomenon but its effect on recent graduates' decision-making. As a hiring manager in a Federally Funded Research and Development Center (FFRDC) explained, "There are lots of PhD students who think they're going to be a university professor. Okay, like a kid playing little league baseball, what are your chances of being a professional baseball player? You think you're going to be a professor, here's a reality check. Here's what it actually takes, here's the actual percentages. Sure try to be one, but don't go and spend five years and find out five years later you're not ...". Additionally, a director of a national lab remarked that when it came to STEM PhDs applying for jobs at his institution, he often saw people who didn't seem to understand that it took more than the simple degree to make them the best fit for a job:

"You have to add value. It's not about 'hey I'm the three star candidate, you're going to hire me, I have a PhD from Stanford in physics and whatever,' what do you bring to the table that's gonna help us? How are you going to help me? How are you going to help this institution, this organization, this team? If you go 'well I don't know,' then my eye's half closed and you just think you're all that and you're not bringing anything here, you just want a job because you're you."

It seems that higher education institutions, students, and their possible future employers all understand and acknowledge that not all PhDs will become professors.

And while perhaps a depressing realization to some, I argue that it provides an important opportunity for building shared value: if we all agree that this is the case, then we can begin to move forward towards adjusting the system which produces this human capital so as to provide students the opportunities, resources, and experiences that would help them find those jobs outside academia.

5.0.3 *Value Disconnect*

In this section, I focus on the articulations of value in a STEM PhD from the academic and non-academic employer perspective which disagree or simply talk past each other.

A student’s intellectual lineage matters, but is only a partial factor in their future employability.

Academic achievement matters, as does the institution which confers an individual’s ultimate degree. This is something all stakeholders in the STEM ecosystem largely agree on, but disagree about *the way in which* it matters to a student’s employment prospects. During the analysis of plan of study documents and student handbooks in Chapter 3, I saw page after page describing the expected academic performance of students in various programs, including outlining specific GPAs which merit academic probation, for example. Performance in school is mostly measured by a student’s grades, and that trend evidently continues into graduate school. Of course, as you go further along in a PhD program, you eventually stop taking classes and start publishing your own work: but in academia, intellectual lineage and academic achievement serve as some of the most important metrics of success. However, as described in Chapter 4, my industry interviewees spoke about those metrics as “givens,” almost unimportant in their ultimate decision of whether or not to hire someone. They essen-

tially told me that they wouldn't be considering a student's resume if they were not a high achiever, so it mattered in that sense. But when describing how they decided between equally competent candidates, my interviewees made their choices based the more intangible demonstrations of value. This suggests a disconnect between the importance of academic achievement and intellectual lineage to the academy and to the outside world, one which is perhaps unsurprising and obvious to some. But based on the results of this study, I argue that this disconnect has consequences for the value of a STEM PhD if higher education institutions make this emphasis during the course of a student's training at the expense of providing space for the development of the more intangible skills so valued by my interviewees.

Academia may think its responsibility is to produce independent scientists, but that may not serve students well in their future careers depending on where they want to work.

Many of the STEM PhD programs at ASU advertise themselves as valuable in their ability to create "independent" scientists. This value makes a certain amount of sense when taken in consideration with the history of publicly funded science in the U.S., including a preference for Science to remain objective and verifiable independent of its various funding sources. This desire was of course magnified by the effects of WWII-era collaboration between the defense industrial complex and university labs, partnerships largely credited with "winning the war." The subsequent creation of the National Science Foundation instead of a Department of Science further emphasizes the desire on the part of the science community to remain independent of external pressures in their pursuit of knowledge. We can argue, of course (and many have) that the funding system that exists today for "basic" research does in fact substantially influence the kind of research done, and the kind of independent scientists we

talk about and seem to value so highly rarely exist in nature. For the purposes of this study, however, an emphasis on training PhD students to be independent could possibly threaten the value of that degree outside academia. A large number of my interviewees placed demonstrable value on the ability to effectively integrate into a team. This is not to suggest that independent scientists are incapable of working on teams, of course. But I had several industry and governmental employers describe situations to me in which an applicant's independence translated into an attitude or disposition that made them a poor fit for a specific team or their company on the whole. Conversely, I had a couple subjects tell me that if a possible future employee couldn't work independently they likely wouldn't get hired. That latter sentiment came from individuals in work environments modeled after academia to a large extent in terms of their organizational management, suggesting to me that there exists a spectrum of value when it comes to the issue of independence. An employer's preferences for independence or teamwork (or something in-between) may have a lot to do with how closely their work environment resembles academia. This suggests that the value of a STEM PhD may be closely coupled with a student's relative independence in the work environment, which presents an opportunity to cultivate team experiences which might better translate across sectors and kinds of possible future employers.

Leadership and community development really matter to future employers, but are qualities and experiences often overlooked in graduate school.

This was perhaps one of the most significant findings from the analysis of my interview data. As discussed in Chapter 4, the employers I spoke with overwhelmingly indicated that they valued demonstrations of leadership and community development in their future employees. However, as evidenced by the student handbook analysis in Chapter 3, these kinds of activities and qualities play little to no role in the value

of these degrees while they are underway. The only explicit mention of community development occurred in some of the engineering handbooks by way of a description of the various student engineering organizations available for participation. Perhaps faculty and administrators assume that students will find opportunity to develop these skills elsewhere at ASU outside their specific PhD programs, or even in their personal lives. And yet, companies and organizations ascribe significant value to organized and purposeful volunteering, as seen in the interview data, and especially those activities in which employees bring the skills that make them valuable in the workplace to the greater community. This suggests an opportunity for growth in STEM PhD programs to create more organized means by which their students could take their training out of the lab and into the world, which not only improves the learning experience for everyone involved, but strengthens relationships between academic units and their local communities. An academic system which places such emphasis on publication records and course performance at the expense of leadership and community development evidently risks producing graduates who lack a certain set of skills, as it were, which make them attractive to future employers across multiple sectors.

What actually demonstrates a student's communication skills?

Employers told me how much an individual's communication skills factor in their ultimate decision of whether to hire someone with a PhD. I doubt that any faculty member or administrator would suggest that communication skills were somehow unimportant, but in my analysis of program descriptions and student handbooks, I saw very little evidence for actual training in communication. The School for Engineering of Matter, Transport, and Energy (SEMTE) did stand out among those offering STEM PhDs in their mention of communication and professionalism as a core competency gained by participating in their programs. However, upon further exam-

ination (and after a few informal conversations with current and former students), I determined that the only formalized communication training offered to those students happens as an undergraduate. Graduate students are of course expected to present their work at conferences, and some hold TA positions during their degree, both activities which might provide an environment in which to learn how to communicate one's research to a wider audience. However, participation does not necessarily imply competence, as evidenced by the many interviews in which my respondents and I discussed their experiences of PhD qualified applicants who were turned away due to a failure to communicate. For those to whom networking a crowded cocktail party comes easily, or are lucky enough to have a faculty mentor who shows them how to design lesson plans and communicate complex topics to their students, the system as it stands largely works. But my data suggests that we have an opportunity to demonstrably increase STEM PhD students' employability by figuring out how to give them some directed training in communication before they defend their dissertations.

5.0.4 *Value Erosion*

In this last section, I detail the areas where the data indicates certain perspectives, attitudes, or practices of one stakeholder group which erode the value of a STEM PhD in the eyes of another. This also encompasses cultural factors which the data suggests erode the value of these degrees to multiple groups within the ecosystem.

Continuing to support and continue the STEM PhD shortage narrative actively erodes the value of those degrees.¹

¹The material in this subsection appeared in an article I wrote for Slate in Fall of 2017.

As described in more detail in Chapter 2, the shortage predictions from the late 1980s were based largely on calculations used within the NSF to try to understand how much money it ought to spend on science and technology research and development as well as pre-college science education. The idea was based largely on the understanding that the U.S. couldn't keep up the pace of Cold War science demand for much longer without a serious increase in funding. Funding the production of more science PhDs became a proxy for increased funding for science research in general. Need more science to keep up with competitive global power in Eurasia and Japan? That must mean we need more scientists, and more scientists means more science PhDs. The way society (and the government) thinks about the pipeline of STEM education is flawed in several ways, but there are two chief problems. First, it often promises students employment in their field at the end of a STEM PhD and increasingly can't deliver as discussed in detail in Chapter 2, many bright, successful, well credentialed STEM PhDs can't find jobs. Second, embedded in this STEM push is the implicit understanding that PhDs are just inherently more valuable than other degrees. Anything less is a leak in this pipeline. That kind of thinking disregards all the ways in which individuals with all types of science backgrounds could positively contribute to our economy and to our knowledge. We don't need more STEM PhDs. We need to figure out how to employ the ones we already have and adjust our science education system to produce people who can succeed in whichever path they choose for themselves.

Aspects of the culture of academia in the U.S. are often demonstrably toxic to graduate student success.

Since academic culture is not a monolith, and is as diverse and varied as institutions of higher education themselves, it is more difficult to succinctly describe value erosion due to the culture of academia in the U.S. But study after study (some of which are

highlighted in Chapter 2) demonstrates the impact of graduate student mental and emotional health on their performance in the programs (Hyun *et al.*, 2006; Oswalt and Riddock, 2007; Offstein *et al.*, 2004; Longfield *et al.*, 2006), which in turn heavily influences possible career paths after graduation. My data suggests that workplace culture heavily influences employee performance, and many of my interviewees who earned PhDs themselves reflected on how grueling they found the experience, and remarked on the number of colleagues they saw drop out of school before finishing because of some sort of mental or emotional struggle. This takes yet another shape when viewed from the perspective of the number of people subject to abuse, sexual harassment, and various forms of assault while in school. An adversarial culture, whether in the classroom or the corporate workplace, erodes the value of the work produced by the people subject to and participating in such a culture: and this study indicates that STEM PhDs are by no means exempt from these forces.

A student's perception of employment options after graduate school may or may not reflect reality, a factor heavily dependent on individual advisors and sheer luck.

We know from the literature surveyed in Chapter 2 that the job market for STEM PhDs is not only incredibly unpredictable, but that our best data at the time of intake is often already out of date by the time a student graduates simply due to how long it takes to get a PhD. In the absence of significant and evenly distributed career services for graduate students, advisors and professors often serve that role for their students. And while not an issue on its own, some literature highlighted in Chapter 2 and a few of my interviewees suggested that this might lead to a demonstrable disconnect between the kinds of career options actually available to students after graduation, and the ones of which they are made aware. The result? Entire generations of stu-

dents entering PhD programs, like one of my interviewees quoted above, who simply cross their fingers that they'll be employable when they graduate.

5.0.5 The Path Forward

While it's incredible progress to be able to identify these areas of value alignment, value disconnect, and value erosion upon which to build the value of these degrees for all stakeholders involved, awareness is only the beginning. In the next and penultimate chapter, I take the broader trends which these areas represent and provide some different ways of thinking about what the STEM PhD ecosystem could look like in the future. It may at times feel as if this is uncharted territory, but the landscape may in fact be more familiar than we think.

Chapter 6

THE FUTURE OF THE STEM PHD ECOSYSTEM

In the course of this research, I've studied the assumptions of value implicit in materials and resources STEM PhD programs use to draw in and support students, and generated new data on the actual and practical value of such a degree to industry and government companies and organizations. This led to the uncovering of areas of value alignment, disconnect, and erosion which either bolster or threaten the value of these degrees - once invisible roadblocks, if you will, which policymakers and practitioners can begin to level now that they have been located and identified. I'm not suggesting this work as a panacea to all that ails the system which produces STEM PhDs, far from it. We can't think about these complex, nuanced, and frankly messy issues as problems simply awaiting the "right" solution. Instead, in this last chapter, I hope to offer some ways of thinking about these issues which may lower the overall risk in the ecosystem, gesturing at ways we can adjust the environment so as to support new growth and the continued evolution of all involved. However, in order for any of these changes to come about, adjustments and course corrections at the institutional and cultural level have to work in harmony to increase the value of employment outside academia.

In Part One, I identify possible adjustments or interventions based on the major findings from the study as a whole which might begin to address the aforementioned findings. To extend the metaphor from Chapter 5, now that we know what the landscape looks like, we can begin to chart a path through towards increased value of these degrees for all the stakeholders represented by this work. Part Two of this chapter details more personal observations presented as advice stratified according to

stakeholder.

6.0.1 Part One: Adjustments and Interventions

The analysis suggests three categories for further exploration in terms of adjustments or interventions: resources and mechanisms, culture, and the relationship between academia and non-academic employers. The first deals with what universities and higher education institutions are currently doing or could adjust in order to provide students the resources and experience necessary to fully realize the value of their degrees outside academia. The second category, culture, involves the ways in which departmental and institutional cultures blocks, erodes, or potentially enhances the value of STEM PhDs, even when the practical tools for shifting the culture already exist. For example, one could imagine the threat to the value of a degree posed by a departmental attitude which says “students already have everything they need” even as the students operate within a culture that means the students don’t know about the tools and resources available, or are actively or passively discouraged from using what’s available (in some cases subconsciously suggesting that those students who take advantage of these tools and resources are somehow lesser scholars, or at worst, lesser adults). The responsibility for change rests on everyone who has a stake in the future of these degrees, and the economy which they support - so this last section deals not with academic interventions, but with potential opportunities presented by more frequent and meaningful cross-sector communication between non-academic employers and the institutions which train their potential future employees.

Institutional Design

Career Development

It may seem that creating some kind of comprehensive career awareness and counseling service that would serve more than just one STEM PhD degree program would be impossible. However, the data and analysis in this study suggest otherwise. The qualities and characteristics which make a STEM PhD valuable to future employers include a laundry list of the kinds of qualities developed by the pursuit of a graduate degree in general: determination, grit, curiosity, passion, leadership, communication skills, and teamwork, to name a few. Over and over my interviewees told me that they cared much less about a student's specific thesis topic than on the abilities they developed over the course of earning their PhD. And when these companies and organizations described the value of their STEM human capital in terms of their effect on the company's overall social impact, the things that separated PhD-qualified individuals from one another were much less important than the things they had in common, like a spirit of service. All of which suggests that we do, in fact, have a common foundation of value which talented experts and practitioners in the field of career counseling can build upon to serve PhD students as they leave the university. There are people who are experts at cultivating real teambuilding, communication, and leadership skills - let's take advantage of them.

Professional Development

The data also suggest a few low-hanging-fruit items which would vastly increase a student's chances of finding non-academic employment after graduation. For example, a number of my interviewees told me that a poorly written resume or cover letter put a student's application in the circular file, and that they saw quite a few in their stacks of applications every day. This is a type of writing and style which doesn't factor into the kinds of writing and publication valued by a student's every

day experience during their degree, and which faculty are often unable to help with in a meaningful way simply by nature of their own employment history. Thankfully, nearly every university campus has an expert or two in writing resumes and cover letters. Making that kind of expertise not only available to STEM PhD students, but easily accessible and integrated into their program would make a world of difference in helping a student seem attractive to future employers. Some programs are clearly better at this than others, but its value across the board cannot be overstated.

Career Awareness

Even before they get to the point of needing that level of career counseling, however, the data suggest that students need to better understand the wide variety of jobs and careers available to them with a certain set of qualifications before they start a program, not after graduation. I coded this as “job research” in my data, a theme which resurfaced in nearly every one of my interviews in terms of advice professionals would give their past selves and current students going on the job market. In this era of such widespread access to enormous amounts of information through the internet, we might assume that students could just go figure this out for themselves: but the analysis demonstrates that such an assumption is *in itself* a compounding risk. Just because those job research resources exist doesn’t mean that students know where to find them or how to use them not to mention the sorts of interpersonal skills often necessary to take advantage of them. One of my own friends in fact, who recently graduated from a masters program, struggled with this last aspect of their own job hunt in a way that surprised me. Based on this research, I suggested they might reach out to a few people at the companies they were applying to in order to schedule a quick informational interview or phone call to get more information than was available on the website (partly because one of my interviewees told me that a phone call

would get her attention more than an email would). At this suggestion, my friend turned to me with wide eyes and said, “But phone calls are scary!” I was floored. Fear of picking up the phone was keeping my friend from getting their application to the top of the pile. If we can somehow manage to intentionally and programmatically help instill some confidence in our graduate students when it comes to doing the kind of job research my analysis indicates is necessary in this day and age, our graduates stand an even better chance of landing that interview or making a great first impression on a future employer.

PhD Deliverable

Additionally, this study suggests in subtle ways that a dissertation or thesis might not be the only valuable outcome from a PhD program, especially if a student wants to find employment outside academia upon graduation. My interviewees suggested that what they valued more than the thesis itself were the program management and research skills developed along the way, and also indicated that while a publication record might factor in an initial screening of applicants, it factored very little if at all in the final hiring decision-making process. The final deliverable as currently designed in a majority of the STEM PhD programs at ASU, and in general across higher education institutions, clearly aims to position students for the kind of publication record necessary for a post-doc or tenure track professorship. We know, of course, that much more goes into being a professor than the ability to write peer-reviewed articles, and that students need teaching and management experience as well if that’s a career that interests them. But if we are earnest in our desire to adjust the program which trains these students in order to also better prepare them for a wide variety of non-academic careers, it might be worth reconsidering ways we could adjust the final deliverable to demonstrate more of the qualifications and skills which employers say

make STEM PhD qualified candidates valuable to their organizations.

Interpersonal Skills

This research also throws the critical importance of networking skills into stark relief, skills which experts know don't rely on personality traits so much as practice and experience. The tropes and stereotypes surrounding introverted and socially awkward scientists also made their way into my data, often describing real life experiences my interviewees had with potential future employees during the interview process. Additionally, nearly every one of the people I spoke with mentioned the role personal and professional relationships played in securing their own jobs, and also in a student's chance of having their application make it to the top of a hiring manager's stack. These two observations go hand in hand. Graduate students, and STEM PhD students in particular, are often expected to somehow learn how to network by simply going to conferences or belonging to professional organizations. But participation does not immediately confer competence. If the number of books on networking and building professional relationships in my local Barnes and Noble is any indication, one of the few things we don't suffer from in our western professional culture is a lack of expertise on how to network. If integrated into a student's graduate experience in an intentional and programmatic way, instead of assumed to be absorbed through osmosis somewhere over the years, students might stand a much better chance of communicating their value to interviewers and collaborators.

Community Development

Another huge area of potentially untapped value development during the STEM PhD process involves creating and nurturing opportunities for students to get out and serve their community. This is, of course, not to suggest that programs don't already do

this to some extent: rather, I want to call this aspect of value out especially simply due to its overwhelming presence in my data. Non-academic employers want to see STEM PhD students who have taken their skills and expertise out of the lab and into the world in an engaging and meaningful way. However, in order for this to happen in more than just one or two academic units, it might benefit institutions to think about this issue holistically. Are there more tangible and practical means by which we can indicate that we value a spirit of service? Is there a way, for example, to give students credit towards their degree for community service or volunteering? Can we adjust the way we think about how a graduate student ought to spend their time in order to make room for those organic and authentic opportunities to go out and serve? Selecting for and actively developing that kind of community would not only serve students in their future job hunts, but would go a long way towards bolstering the engagement of the university community as well.

Cultural Design

There are clearly both minor and major adjustments at the institutional level which could greatly increase the value of a STEM PhD across the board. But what are some of the cultural forces at work that shape a PhD student's experience during their degree, and then that make them valuable afterwards?

Graduate Student Mental Health

The subject of graduate student mental health is by no means a new area of research, but has thankfully seen a resurgence in the past decade (Hyun *et al.*, 2006; Oswalt and Riddock, 2007; Offstein *et al.*, 2004; Longfield *et al.*, 2006). Improved graduate student mental health overall is also something that a couple of my interviewees hinted at, but which didn't make it to the level of a code. The literature on graduate

student mental health indicates, to a large extent, that students feel pushed in so many different directions and live in a liminal space between being a professional and being a student. This tension makes it difficult for students to know what's expected of them in their relationships on any given day, both personally and professionally. The process between admission and graduation is so draining and wears students down so much that often by the end, individuals are nearly incapable of being able to articulate their worth to potential future employers (Abel, 1996; Spencer *et al.*, 1993). Not to mention all the gendered power dynamics that all students, not just women, have to endure and encounter as grad students. The power dynamics created by a system in which students are dependent upon their advisors for continued funding enforces a patronage relationship that can make it hard for students to assimilate to professional life afterwards (Kennedy, 2000). We also know that mental health outcomes significantly affect job performance, a trend to which graduate students are not immune (Bond and Flaxman, 2006; Hourani *et al.*, 2006). There is no easy fix here, of course, but rather a series of small steps which can add up to a sea change in terms of how we view and talk about graduate student mental health. It begins, like so many of these things do, by acknowledging the magnitude of the problem.

Faculty Priorities

The academic training system, for the most part, is designed to create professors. For those students who choose to pursue an academic career after graduation, however, this system largely fails to provide the robust teacher training or management skills which would further a students' success in the academic job market. This lack is often compounded by the fact that in the trinity of things that ostensibly matter in a tenure track job at many higher education institutions (research, teaching, service), the system primarily rewards research because it's what brings in the majority of the

financial resources. Not to suggest, of course, that there aren't professors out there who care about their teaching, or who manage to do it well in spite of no formal teaching or management training. But the system is designed to reward research outcomes over any others, meaning that if an individual wants to be successful in a tenured career, he or she has to focus on the thing that the system rewards: research. There's the argument that this is good for students, because more research funding means more RAs. But we know that good researchers don't automatically make good mentors, and I'm certain we all have our own advisor horror stories.

What does this mean for the value of a STEM PhD? Often students are either implicitly or explicitly steered away from industry, government, or private sector positions and instead pushed towards faculty positions which are increasingly rare and difficult to land. What this inevitably means is a few visible success stories and scores more students who spent the majority of their 20s getting training that only really prepares them for a job that they can't get. This picture doesn't have to sound this bleak, though, because this research suggests that all that training is actually valuable to employers outside academia *if framed properly*. What needs to change is the general academic cultural attitude towards those kinds of jobs, and an adjustment of the system to create more space and opportunity for the things that make students universally valuable. What would help the culture shift is an honest appraisal of a student's increasingly low chances of getting a faculty job. While it may sound harsh, a rose-colored-glasses attitude when it comes to the academic job market is actually toxic and damaging to students and academic culture writ large in the long term.

"Selling Yourself"

Part of this academic cultural reckoning will necessarily involve recognizing that science doesn't actually speak for itself. This may practically prevent a lot of students

from learning how to “sell” or market themselves, something which came up frequently in the data. Many operate under this false assumption in STEM PhD programs that all someone has to do is good science, and just showing it to the right people would be enough to get a job. But in the outside world that’s not the case. The people I talked to suggested that the STEM PhD qualified applicants in particular struggled to articulate their value and worth, and hinted that may be due in part to a scientific culture which looks down on that kind of self promotion. Like other findings in the realm of cultural design, this defies a simple solution: but institutions could begin by giving students more structured opportunities to practice and develop those skills, besides just presenting at conferences (which we all know is insufficient). But in order for that to happen, those in the academic STEM community may have to adjust their collective attitude regarding self promotion.

Cross-Sector Communication

Individualism

Additionally, the cult of individualism in academia may itself pose a threat to the value of the STEM PhD. There’s also a lot of room for improvement when it comes to teams in academia, and this is based largely on how people are given credit for their work and intellectual labor. A couple of my interviewees said that their academic hires struggled with teamwork because they were so used to environments where their performance was judged by their own individual pedigree as opposed to the greater success of a team or a company. I think there’s some opportunity here for academia and industry to meet in the middle when it comes to professional recognition. This would be especially easy at a school like ASU that’s already so invested in programmatic and institutional innovation in terms of interdisciplinarity teams. Again, this

defies a simple solution, but bears serious scrutiny in terms of increasing the value of a STEM PhD.

Perceptions of Job Markets

A long-standing headache in terms of PhD career preparation involves the length of time it takes to complete a degree, and the degree to which jobs in the tech sector fluctuate. It's hard to predict the job market 5-7 years out - but this research suggests that we don't actually need that information to help students prepare for a career. That's only a concern as long as we continue to focus on job hunts which center around a student's thesis topic or concentration. What this work overwhelmingly demonstrates is that those things don't actually really matter to employers as much as the skills that students learn along the way. Those skills will always be valuable, no matter what the job market does in the coming decades. We just need to help students figure out how to think about their degrees in terms of those skills instead of their thesis topic, which would likely make their job hunt a little easier. A first step could involve more intentional and programmatic communication between potential employers and academic institutions at the level of course content and curriculum design. Of all the STEM disciplines, engineering has the longest history of partnership with non-academic organizations in terms of student career preparation.

Recruitment and Outreach

Industry could vastly increase the value of STEM PhDs broadly by not just focusing on K-12 for outreach activities - recruitment fairs are not outreach. Graduate students need enrichment and outreach too. It's tempting to think that internships and fellowships are sufficient, and for those few who get them that may indeed be the case. But a lot of students don't have any idea if they would actually enjoy

a job in a given industry unless they're one of those lucky few. What if schools gave everyone in these PhD programs the flexibility to take internships for credit, or provide leeway in their schedules for them do participate in them concurrently like engineers do sometimes? Several of my interviewees indicated that they got a lot of their hiring leads from professors they work with or recommendations from their own professional network. What if companies and organizations adjusted the way we do graduate student recruitment to actually include honest and specific information about what opportunities might be available with that degree?

For those employers who see their talent pools shrinking: what can you do to make those jobs more appealing? The answer may not always be higher wages. Especially when it comes to those jobs in the defense industry and in DoD specifically, these data tell us that there are some relatively straightforward procedural things that create a high barrier to entry for a lot of students coming out of graduate school. Firstly, the time it takes to get a security clearance often prevents new employees from being able to do meaningful work for the first six months of their employment, if they don't abandon the idea all together and go work for a company that's done training them after the first week. I am not the first scholar to make this observation, nor will I be the last. Experts and practitioners agree that an overhaul of the classification system is long overdue, and restructuring which jobs need clearance and how government organizations operationalize that process would go a long way towards making these sorts of jobs more attractive to new graduates. Secondly, we know that structural forces beyond the scope of this research can keep government wages and benefits low, something which the data suggests makes it even more difficult to compete with jobs available in the private sector. But when asked what they valued most about their jobs, none of my interviewees wanted to talk about their paycheck or benefits package: instead they focused on the work environment, the caliber and quality of people on

their team, and the ability to work within a framework that gave their jobs a greater meaning and impact. Those are, of course, much harder to measure than salaries on a pay scale, but I would argue that of all organizations, the military knows how to inspire people to work together towards a greater goal and build committed and cohesive teams. Put simply, DoD knows how to recruit. So perhaps when faced with a looming shortage of talent to fill positions left vacant by retiring baby boomers, the military and other defense organizations might be better served by applying those same sorts of recruitment techniques to their civilian STEM PhD employees.

6.0.2 Part Two: Observations and Advice

I wanted to close this chapter with a much more informal, but equally meaningful series of observations and advice I have for each of the stakeholder groups represented by this work. After months and months of steeping myself in the data, collecting stories and shared experiences, this last section is what's left after reading between the lines of all that went into this research. No citations, no charts or figures, just what I would say to each if I could sit down with them face to face.

To the PhD students: know your worth.

I know right now it seems like the last five or more years of your life have been a shot in the dark, a postponement of the inevitable job search process which scares the living daylights out of you. But I want you to know that the people on the other side of the interview table aren't out to make you feel small (most of the time), they're genuinely curious about what you have to offer. But there's no way for them to be able to see your value if you don't even see it yourself. I'm not talking about the number of papers you've authored or the individual awards you've won. I'm talking

about what you bring to your research teams and your communities. How do you make people feel when you work with them? Do you bring them along with you into the unknown or do you leave them behind? Do they feel like they can count on you? Is there something that really lights you up, regardless of whether it has anything to do with your dissertation or not? These are the things that will set you apart from all other applicants, because it's what makes you *you*. This is your real worth. Every applicant these employers see coming out of a PhD program have demonstrated that they're smart and that they can learn quickly and effectively. But nobody has your same drive, motivation, passion, and energy. If you can show people that you would be an asset on their team in all these more subtle and intangible ways, I can guarantee that you'll have a much better chance of landing an interview or getting the job. Show them that you're the kind of "people" they talk about when they say that's what they value the most about their jobs.

To the people who form academia and the higher education institutions:

We're counting on you, and we're in this together.

I know you have pressures on you from all sides and that an entire way of life depends on your continued thriving. Especially in an environment that seems to constantly threaten your funding, your validity, and your very existence, it can be tempting to act from fear and just batten down the hatches. Opening yourself up to innovation in your very structure and purpose is sometimes life threatening. But we need to do more than just survive. The world has changed faster than you've been able to adapt in most cases, and that's largely not your fault - we've designed institutions like yours to withstand changing tides of public opinion and federal priorities. But I'm telling you that the status quo, what we value in terms of employment and how

we train our PhD students, is actually threatening the value of these degrees. The focus on individual accomplishment, deliverables meant to confer status in academia, and a culture of toxic competition and dependence shrink the world of possibilities for students when they leave. But there's great news. There are plenty of companies and organizations who desperately want the kind of big picture, critical thinking, and research development skills that we already instill in our PhD students. They also want to see students who demonstrate excellent communication, community development, leadership, and teamwork. These are things I know you want for your students too. Don't think of this as a threat to your value, a criticism of your validity. Instead, I want you to know that the fact that these potential future employers take academic achievement and intellectual excellence as a given signals that what you do matters. It matters so much that these people don't question it. What they're asking for on top of that are not only things that would enrich students' experiences while they're at your institution, but would give them many more opportunities after they leave - and that's something we can all get behind. Let's take this as a challenge to build even more on top of the bedrock of value you've already established.

To future employers of STEM PhD students: Building a student's confidence and experience is never a bad investment.

For those of you with PhDs yourselves, you know how grueling this process is for students. And often when they walk in for an interview with you, you know better than them what they're worth to your company. But I think they would be even more valuable to you if they were able to understand their own worth much sooner than that. This is something you're uniquely qualified to help with. You know what you're looking for - so rather than assume students and their academic institutions

know too, why not come to the table and lay it out for everyone? I can guarantee any investment you make in terms of time or financial resources in developing STEM human capital while they're still being trained, even if they don't end up working for you, will pay huge dividends for your social and cultural impact, while bolstering our economic competitiveness and national security in the process. Offering internships is a great start, but you can do more. A lot of these students have never had the opportunity to see what working for a company or organization like yours is like - why not show them around and let them shadow one of your employees for a day? You tell me how much you want to see students get out of their shell in interviews, but that shell is what protected them in grad school and was often the thing that got them the kind of recognition necessary to stay competitive amongst their peers. Before they even graduate, don't just tell them, show them what it means to work in a team and be a leader in their field.

6.0.3 Purpose-driven Passionate People

At the end of the day, what this ecosystem produces is actually largely what employers are looking for: purpose-driven passionate people. There are some things we can change to make it so that passionate spirit isn't beaten out of students by the time they graduate, and some ways we can change our own narratives to help better position these students and frame the opportunities they've already had in a new light. This will necessarily require teamwork on the parts of all stakeholders involved, but I think that's possible to achieve because we have a shared mission here. We all want the best for our students, our institutions, and our employees.

Chapter 7

CONCLUSION

What we call the beginning is often the end
And to make an end is to make a beginning.

The end is where we start from ...

We shall not cease from exploration

And the end of all our exploring

Will be to arrive where we started

And know the place for the first time.

-TS Eliot, *Little Gidding*

The view from the cloisters of an ivory tower can fool any observer into thinking that the surrounding landscape is monotone and featureless, a washed out field totally removed from life inside its walls. And from the ground, where particular details of geography and ecology dominate one's experience of the place, that tower seems distant and isolated - as if the builders just couldn't wait to get away from the dust and soil, and anything else that made life outside messy and complicated. But the separation between the world "in here" and the world "out there" is a fiction, and one which makes it extraordinarily difficult for anyone who wants to move between the two. Both belong to a much larger ecosystem dependent, in part, on an exchange of knowledge and expertise. And in the case of this study, that transfer comes from the exchange of highly trained scientists and engineers.

While its form is relatively new in terms of modern governmental systems, as citizens of the United States we expect our government to perform many functions. Some

of these expectations change with the development of new technologies, especially in the cases of national security and economic competitiveness. But even though not explicitly laid out in the Constitution, it is pretty well accepted that one of the most important responsibilities of our federal government is to provide the means by which we continually renew the ranks of our educated citizenry. In the modern world, as it was at our founding, education enables us to participate in our own self-governance, and serves as the most reliable vehicle for self-determination.

In the past few decades, policymakers and other analysts have tried to breathe new life into the argument for education by linking its future with other more powerful and enticing narratives - and this is especially the case when it comes to STEM higher education. Since the mid-1980s, we have too often fallen into the trope of talking about STEM education in terms of a pipeline with one output valued above all others: the PhD. But even more importantly, embedded in this metaphor is the idea that the only thing we can do to improve the educational outcomes tied to this pipe is to increase the supply of impressionable minds at the intake. This boots-on-the-ground framing, in which the STEM higher education enterprise depends on feeding more people through a unidirectional and pre-defined pipe, threatens the value of the system's educational outputs, as well as the rest of the governmental functions dependent on the human capital this system produces.

The research presented in the previous chapters lays out a new approach based on the principles of risk innovation for examining the value of the STEM PhD from institutional and employer perspectives. This was an initial exploration, and while it was limited in scope and depth, establishes a well-defined framework for further investigation. Using the framework of risk innovation, wherein risk is approached as a threat to existing or future value, this research offers a way of surveying the landscape of a certain risk or threat which allows the user to think outside the box, to bridge

the gap between the tower and the ground from a perspective of shared value. This risk can come from many directions and take many forms, often defying a traditional approach to assessment or mitigation. Take, for example, the risks to a student of not achieving hers or his personal goals, or failing to find fulfilling employment after graduation. A conventional risk assessment could easily miss these more subtle, yet no less impactful, threats to the value of this degree for a given individual.

In the case of this study, formulating the current system by which we produce STEM PhDs as a threat to the value of these degrees for all stakeholders involved also lends itself to a stakeholder-centered analysis, something which is often missing in discussions of employment outcomes for degree holders. The research program was structured so as to investigate the articulated and assumed value of these degrees for two of those stakeholder groups which also get comparatively less attention in the existing literature: the individual departments at higher education institutions, and non-academic employers who hire STEM PhDs. This approach results naturally in two sets of questions for both academic units and future employers: what is the articulated value of a STEM PhD from their perspective, as evidenced by their communication of that value to students? And how do those articulations of value align with or differ from one another, and in some cases work against each other?

Past efforts, such as the NSF Survey of Earned Doctorates (SED), do a relatively good job of collecting *some* data about job titles for STEM PhD graduates, but provide little to no insight as to the way these graduates use their training in their current jobs and careers. Additionally, most of these and other similar data collection efforts focus on student career outcomes; which while an important part of the picture, neglect to ask some fundamental questions about what these employers expect from their STEM PhD human capital, a trend only exacerbated when considering employers outside of academia. Despite a new SED every year, and many other

data sets besides, the numbers on STEM PhD employment are often incomplete or murky at best, and they fail to tell us *how* students are using their PhD training in the employment they do eventually find. Put simply, these credentials are generally assumed to be valuable, but it seems that students, academics, and employers often disagree about the nature and degree of that value. Importantly, very few of the existing data thoroughly investigate what it is non-academic employers specifically look for when they consider hiring someone with a STEM PhD, a crucial piece of the STEM employment puzzle. Since this is still relatively uncharted territory, I wanted to focus my efforts in this research towards establishing some baseline evidence as to the nature of the value of a STEM PhD as expressed by these non-academic employers, as well as create the framework by which that work could be expanded. In general, (non-STEM specific) future industry employers look for advanced general education and skills rather than specialization (Carnevale *et al.*, 2010) but put a premium on demonstrated ability to think broadly and critically (Carr, 2013), creativity (Lee *et al.*, 2013), leadership (Anonymous, 2007; Nyquist and Woodford, 2000), teamwork, relationships, networking (Lee *et al.*, 2013), written and oral communication skills (Anonymous, 2007; Carr, 2013; G. Jensen and Pm, 0400; Lee *et al.*, 2013; Pratt *et al.*, 2010). But little, if any, work has been done in the US to understand how these preferences change or gain specificity when it comes to STEM PhD employment outside of academia.

On its own, this study does not conclusively solve the issue of re-aligning the value of these degrees between academia and non-academic employers. For a start, the conclusions and recommendations based on the data presented here are significantly limited both in breadth and scope. These limitations are due in large part to the method of collection and sample size of the new interview data generated, both of which also limit the generalizability of the associated findings. The combi-

nation of personal contacts and snowball sampling made it impossible to calculate sampling error or robustly generalize conclusions from the study population based on the individuals contacted through this methodology. In this way, the findings are descriptive as opposed to predictive, limiting their future explanatory power. One avenue of future work would address this by taking the interview protocol I developed and targeting more individuals in industries which employ STEM PhDs, perhaps by beginning with those underrepresented in this study, such as the medical and health professions. These individuals could be targeted through a pre-defined identification process, an approach which while vastly more resource intensive would be more statistically rigorous.

The greatest strengths of the approach detailed in this research lie in its evidentiary point of view and the codebook developed to analyze the interview data generated. By not assuming a given value (economic or otherwise) for these degrees, this research took on a grounded theory-like attitude towards its findings, letting the data determine the structure of the analytical framework as opposed to a much stricter form of hypothesis testing. This enabled some startling insights to emerge from the data, which I had not anticipated prior to the start of this research. For example, the emphasis my interviewees placed on community service and development would have gone totally unexplored had I approached the interviews with the intent of testing dependence on a single predetermined variable. Additionally, the codebook developed to analyze the newly generated interview data provides a thorough scaffolding with which to assemble a much larger understanding of the value of these degrees. With three independent coders and multiple rounds of inductive and deductive coding, sorting the seemingly diverse interview data into discrete thematic categories ultimately proved both easy and illuminating. The findings which resulted from the application of the codebook not only addressed the core research questions

which drove the design of this study, but also pointed towards some discrete and actionable opportunities for value re-alignment.

From the data gathered and generated in Chapters 3 and 4, and the resulting analysis in Chapters 5 and 6, we see some broad trends begin to emerge that align with what little we know from non-academic employers generally (see above) and also present opportunities to increase the value of the STEM PhD for all stakeholders involved, a value re-alignment. For example, the emphasis the employers I interviewed placed on service and community development as part of their hiring decision-making process is largely unmatched in the STEM PhD programs at ASU, the example institution for R1 universities as a broad category. Intentionally designing opportunities for students to serve in authentic ways in their communities, and valuing that service in their individual PhD programs, would go a long way towards giving students an even better chance of being seriously considered by those non-academic employers, as well as strengthen the community of the university as a whole. The data and analysis revealed some perhaps surprising areas of value alignment between these two groups of stakeholders: most notably the acknowledgment that *not every student is going to become a tenured professor*, so perhaps we should broaden their training to similarly broaden their employment opportunities after graduation. Treating the risks of maintaining the status quo in U.S. STEM higher education as a threat to the value of these degrees allowed this work to identify some perhaps previously hidden opportunities to increase the value of these degrees across the board.

Identifying areas of value alignment, value disconnect, and value erosion in the ecosystem of STEM PhDs also enabled this research to point towards some course corrections and adjustments to the system which would make these degrees more valuable to schools, students, and their future employers. For example, this data suggests that we do, in fact, have a common foundation of value which talented ex-

perts and practitioners in the field of career counseling can build upon to serve PhD students as they leave the university: determination, grit, curiosity, passion, leadership, communication skills, and teamwork, to name a few. What's more, intentional instruction in resume or cover letter writing tailored towards STEM PhD students, easily accessible and integrated into their program, would make a world of difference in helping a student seem attractive to future employers. The data also suggest that students need to better understand the wide variety of jobs and careers available to them with a certain set of qualifications - before they start a program, not after graduation. And a dissertation or thesis might not be the only valuable outcome from a PhD program, especially if a student wants to find employment outside academia. My interviewees suggested that what they valued more than the thesis itself were the program management and research skills developed along the way, and also indicated that while a publication record might factor in an initial screening of applicants, it factored very little if at all in the final hiring decision-making process. These findings, as well as others detailed in previous chapters, all lend themselves towards relatively manageable adjustments at the institutional level. Some, like the PhD deliverable and graduate student mental health, rest more heavily on a broader cultural shift, the most effective change agent in a system so thoroughly decentralized as graduate education.

Additionally, any future work investigating the value of a STEM PhD through the framework I've laid out in this study will have to involve students. A next step, for example, would involve someone developing a survey which doesn't ask students about their employment *outcomes*, but rather their *expectations* given their current STEM PhD programs. At the time they applied to their current PhD program, what skills, experiences, or qualifications did they expect to gain from the program? What kinds of future jobs do they think this PhD would qualify them for, and why? In what

ways will the research they are participating in be important to the achievement of their career goals? And how do they think their success in their program is measured by their colleagues and superiors? Data from such a survey would provide key insight into many aspects of this process that employer or informant interviews could not. For example, research suggests that students identify much more strongly with a position within their specific discipline and not a given sector. Probing career *expectations* based on students' perceived value of their specific degree program would tell us how students see themselves in their program and what aspects of their program they think would be the most valuable to a future employer. Comparing these data to those generated from employer interviews could identify even more specific and potentially more actionable value disconnects. Furthermore, a series of informant interviews with professors and administrators in STEM PhD programs here at ASU and other public universities around the country would shed even more light on the phenomena represented by the chapter which analyzes the advertising prospective ASU students receive when they apply for STEM PhD programs here. We know that these documents are only part of the story, and further qualitative investigation into the daily practices and pedagogy of professors and departments would go a long way towards understanding the value of these degrees from the institutional perspective.

Of course, re-evaluating the ultimate degree produced by the STEM higher education ecosystem in the United States only begins to address the larger concerns of ensuring our educational system is of the highest possible quality, and amplifies the value brought to the table by all who participate in it. The end of this study is only the beginning, and the implications of possible future work in this area are bigger than just STEM. The National Academies of Science, Engineering, and Medicine are preparing as we speak to release their revisiting of their 1995 survey of the STEM graduate education system, whose first mandate in their statement of task is to “Con-

duct a systems analysis of graduate education, with the aim of identifying policies, programs and practices that could better meet the diverse education and career needs of graduate students in coming years ... and also aimed at identifying deficiencies and gaps in the system that could improve graduate education programs.”¹ There are serious and well-documented flaws in our graduate education training system across the board, not just in the sciences. And what’s more, I think we know it.

In general, a PhD is meant to train an individual to generate new knowledge in their chosen field, after having mastered its methodologies and evidentiary lineage. Historically, this knowledge production stemmed largely from academia as did the employment of people with PhDs. Of course, that path is well worn and still contributes to the enriching of the professoriate. But increasingly, as discussed at length earlier in Chapter 2, the PhD has come to serve more as a multi-tool, demonstrating robust analytical abilities and investigative skills to employers outside of the academy. The purpose of the degree has largely remained the same - but its applications have diverged as the role of the STEM PhD has evolved in our modern economy and bureaucratic institutions. With increased utility and divergent application comes a new set of pre-requisites, and when those in charge of designing these training programs have not themselves either investigated or experienced these relatively new career paths, we see profound lag in the system as it struggles to keep pace with the evolving reality on the outside.

One of the biggest challenges with the STEM PhD, and PhDs more broadly, is adapting to this divergence: it is one certification that simultaneously confers different measures of value and expertise dependent on the individual receiving it, the institution that granted it, and the person hiring individuals who have earned it. But

¹Board of Higher Education and Workforce, National Academy of Sciences. “Graduate Education for the 21st Century”: <http://sites.nationalacademies.org/pga/bhew/graded/index.htm> (Accessed March 1, 2018)

that is also its strength. This study shows that the value of a STEM PhD is more transferrable than some may have previously thought. However, that transfer is neither obvious nor automatic under the current training system - and this significantly threatens the value of these degrees going forward. Adjustments at the institutional level, such as those outlined in previous chapters, would enable students to translate their degree's value to more than just an academic audience; would help non-academic employers more readily identify top talent for available positions; and would broaden the base of support for these degrees at universities. This research, then, ends where it began - with the conviction that evidence-based adjustments to the system which produces STEM PhDs can increase the value of these degrees for students, employers, and academia.

AFTERWORD

It's not lost on me that I did the majority of this work the last year of my own PhD. I might have been able to pay my own tuition this year if I had a dollar for every time I'd mutter "you've gotta be kidding me" under my breath at work, and it was often difficult for me to distance myself from the trends which began to emerge in the data. And while my own degree is not one which fits under the STEM umbrella (regardless of its many permutations), I saw myself and my friends in the stories my interviewees would tell, or the literature concerning PhD employability. I felt a tinge of anguish deep in my gut every time someone told me in an interview that they didn't know if their PhD had been worth it; when the director of a national lab said that PhDs these days seemed to be full of themselves; and when my dear friend, himself with dreams of a career in academia, sent out his 46th job application that would likely go unanswered, just like the rest of them.

I hope that if you only come away from this work with one thing, it's the empowerment and reassurance that small changes really can make an incredible difference in the lives of STEM PhD students, and graduate student success in general. We're the change we've been waiting for. And to paraphrase Ovid, this burden of potentially overhauling our graduate education system will be light if we carry it willingly - and carry it together. The system is big and unwieldy, I know that, and many of the data we need to bring about systemic change are hard to gather. But here's the thing: it's easy to measure what's easy to measure. If this were easy, we would have done it already. It's much harder to measure what we value. So we first have to come to consensus about what we value.

If we do what we have always done, we will see the results we have always seen. The spirit of innovation which drives our national investment in a graduate level

STEM PhD workforce infuses our students, our academic institutions, and the engines of our economy. We just have to be brave enough to embrace the flaws in our system with that same spirit of innovation: to take them not as indications of failure or impossibility, but rather as a challenge to build something new together on a foundation of shared vision and value. The kind of change this research points to won't be painless, and certainly won't be easy. But I firmly believe that especially in this century and in this country, we can once again choose to do these things not because they are easy, but because they are hard - and worth doing.

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APPENDIX A
INTERVIEW SELECTION LIST

A2Z Development Center
ABB
All-In Analytics
Amazon Corporate LLC
Amazon Web Services
Analytic Recruiting
Apple
Argo AI
BASF Corporation
Bank of America
Biogen
Boeing
Booz Allen Hamilton
Bristol Myers Squibb
Brookhaven
Celgene
Citi
Corning
Cummins Inc
Dana-Farber Cancer Institute
EATON
EMD
Facebook
Fairway Consulting Group
General Atomics and Affiliated Companies
General Dynamics Gulfstream Aerospace
General Dynamics Mission Systems
Geocent LLC
GlobalFoundries
Google
Harnham
Honeywell
IBM
IP Recruiter Group
Illumina
Institute for Biomedical Informatics
JP Morgan Chase
JPL
Johns Hopkins APL
Johnson and Johnson
KPMG
LLNL
Lam Research
Leidos
Lockheed Martin
Los Alamos
MIT Lincoln Lab

Merck
Micron
Microsoft
Mitre Corporation
NIBR
NVIDIA
NetApp
Northrop Grumman
Oak Ridge
Oracle
Orbital ATK
PPG Industries
Pfizer
Qualcomm
Raytheon
SAIC
SLAC
Samsung Research America
Sandia
Sanofi US
Shire
Skills Inc.
Smith Hanley Associates
Software Engineering Institute
Southwest Research Institute
Sustainable Recruitment Concepts
Takeda Pharmaceutical
Terracon
The Aerospace Corporation
The Jackson Laboratory
The Medical Affairs Company
Thermo Fisher Scientific
ThinkingAhead
UCSB
UNC Chapel Hill
USAA
Universities Space Research Association
Vencore
ZS Associates

APPENDIX B

STEM EMPLOYER SEMI-STRUCTURED INTERVIEW PROTOCOL

Thank you so much for volunteering to participate in this research!

Would you describe to me how you came to your organization?

Prompt: what is your own educational background?

Prompt: where have you worked previously?

Prompt: what drew you to this company / organization / department?

What do you value most about working here?

What would you say is the skill or ability that helps you the most in your work?

Prompt: what class / workshop are you the most grateful that you took in college / graduate school?

Prompt: looking back, is there a class you wish you had taken? An experience you wish you had?

Now I'd like to switch gears a little bit.

Is there a skill or ability that you specifically look for when hiring people out of graduate school?

Prompt: what might disqualify someone from working here?

Prompt: is there something that really excites you when you see it on a resume?

Have you noticed any trends in the people with PhDs who have been applying to work here recently?

In your experience, do the PhDs you work with have a trait or a characteristic in common?

I have a couple of final questions.

Knowing what you know now, what advice would you give your younger self as he / she / they / applied for their first job out of college / graduate school?

What advice would you give a PhD student who is interested in working here when they graduate?