Chapter 3
STEM PhD Student Preparation in the Eras of Cross-sector Convergence and Global Climate Crisis: An Autobiographical Exploration

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Abstract Research universities have over the past four decades become increasingly entangled with private industry and government agencies largely due to growing resource constraints and rising pressures to commercialize discoveries. The cross-sector convergence that underpins this so-called triple helix model has received significant scholarly attention. Yet, the influence of cross-sector convergence on the preparation and socialization of STEM PhD students, and in particular those with academic and professional intentions relevant to the global climate change, has been neglected. In this essay, we rely on the concept of blended institutional logics to guide an autobiographical exploration of one of our own lived experiences as an environmental science PhD student and before that an environmentalist within government, private industry, and the public sector. From the insights generated, we develop early propositions on how cross-sector convergence is likely influencing the academic training and professional intentions of PhD students with career trajectories that intersect the global climate crisis. Recommendations for instructional practice and mentoring and future research are provided.

Introduction and Background

For nearly four decades, scholars have worked to develop an understanding of the implications of the increasing entanglement of academia, industry, and government, which is now widely known as the "triple-helix" model (Leydesdorff and Etzkowitz

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1996). The underlying claim of the triple-helix model is that the public good is most effectively and efficiently served when scientific and technological innovations are developed and diffused via market channels that involve strategic partnerships between research universities and private corporations. These channels have been fostered through neoliberal government policies that blur the once clear lines between the academy as a public good and the private marketplace as a standalone institution (Slaughter and Rhoades 2004). For example, consider the Bayh-Dole Act of 1980, which enabled American universities and colleges to protect and profit from the rights to intellectual properties developed through federally funded research activities.

Critics of the triple helix model and the research paradigm it now supports argue that it leads to an inherent bias that favors market-oriented activities over those that are more intellectually and socially oriented (Carayannis and Campbell 2009). Such concerns have led some scholars and policymakers to call for the inclusion of civil society as a fourth paradigmatic element to form what is being referred to as the "quadruple helix" model. Advocates for such a model are particularly attentive to the need to purposefully stimulate and advance innovations that are not only commercially viable, but also environmentally and socially just (Carayannis et al. 2012; Gouvea et al. 2013). Other more adamant critics of the helix model, regardless of the inclusion of a socioecological strand, argue for an entirely different approach to transdisciplinary environmental science that is altogether isolated from market-based pressures and politically biased influences (Klenk and Meehan 2015).

There is an extensive body of research that interrogates the various economic, scientific, and socioecological implications of academic-industry-government-societal entanglements, which hereafter we refer to as cross-sector convergence. Yet, inadequate attention has been directed specifically at how the convergence of the once relatively isolated sectors of academia, industry, and government and the resulting implications on society, to include the environment, is influencing the training, perspectives, and professional trajectories of Doctor of Philosophy (PhD) students. Thus, there is a pressing need to better understand the influence of cross-sector convergence on the preparation and socialization of PhD students who are entering scientific and technological fields that are on the forefront of either confronting or exacerbating the global climate crisis. Research on how to best prepare the next generation of scientists and engineers to negotiate the complex intersections of academia, industry, government, and society in environmentally centered ways, whether at bench, in the field, or in the boardroom, is desperately needed. In response to this need, we conducted an autobiographical study of one of our own lived experiences first as an environmentalist within government, industry, and the public sector, and then as a PhD student in an environmental science program.

Graduate students in the science, technology, engineering, and mathematical (STEM) disciplines have not been entirely neglected within the cross-sector convergence literature. In some cases, increased interactions with industry professionals and government representatives have been found to be effective in preparing students for research careers that span academic, government, public, and industry boundaries (Mendoza 2007; Thune 2010). In other cases, cross-sector activities

have been shown to encourage PhD students to more purposefully consider the entrepreneurial potential of their research interests and career paths (Bienkowska and Klofsten 2012; Mars et al. 2014).

More critical assessments of the effects of cross-sector convergence have also been provided. Examples of such criticisms include the dilution of academic values held by PhD students and subsequent declines in their engagement in traditional activities (i.e., basic research, journal publications; Lee and Miozzo 2015). More broadly, the inclusion of PhD students in industry collaborations has been associated with the shift of higher education away from a public good regime and toward what has been widely referred to as academic capitalism (Gumport 2005; Slaughter and Rhoades 2004). Critics of academic capitalism argue that market permeation in higher education in part incentivizes graduate students, and especially those in the STEM fields, to view their current and future research through an entrepreneurial lens that privileges resource acquisition over more altruistic aspirations that are tied to the public good (Mars et al. 2008, 2014; Mars and Metcalfe 2009).

Finally, the effects of PhD student engagement in cross-sector collaborations and networks have been further considered under the contexts of economic development and organizational competitiveness. For instance, Gustavsson et al. (2016) provide evidence that PhD student participation in university-industrial collaborations has positive effects on both the competitiveness of their universities and the growth of the surrounding economies. Similarly, the competitive benefits realized by firms that participate in university collaborations involving PhD students, which most commonly come in the forms of knowledge transfer and talent acquisition, are well documented (e.g., Assbring and Nuur 2017; Mendoza 2007; Thune 2009).

Conceptual Framework

In this chapter, our aim is to develop neither further support for nor critique of cross-sector convergence relevant to how STEM PhD students are being prepared to respond to the global climate crisis. Instead, our focus is on how these students come to recognize, understand, and negotiate the entanglement of academic, industrial, political, and societal beliefs, norms, values, and activities relevant to their PhD-level training and academic and professional aspirations specific to the current climate crisis. We frame our exploration in the context of institutional logics, which Thornton and Ocasio (1999) define as, “the socially constructed, historical patterns of material practices, assumptions, values, beliefs, and rules by which individuals produce and reproduce their material subsistence, organize time and space, and provide meaning to their social reality” (p. 804). The theoretical root of institutional logics is the recognition that individual actors, the organizations they compose, and the broader institutions in which they are positioned are being influenced by constant shifts between states of coordination and compatibility to those of competition and discord (Lounsbury and Boxenbaum 2013).

A full review of the extensive body of work on institutional logics is well beyond the scope of this chapter (see Greenwood et al. (2011) and Thornton et al. (2012) for more thorough reviews of the institutional logic and complexity literature). Instead, we focus specifically on the concept of logic multiplicity, which refers to the concurrent presence and influence of multiple logics on the activities, perspectives, and values of organizational actors (Besharov and Smith 2014). No less than five co-occurring logics (environmental, market, political-regulatory, scientific, societal) are likely influencing STEM education at the PhD-level and its relation to the global climate crisis in this era of academic capitalism and cross-sector convergence.

Logic multiplicity requires constant negotiation on the part of organizational actors. In some cases, actors are able to constantly navigate back and forth between the influences and pressures of multiple logics that are sometimes compatible and other times oppositional (Reay and Hinings 2009; Saz-Carranza and Longo 2012). Examples of studies on the navigation of co-existing logics that are particularly relevant to our current work include academics who balance the simultaneous demands for both basic and applied research (Bullinger et al. 2015), environmental managers within firms who are accountable to both market- and environment-based goals and motives (Dahlmann and Grosvold 2017), and ecopreneurs who routinely shift between the quest for profits and commitment to moral decision making (Suckert 2019). In other cases, actors draw on one dominant logic to resist the influence, if not adoption, of a competing logic, as Marquis and Lounsbury (2007) depict in the case of community bankers working to prevent their locally based institutions from being acquired by corporate banks.

Actor response to logic multiplicity is not limited to accommodation, negotiation, and/or resistance. Instead, actors sometimes work within the contexts of their organizations and respective fields to couple otherwise disparate elements from competing logics and thereby forming new hybrids (Pache and Santos 2013; Ramus et al. 2016). Such logic blending is a strategy that actors often pursue when introducing and eventually legitimizing new and disruptive practices within otherwise rigid and well-established organizations and fields (Mars and Schau 2017; Skelcher and Rathgeb-Smith 2015; Tracey et al. 2011). In the specific context of the global climate crisis, logic blending has been shown to be a highly common feature of the environmental work that is performed by a diverse set of actor types that include, but not limited to activists, college student entrepreneurs, and sustainability officers in private firms (Ansari et al. 2013; Mars and Lounsbury 2009; York et al. 2016). This rich line of inquiry points to logic blending as an approach to embedding conservation and sustainability into the activities, practices, and values of well-established organizations and fields. This functional view of embeddedness is framed as a strategic alternative to directly challenging well-established and firmly positioned organizations and fields.

Clearly, the ways in which actors are influenced by and respond to logic multiplicity and the resulting implications on practice, whether at the individual, organization, or field level, are both opaque and highly complex. Considering PhD students, and especially those in the STEM fields, are on the leading edge of confronting the global climate crisis, a greater understanding of how logic multiplicity

is shaping their learning, current practices, and anticipated career trajectories is warranted. These PhD students are being trained in organizational settings that are simultaneously shaped by elements that stem from environmental, market, political-regulatory, scientific, and societal logics. Accordingly, their scientific preparation involves, implicitly or explicitly, the confrontation and navigation of multiple logics. Yet, to our knowledge we are the first to directly consider how individual students come to recognize and make sense of logic multiplicity specific to both their PhD-level education and their future roles in responding to the global climate crisis. Moreover, the theoretical work on logic multiplicity has been conducted almost entirely at the organization and field levels. We depart from this tradition by exploring how an individual actor, in this case a PhD student in environmental geochemistry, makes sense of and responds to the various influences and pressures that intersect the role of scientific research and development in responding to the current global climate crisis.

Autobiographical Approach

Here, we use an autobiographical self-study approach to explore the ways in which one of us, Bryan, made sense of and responded to cross-sector influences and pressures as a PhD-level environmental geochemistry student with a deep interest in addressing climate change. This approach is particularly well suited for our exploration in that self-study fosters an intimate connection between readers and the insights contained within the lived experiences of the researcher (Bullough and Pinnegar 2001). Moreover, there is precedence of conducting research using self-study design in the fields in which our exploration is most firmly anchored, specifically education and sociology (e.g., Bullough and Pinnegar 2001; DeGloma 2010; Friedman 1990; Hamilton et al. 2008; Swedberg 2016),

Bryan's written reflections on how he recognized, navigated, and generally made sense of the various influences and pressures of cross-sector convergence during his experience as a PhD student relevant to the global climate crisis served as our data. The analytical use of reflective narratives written by researchers is an established self-study practice (Connelly and Clandinin 1990). Our decision to take this approach was aided by Bryan's longstanding practice of purposeful reflection on his professional experiences and overall personal growth and development that began in earnest as a Peace Corps volunteer in the early 2000s. The reflective process he routinely engages is informal and thus not structured according to any particular set of prompts or objectives, or for that matter overarching theme. As such, we applied a conceptual lens specific to cross-sector convergence and logic blending to a more freely formed reflective account of the diverse array of academic, civic, and professional experiences that have over time contributed to Bryan's development as a now PhD-level environmental scientist. The application of a theoretical lens to derive objective meaning within reflective accounts is a technique commonly deployed during autobiographical inquiry (Polkinghorne 1995; Smith and Sparkes 2006).

The analysis of reflective narratives is typically bound to a specific timespan that is appropriate to the phenomenon of study (Polkinghorne 1995). Our general focus is on the period when Bryan was a PhD student. However, we recognize his prior experiences working as an environmental engineer in both government and the mining industry, as well as his early experience immediately out of his undergraduate degree program working for a non-governmental organization (NGO), heavily influenced his perspective on the global climate crisis. Accordingly, Bryan temporally bound his reflections to 2001, which is when he began his post-baccalaureate position with the Peace Corps, to December 2020 when he completed a PhD degree in environmental geochemistry. Two themes remained particularly prevalent throughout this bounded period of reflection that made the narrative particularly amendable to the analysis: (1) the range of cross-sector experiences that Bryan accumulated up to and throughout his PhD training and (2) the consistent progression of his development and evolving identity as an environmental scientist.

Researchers inherently begin to apply subjective meaning to their experiences and perspectives as they engage in reflection and journaling processes (Bamberg 2012). Thus, Bryan used a qualitive memo format (Mason 2017) to record in "real time" any early insights into the potential patterns or themes on how as a PhD student he navigated and made sense of cross-sector influences and pressures relative to the global climate crisis. We initiated formal analysis only after Bryan was no longer generating new reflections on how his perspective on the global climate crisis came to be prior to entering his PhD program and how he navigated the influences of cross-sector convergence thereafter.

Formal analysis began with us each individually coding the written narrative and subjective memos using a deductive framework composed of the quadruple helix and logic multiplicity concepts described earlier in the chapter. We also each performed a round of inductive analysis of the narrative using an open code framework. Next, we engaged in researcher triangulation in order to reveal both consistencies and discrepancies in our individual findings (Denzin 1978; Onwuegbuzie and Leech 2007). We continually discussed the consistencies ad discrepancies, to include individually and collectively returning to the data on multiple occasions, until consensus on the salient themes was reached. We then engaged in a final round of both deductive and inductive analysis of the narrative and memos in order to further refine the themes into what ultimately became our final set of findings.

Establishing trustworthiness in the analytical processes that are associated with self-study and narrative inquiry is especially challenging given the inherent presence of subjectivity (Bullough and Pinnegar 2001; Feldman 2003). Our engagement in researcher triangulation, as just described, was one measure we took to enhance the trustworthiness of our findings. Additionally, we also developed an audit trail that articulates the decisions we made and the steps we took when designing and carrying out our approach (Creswell and Miller 2000). Finally, we frame our findings as initial propositions to be empirically pursued in future studies that have a greater capacity to generate more transferable findings.

Findings

Bryan's autobiographic narrative is centered on his experiences as a PhD student (2015–2019). Yet, he recognizes that his perspective on global climate crisis upon entering the PhD program was significantly influenced by his previous experiences as a Peace Corps volunteer in West Africa, as an environmental engineer with several local and federal government agencies in the United States, and as an environmental consultant for the mining industry. Accordingly, the following narrative draws from these experiences to provide deeper context on his viewpoint of how cross-sector convergence influenced his perspective on the global climate crisis throughout his PhD-level training. In 2001, Bryan completed a Bachelor of Science (BS) degree in geology from the University of Colorado. He worked for the US Geological Survey from 1999 to 2001 while completing the BS degree, which was his first professional experience related to the climate crisis. Following the completion of the BS, Bryan served as an environmental Peace Corps volunteer in Benin, West Africa from 2001 to 2004 working on development projects focused on the urban environment in a city located on the edge of the Sahara Desert. Upon returning to the USA, he next worked for a Public Works Department in a small resort town in the mountains of Colorado. Recognizing the need for advanced training, Bryan returned to academia in 2005 to pursue and eventually earn a Master of Science (MS) degree in hydrogeology from Washington State University and then a second MS degree in environmental engineering from the University of Arizona (UA). While at the UA, Bryan concurrently expanded his professional experience first as an engineering technician for the City of Tucson Wastewater Reclamation Department (2009–2011) and then as a senior project environmental engineer for an international consulting firm (2011–2018), focusing on environmental assessments and remediation associated with large-scale mining projects in the western USA, Mexico, and South America. In December 2019, Bryan completed a PhD in environmental science with a focus on geochemistry. He has since joined the UA faculty as an assistant research scientist with current projects focusing on geochemical processes at closed mine sites in the western US, with an emphasis on contaminant fate and transport processes that are driven by changes in the regional and global climate.

Bryan's written narrative clearly articulated an academic and career progression that has been continually influenced by multiple logics that are sometimes compatible and other times in conflict when it comes to the global climate crisis. The five primary logics that were identified within the narrative as having had the most consistent influence on Bryan's academic and professional development leading up to and continuing through his doctorial training: environmental, market, political-regulatory, scientific, and societal (see Table 3.1). Our focus hereafter is on how Bryan negotiated the various and often competing pressures that these logics brought to bear on his PhD-level training and evolving perspective on the global climate crisis. Specific attention is given to the processes that he consistently engaged as a PhD student to negotiate the influence of cross-sector convergence and

Table 3.1 Logic-types

Logic-type	Description
Environmental	GCC is framed specific to environmental impact and change
Market	GCC is framed specific to profit making and loss
Political-regulatory	GCC is framed specific to political agendas and government oversight
Scientific	GCC is framed specific to knowledge generation and dissemination
Societal	GCC is framed specific to the security and well-being of communities and society

logic multiplicity relative to the global climate crisis. The processes are (1) self-reflection, (2) bargaining, and (3) adaptation.

Bryan first identified as an environmentalist as an undergraduate student studying geology. He entered college with deep appreciation for nature, which was largely instilled and reinforced by his upbringing and family value system. He writes, "Viewing the environment as the key issue that I wanted my professional career to focus on, I pursued my Bachelor's degree in geology with the intention to using it towards solving problems related to environmental contamination and cleanup." This appreciation became more formally anchored in an environmental logic throughout his undergraduate studies, which included participation in various environment-related co-curricular activities and experiences (e.g., student organizations, internships).

It was also during Bryan's undergraduate years that he first experienced the complexities associated with cross-sector convergence and the pressures of logic multiplicity. In particular, he observed firsthand through his work in the US Geological Survey the slowing and sometimes crippling effects of governmental bureaucracy on environmental action. This experience helped him better understand bureaucratic realities and the relationship between regulated activity and environmental stewardship. He also came to realize a government career entrenched in a political-regulatory logic would not provide the degree of impact he aimed to have on environmental renewal and conservation. This early career self-reflection marks Bryan's first experience in logic negotiation as he worked to retain alignment with a core environmental logic, while making sense of what is best described in this instance as an overlapping political-regulatory logic. Minimal negotiation was needed in this instance due the exploratory freedoms that typify the developmental trajectory of an undergraduate education. The need for more complex negotiation was soon to come.

Bryan's next encounter with logic multiplicity came during his time volunteering with the Peace Corps. On one hand, he recalls the societal logic that guided the Peace Corps being clearly aligned with the activities, strategies, and values that characterized the environmental movement. On one hand, the blending of the environment and societal logics required the integration of a community development focus with his environment-oriented agenda, which demanded little to no compromise on his part. On the other hand, he was also forced to negotiate the tension between applying entrepreneurial approaches (i.e., a market logic) to environmental

and social causes that were both justice-oriented and rooted in local culture. Looking back, he attributes the impact he was ultimately able to have on the local community and its surrounding environment to his growing sense of adaptability. He writes:

> I had to be willing to blend social and environmental justice with capitalist ingenuity and entrepreneurship, while at the same time honoring local social norms and cultural identities. I learned to adapt the scope and motivation for the project to align with community needs and be more willing to sacrifice time and materials without immediate progress.

Pointing to his own experience and several well-known cases of Peace Corps volunteers-turned social entrepreneurs, Bryan now embraces the promise of a blended societal-market logic that fosters social change and environmental justice through entrepreneurial activities. Thus, the experience and perspective he gained in the Peace Corps enhanced his early capacity to blend otherwise competing logics in ways that remain consistent with his own environmental and social values.

Following a brief period working in a city public works department, Bryan returned to college to pursue his first master-level degree in hydrogeology. He entered this program under the belief that academic laboratories are fully isolated from outside pressures and thereby driven solely by scientific curiosity. He was quickly confronted with the reality that external pressures tied to both market and political-regulatory logics continually permeate the walls of the academy. Market pressures are tied to inherent resource scarcities and the ongoing need to support research activities (including graduate student employment) through outside funding. Political and regulatory pressures stem from the need to align research projects with the funding priorities of government agencies, as well as the rigid and often complicated policies associated with subsequent support. Market pressures, as well as those that are political and regulatory in nature, did not explicitly influence Bryan's daily routine as a Master student. Instead, his attention remained mostly fixed on experiments, manuscript writing, and other typical student activities. Upon reflection, however, he recognizes the immediate, yet implicit influence cross-sector pressures had on both his training and how he was socialized as an emergent scientist. Specifically, he describes having to "modify my [his] ideological view of science to fit with my [his] supervisor's expectations and funder priorities. I [he] had to learn to mix a sense of idealism with one of reality."

Presently, Bryan increasingly sees the value in being a scientist with the ability to find and act on cross-sector synergies, no matter how subtle. He especially recognizes the value of his "bargaining skills" now that the global climate crisis has become a contentious point of political rhetoric and public debate. While Bryan began to gain these bargaining skills first as a Peace Corps volunteer and then as a graduate student, it was during his time in industry that he clearly recognized their value and began to purposefully sharpen and utilize them. As an environmental engineer in the mining industry, Bryan had to be flexible enough to perform under a market logic that viewed environmental responsibility as a regulatory obligation that should be kept to a minimum, while retaining and when possible acting on his core environmental beliefs. He summarizes his role in the mining industry and the associated challenges in the following way:

> I was part of the water group that dealt with environmental issues at primarily copper, gold, and silver mines across the western US and Mexico. Those of us in the water group were viewed as "tree huggers" and mostly a burden to the company, in comparison with the design engineers that were at the profit center of the mines – we [hydrologists] were just added cost, taking away from the profitability of the mines with whom we worked.

Despite the challenges and sense of alienation, Bryan was able to adapt to the market logic in ways that allowed him to quietly pursue environmental justice along the margins. He says, "understanding and adapting to the profit-driven perspective is necessary for the industry-based scientist to do their job and satisfy their need for environmental justice." Though, over time the intensity involved in constantly bargaining and adapting to the convergence of environmental, market, political-regulatory, and scientific logics eventually pushed Bryan to return to academia to further pursue his graduate education and recapture a stronger sense of "environmental altruism."

Bryan's decision to return to graduate school was not driven by a single dominant logic. Rather, he was motivated by an environmental-scientific-market blend that was continually evolving with each new experience. He had by now come to see the notion of pure research as being overly idealistic and that his scientific career, even if positioned in academia, would require the negotiation and blending of elements from otherwise distinct and oftentimes competing logics. This realization that had developed out of various experiences accumulated through volunteer work, earlier graduate training, and time working in both industry and government created within Bryan a "pragmatic view of how science can be used to solve the climate crisis."

From the start of his PhD program, Bryan noticed a difference in how he understood the research process compared to his younger, more traditional peers who entered their programs with less depth and breadth of experience and perspective. He writes,

> I think my experience navigating competing agendas and pressures in the different positions I have had perhaps better prepared me to recognize and learn to deal with the capitalist realities and political controversies that influence how science needs to be approached and framed when it comes to the climate crisis.

He observed other students struggling to accept that science, even in universities, does not happen in a bubble and that scientists have to adapt in order to account for the constant outside push for practical solutions with market potential, shifts in the political climate, and so on. He writes,

> I know firsthand that flexibility is necessary to move research forward. You have to bend without breaking at times in terms of your agenda and values. If you don't, you'll get stuck and be unsuccessful in making any kind of impact. Other students with less experience believe academic freedom releases them from compromise and thus have a really hard time adapting to the realities.

Overall, Bryan's observations of his peers suggest that the romantic view of academia that incoming PhD students seem to hold when entering their programs is inconsistent with how research is approached, framed, and conducted in this era of

cross-sector convergence. The disillusionment that is likely to develop from such naivete puts students at greater risk of abandoning their research aspirations altogether and consequently the scientific arm of the environment movement.

Bryan concluded his narrative with a reflection on how faculty work with students relevant to the influences of cross-sector convergence on the research process and, more generally, the scientific process. His reflections indicate that faculty primarily aim to protect graduate students from external pressures to acquire and sustain funding. Bryan writes:

> Faculty wanted us focused on learning scientific theories and research techniques, doing analysis, writing papers, etc. They did not want us to be concerned about or distracted by what was needed to support us doing this work. This really helped us develop our scientific abilities, but at the same time it left many of us in the dark about overarching realities. When some type of funding issue or political nuance interrupted or halted a project, students often became very unsettled and even jaded. I think this is because they simply didn't have enough understanding of all that was going on around them. I, too, got frustrated, but also seemed to be able to cope and adapt much more easily.

This particular reflection not only makes clear the strategic value of logic negotiation relevant to the influences and pressures of cross-sector convergence, but also provides indication of the need to more purposefully embed the development of associated skills in STEM PhD programs. As Bryan warns in his reflection, not doing so may be contributing to the attrition of young scientists who entered their PhD programs motivated and poised to make meaningful contributions to the efforts to overcome the global climate crisis.

Discussion and Conclusion

Bryan's story is somewhat unique in that he entered his PhD program with a diverse range of experiences that spanned the academic, government, NGO, and private industry sectors. He is an outlier in this regard. Yet, the wisdom gained through his experiences equipped him with a unique perspective from which to compare how he and his peers with more conventional backgrounds responded differently to various cross-sector tensions that now permeate the STEM PhD experience. From his vantage point, we have been led to argue the need to integrate new training and socialization approaches designed to better prepare the next generation of scientists who aim to confront the global climate crisis within this era of cross-sector convergence. Specifically, we conclude the chapter with a call for the integration of the skills, insights, and knowledge associated with what organizational scientists and sociologists have termed "boundary spanning" (Aldrich and Herker 1977; Comacchio et al. 2012; Schotter et al. 2017; Tushman and Scanlan 1981).

Our argument for the inclusion of boundary spanning in the preparation of PhD scientists is anchored in the assumption that the quadruple helix model and the era of cross-sector convergence will remain firmly intact for the foreseeable future. Meanwhile, the global climate crisis will unfortunately continue to escalate without

the development and implementation of more effective scientific and technological interventions. Thus, our aim is to constructively influence how STEM PhD students are being prepared as entrepreneurial scientists who are as well-equipped as possible to, in relative terms, quickly contribute to the alleviation of the global climate crisis.

Boundary spanning refers to the strategies actors deploy in order to resist, counter, and/or leverage the external pressures and influences that continually permeate the boundaries of their organizations and fields (Wang et al. 2018). For reasons described in the introduction section, the researcher capacity to effectively engage in boundary spanning when working under the influence of cross-sector convergence is especially important (Lundberg 2013). Yet, meager attention has been directed at how PhD students are being equipped to not only cope with, but to strategically leverage cross-sector convergence to the benefit and impact of their science on the global climate crisis (Meyer et al. 2016). The little work that has been done in this area is mostly focused on how graduate students are increasingly engaging in sustainability research by spanning disciplinary boundaries within the academy (Gosselin et al. 2016). This type of work is critical and to be applauded. However, equally important is how students are being both trained and socialized to engage in boundary spanning across sectors that extend beyond the partitions of their labs and the walls of the academy.

We explored the rich set of cross-sector experiences that Bryan called on to make sense of the organizational conditions under which he completed his PhD program through the lens of logic multiplicity. In doing so, we identified and illustrated the consistencies and clashes between the logics that shape the otherwise disparate sectors that become entangled under the quadruple helix model. We also showed how Bryan's diverse experiences enhanced his capacity to productively navigate the underlying tensions and remain committed to helping end the global climate crisis through scientific research. Unfortunately, his peers generally lacked similar breadth of experience and thus were at greater jeopardy of abandoning their research career trajectories as their idealistic views on the sanctity of science became clouded. This comparative gap leads us to recommend greater attention be given to the inclusion of mentoring approaches in STEM PhD programs that directly address logic negotiation and cross-sector boundary spanning, especially in the context of the global climate crisis.

Three overlapping inter-organizational boundary spanning skill sets can provide a foundation upon which faculty can begin to more directly mentor students in logic negotiation. The first of these sets pertains to cultural skills (Barner-Rasmussen et al. 2014). Recall that dominant logics work to establish and protect the cultures of fields (Marquis and Lounsbury 2007). Accordingly, students must learn to recognize the similarities and differences in the cultures that guide the activities, priorities, and strategies of the various sectors that converge under the quadruple helix model. Such recognition should not be aimed at determining who is right and who is wrong. Instead, the goal is to identify differences, act on opportunities for adaption, and acknowledge elements that are non-negotiable. This objective approach

prioritizes the discovery of common ground rather than the accentuation of differences and impasses.

The second and third skill sets center on information processing and language acquisition. Information processing refers to the capacity of actors (e.g., researchers) to take in, make sense of, and act on the various cross-sector information that converges on their work (e.g., science) (Adler et al. 2003; Tushman and Scanlan 1981). Similarly, effective change agents are able to understand and engage in a shared language that enables productive collaboration across inter-organizational boundaries (Barner-Rasmussen et al. 2014; Harzig et al. 2011). Accordingly, faculty are encouraged to work with their mentees in ways that increase their abilities to translate cross-boundary information relevant to the aims of their research. The focus of such translation should be on adapting to and maximizing that which is conducive to their aims, adjusting their aims as necessary and appropriate, and strategically resisting influence when deemed detrimental to the outcomes. This translation process flows two ways. That is, after receiving, processing, and adapting to external information, students must be prepared to effectively convey their responses and underlying rationales to those outside of the academy. Students should be mindful of the likelihood that external actors are equally unfamiliar with the alternative logics that dominate fields other than their own. Overall, the bargaining that occurs when negotiating the tensions inherent to logic multiplicity requires the ability to openly receive, objectively process, and strategically convey information across inter-organizational boundaries.

Faculty mentors are also encouraged to take great care in how they frame the importance and potential impact of boundary spanning relevant to overcoming the global climate crisis. In particular, the role of the boundary spanner has been positively associated with a change in leadership across a number of contexts that range from market-based collaborations to social movements (e.g., environmentalism) (Roberts and Beamish 2017; Wang et al. 2018; Wright and Nyberg 2012). Students should be prepared to view logic negotiation and boundary spanning as strategies for maintaining (not compromising) their scientific integrity and commitment to environmental justice and stewardship, while effectively advancing the impact of their work on the alleviation of the global climate crisis. In this light, the strategic goal is to maintain the core in adherence with scientific, environmental, and societal logics, while innovating on the margins in ways compatible with market and political-regulatory logics. The empowerment to come from a deeper understanding of cross-sector convergence and the development of negotiation and spanning skills and strategies stands to offset the disillusionment and fleeing of otherwise promising scientists and environmental change agents.

There is also a moral dimension to the purposeful integration of skills and strategies for boundary spanning and logic negotiation with environmentally oriented PhD programs. Indeed, many, if not most, students are likely to enter these programs with values and motives that are directly tied to environmental justice and stewardship. Yet recognizing that environmental crises such as global climate change are not universally accepted concerns, such values and motives may through cross-sector convergence come into conflict with other, less progressive agendas.

Boundary spanning and logic negotiation skills and strategies have the promise of helping students strengthen and retain a sense of agency over their work as competing pressures converge on their training and development. It is imperative that students learn to effectively navigate the complexities of cross-sector engagement without abandoning the moral compasses that direct their quests to contribute to the alleviation and reversal of the global climate crisis. This proposition is consistent with a growing line of inquiry that confronts the authoritative degradation and homogenization of researcher value systems by virtue of the socialization processes and operational realities of PhD programs, post-doc positions, and early-stage career experiences (e.g., Fochler et al. 2016; McAlpine and Amundsen 2009; Roumbanis 2019).

We recognize that faculty themselves will not always be adequately equipped to span boundaries and strategically navigate multiple logics. This is all the more reason to more purposefully engage their colleagues and students in discussions and initiatives that foster the underlying skill sets. True to most mentoring models, the mentor and mentee both stand to learn and grow through the process (Meyer et al. 2016). Conversely, isolating students from external pressures will only serve to stunt their development, as well as that of a scientific community with the promise of creating viable solutions to the global climate crisis.

In summary, the mentoring model we are proposing here is, to our knowledge, the first to directly consider how STEM PhD students are being prepared to contribute to the alleviation of the global climate crisis in an era of cross-sector convergence. Our proposition is anchored in an autobiographical analysis of one of our own stories. While systematically and rigorously conducted our analysis, the insights we have generated here are not transferable. Accordingly, the theory-driven mentoring model that we have framed warrants piloting and subsequent empirical examination and refinement. To this end, we close by suggesting the following three research questions that are likely to be fruitful in carrying forward in the line of inquiry we have initiated here:

1. How, if at all, do faculty introduce STEM PhD students to the realities of cross-sector convergence relevant to work that targets the global climate crisis?
2. How, if at all, do faculty mentor STEM PhD students in the areas of logic negotiation and boundary spanning specific to the global climate crisis?
3. What are the impacts of cross-sector convergence on the career trajectories and attrition patterns of STEM PhD students with interests and goals specific to the global climate crisis?
4. How, if at all, can logic negotiation and boundary spanning enhance the capacities of STEM PhD students to retain their sense of agency and moral commitment to the alleviation and reversal of the global climate crisis?

References

Adler, T., Black, J. A., & Loveland, J. P. (2003). Complex systems: Boundary-spanning training techniques. *Journal of European Industrial Training, 27*(2), 111–124. https://doi.org/10.1108/03090590310468930.

Aldrich, H., & Herker, D. (1977). Boundary spanning roles and organization structure. *Academy of Management Review, 2*(2), 217–230.

Ansari, S., Wijen, F., & Gray, B. (2013). Constructing a climate change logic: An institutional perspective on the 'tragedy of the commons'. *Organization Science, 24*(4), 1014–1040. https://doi.org/10.1287/orsc.1120.0799.

Assbring, L., & Nuur, C. (2017). What's in it for industry? A case study on collaborative doctoral in Sweden. *Industry and Higher Education, 31*(3), 184–194. https://doi.org/10.1177/0950422217705245.

Bamberg, M. (2012). Narrative analysis. In H. Cooper (Ed.), *APA handbook of research methods in psychology* (pp. 77–94). Washington, DC: APA Press.

Barner-Rasmussen, W., Ehrnrooth, M., Koveshnikov, A., & Mäkelä, K. (2014). Cultural and language skills as resources for boundary spanning within the MNC. *Journal of International Business Studies, 45*, 886–905. https://doi.org/10.1057/jibs.2014.7.

Besharov, M. L., & Smith, W. K. (2014). Multiple institutional logics in organizations: Explaining their varied nature and implications. *Academy of Management Review, 39*(3), 364–381. https://doi.org/10.5465/amr.2011.0431.

Bienkowska, D., & Klofsten, M. (2012). Creating entrepreneurial networks: Academic entrepreneurship, mobility and collaboration during PhD education. *Higher Education, 64*(2), 207–222. https://doi.org/10.1007/s10734-011-9488-x.

Bullinger, B., Kieser, A., & Schiller-Merkens, S. (2015). Coping with institutional complexity: Responses of management scholars to competing logics in the field of management studies. *Scandinavian Journal of Management, 31*(3), 437–450. https://doi.org/10.1016/j.scaman.2015.02.001.

Bullough, R. V., Jr., & Pinnegar, S. (2001). Guideline for quality autobiographical forms of self-study research. *Educational Research, 30*(1), 13–21. https://doi.org/10.3102/0013189X030003013.

Carayannis, E. G., & Campbell, D. F. J. (2009). 'Mode 3' and 'Quadruple Helix': Toward a 21st century fractal innovation ecosystem. *International Journal of Technology Management, 46*(3–4), 201–234.

Carayannis, E. G., Barth, T. D., & Campbell, D. F. J. (2012). The Quintuple Helix innovation model: Global warming as a challenge and driver for innovation. *Journal of Innovation and Entrepreneurship, 1*, 2. https://doi.org/10.1186/2192-5372-1-2.

Comacchio, A., Bonesso, S., & Pizzi, C. (2012). Boundary spanning between industry and university: The role of technology transfer centres. *Journal of Technology Transfer, 37*, 943–966. https://doi.org/10.1007/s10961-011-9227-6.

Connelly, F. M., & Clandinin, D. J. (1990). Stories of experience and narrative inquiry. *Educational Researcher, 19*(5), 2–14. https://doi.org/10.3102/0013189X019005002.

Creswell, J. W., & Miller, D. L. (2000). Determining validity in qualitative inquiry. *Theory Into Practice, 39*(3), 124–130. https://doi.org/10.1207/s15430421tip3903_2.

Dahlmann, F., & Grosvold, J. (2017). Environmental managers and institutional work: Reconciling tensions of competing institutional logics. *Business Ethics Quarterly, 27*(2), 263–291. https://doi.org/10.1017/beq.2016.65.

DeGloma, T. (2010). Awakenings: Autobiography, memory, and the social logic of personal discovery. *Sociological Forum, 25*(3), 519–540. https://doi.org/10.1111/j.1573-7861.2010.01194.x.

Denzin, N. K. (1978). *The research act: A theoretical introduction to sociological methods*. New York: Praeger.

Feldman, A. (2003). Validity and quality in self-study. *Educational Researcher, 32*(3), 26–28. https://doi.org/10.3102/0013189X032003026.

Fochler, M., Felt, U., & Müller, R. (2016). Unsustainable growth, hyper-competition, and worth in life science research: Narrowing evaluative repertoires in doctoral and postdoctoral scientists' work and lives. *Minerva, 54*, 175–200. https://doi.org/10.1007/s11024-016-9292-y.

Friedman, N. L. (1990). Autobiographical sociology. *Autobiographical Sociology, 21*, 60–66. https://doi.org/10.1007/BF02691782.

Gosselin, D., Vincent, S., Boone, C., Danielson, A., Parnell, R., & Pennington, D. (2016). Negotiating boundaries: Effective leadership of interdisciplinary environmental and sustainability programs. *Journal of Environmental Studies and Sciences, 6*, 268–274. https://doi.org/10.1007/s13412-015-0357-2.

Gouvea, R., Kassicieh, S., & Montoya, M. J. R. (2013). Using the quadruple helix to design strategies for the green economy. *Technological Forecasting and Social Change, 80*(2), 221–230. https://doi.org/10.1016/j.techfore.2012.05.003.

Greenwood, R., Raynard, M., Kodeih, F., Micelotta, E. R., & Lounsbury, M. (2011). Institutional complexity and organizational responses. *Academy of Management Annals, 5*(1), 317–371. https://doi.org/10.5465/19416520.2011.590299.

Gumport, P. J. (2005). Graduate education and research: Interdependence and strain. In P. G. Altbach, R. O. Berdahl, & P. J. Gumport (Eds.), *American higher education in the twenty-first century: Social, political, and economic challenges* (2nd ed., pp. 425–460). Baltimore: The Johns Hopkins University Press.

Gustavsson, L., Nuur, C., & Söderlind, J. (2016). An impact analysis of regional industry – University interactions: The case of industrial PhD schools. *Industry and Higher Education, 30*(1), 41–51. https://doi.org/10.5367/ihe.2016.0291.

Hamilton, M. L., Smith, L., & Worthington, K. (2008). Fitting the methodology with the research: An exploration of narrative, self-study and auto-ethnography. *Studying Teacher Education, 4*(1), 17–28. https://doi.org/10.1080/17425960801976321.

Harzig, A. W., Köster, K., & Magner, U. (2011). Babel in business: The language barrier and its solutions in the HQ-subsidiary relationship. *Journal of World Business, 46*(3), 279–287. https://doi.org/10.1016/j.jwb.2010.07.005.

Klenk, N., & Meehan, K. (2015). Climate change and transdisciplinary science: Problematizing the integration imperative. *Environmental Science and Policy, 54*, 160–167. https://doi.org/10.1016/j.envsci.2015.05.017.

Lee, H., & Miozzo, M. J. (2015). How does working on university-industry collaborative projects affect science and engineering doctorates' careers? Evidence from a UK research-based university. *Journal of Technology Transfer, 40*(2), 293–317. https://doi.org/10.1007/s10961-014-93400-4.

Leydesdorff, L., & Etzkowitz, H. (1996). Emergence of a triple helix of university-industry-government relations. *Science and Public Policy, 23*(5), 279–286. https://doi.org/10.1093/spp/23.5.279.

Lounsbury, M., & Boxenbaum, E. (2013). *Institutional logics in action*. Bingley: Emerald Group Publishing.

Lundberg, H. (2013). Triple helix in practice: The key role of boundary spanners. *European Journal of Innovation Management, 16*(2), 211–226. https://doi.org/10.1108/14601061311324548.

Marquis, C., & Lounsbury, M. (2007). Vive la resistance: Competing logics and consolidation of U.S. community banking. *Academy of Management Journal, 50*(4), 799–820. https://doi.org/10.5465/amj.2007.26279172.

Mars, M. M., & Lounsbury, M. (2009). Raging against or with the private marketplace? Logic hybridity and eco-entrepreneurship. *Journal of Management Inquiry, 18*(1), 4–13.

Mars, M. M., & Metcalfe, A. S. (2009). The entrepreneurial domains of US higher education. *ASHE –Higher Education Report Series, 34*(5). San Francisco: Jossey-Bass.

Mars, M. M., & Schau, H. J. (2017). Institutional entrepreneurship and the negotiation and blending of the Southern Arizona local food system. *Agriculture and Human Values, 34*(2), 407–422. https://doi.org/10.1007/s10460-016-9722-3.

Mars, M. M., Slaughter, S., & Rhoades, G. (2008). The state-sponsored student entrepreneur. *Journal of Higher Education, 79*(6), 638–670.

Mars, M. M., Bresonis, K., & Szelényi, K. (2014). Science and engineering doctoral student socialization, logics, and the national economic agenda: Alignment or disconnect? *Minerva, 52*(3), 351–379.

Mason, J. (2017). *Qualitative researching* (3rd ed.). Los Angeles: Sage.

McAlpine, L., & Amundsen, C. (2009). Identity and agency: Pleasures and collegiality among the challenges of the doctoral journey. *Studies in Continuing Education, 31*(2), 109–125. https://doi.org/10.1080/01580370902927378.

Mendoza, P. (2007). Academic capitalism and doctoral student socialization: A case study. *Journal of Higher Education, 78*(1), 71–96. https://doi.org/10.1080/00221546.2007.11778964.

Meyer, S. R., Levesque, V. R., Bieluch, K. H., Johnson, M. L., Meyer, S. R., McGreavy, B., Dreyer, S., & Smith, H. (2016). Sustainability graduate students as boundary spanners. *Journal of Environmental Studies and Sciences, 6*, 344–353. https://doi.org/10.1007/s13412-015-0313-1.

Onwuegbuzie, A. J., & Leech, N. L. (2007). Validity and qualitative research: An oxymoron? *Quality & Quantity, 41*, 233–249. https://doi.org/10.1007/s11135-006-9000-3.

Pache, A. C., & Santos, F. (2013). Inside the hybrid organization: Selective coupling as a response to competing institutional logics. *Academy of Management Journal, 56*(4), 972–1001. https://doi.org/10.5465/amj.2011.0405.

Polkinghorne, D. E. (1995). Narrative configuration in qualitative analysis. *International Journal of Qualitative Studies in Education, 8*(1), 5–23. https://doi.org/10.1080/0951839950080103.

Ramus, T., Vaccaro, A., & Brusoni, S. (2016). Institutional complexity in turbulent times: Formalization, collaboration, and the emergence of blended logics. *Academy of Management Journal, 60*(4), 1253. https://doi.org/10.5465/amj.2015.0394.

Reay, T., & Hinings, C. R. (2009). Managing the rivalry of competing institutional logics. *Organization Studies, 30*, 629–652. https://doi.org/10.1177/0170840609104803.

Roberts, M. J. D., & Beamish, P. W. (2017). The scaffolding activities of international returnee executives: A learning based perspective of global boundary spanning. *Journal of Management Studies, 54*(4), 511–539. https://doi.org/10.1111/joms.12266.

Roumbanis, L. (2019). Symbolic violence in academic life: A study of how junior scholars are educated in the art of getting funding. *Minerva, 57*, 197–218. https://doi.org/10.1007/s11024-018-9364-2.

Saz-Carranza, A., & Longo, F. (2012). Managing competing institutional logics in public-private joint ventures. *Public Management Review, 14*(3), 331–357. https://doi.org/10.1080/14719037.2011.637407.

Schotter, A. P. J., Mudambi, R., & Doz, Y. L. (2017). Boundary spanning in global organizations. *Journal of Management Studies, 54*(4), 403–421. https://doi.org/10.1111/joms.12256.

Skelcher, C., & Rathgeb-Smith, S. (2015). Theorizing hybridity: Institutional logics, complex organizations, and actor identities: The case of nonprofits. *Public Administration, 93*(2), 433–448. https://doi.org/10.1111/padm.12105.

Slaughter, S., & Rhoades, G. (2004). *Academic capitalism and the new economy: Markets, state, and higher education*. Baltimore: The Johns Hopkins University Press.

Smith, B., & Sparkes, A. C. (2006). Narrative inquiry in psychology: Exploring the tensions within. *Qualitative Research in Psychology, 3*(3), 169–192. https://doi.org/10.1191/1478088706qrp068oa.

Suckert, L. (2019). Playing the double game: How ecopreneurs cope with opposing field logics in moralized markets. In S. Schiller-Merkens & P. Balsiger (Eds.), *The contested moralities of markets* (Research in the Sociology of Organizations) (Vol. 63, pp. 107–126). London: Emerald Publishing Limited.

Swedberg, R. (2016). Before theory comes theorizing or how to make social science more interesting. *British Journal of Sociology, 67*(1), 5–22. https://doi.org/10.1111/1468-4446.12184.

Thornton, P., & Ocasio, W. (1999). Institutional logics and the historical contingency of power in organizations: Executive succession in the higher education publishing industry, 1958–1990. *American Journal of Sociology, 105*(3), 801–843. https://doi.org/10.1086/210361.

Thornton, P. H., Ocasio, W., & Lonsbury, M. (2012). *The institutional logics perspective; A new approach to culture, structure and process*. Cambridge: Oxford University Press.

Thune, T. (2009). Doctoral students on the university-industry interface: A review of the literature. *Higher Education, 58*, 637–651. https://doi.org/10.1007/s10734-009-9214-0.

Thune, T. (2010). The training of "triple helix workers"? Doctoral students in university-industry-government collaborations. *Minerva, 48*(4), 463–483. https://doi.org/10.1007/s11024-010-9158-7.

Tracey, P., Phillips, N., & Jarvis, O. (2011). Bridging institutional entrepreneurship and the creation of new organizational forms: A multilevel model. *Organization Science, 22*(1), 60–80. https://doi.org/10.1287/orsc.1090.0522.

Tushman, M. L., & Scanlan, T. J. (1981). Boundary spanning individuals: Their role in information transfer and their antecedents. *Academy of Management Journal, 24*(2), 289–305.

Wang, D., Piazza, A., & Soule, S. A. (2018). Boundary-spanning in social movements: Antecedents and outcomes. *Annual Reviews of Sociology, 44*, 167–187. https://doi.org/10.1146/annurev-soc-073117-041258.

Wright, C., & Nyberg, D. (2012). Working with passion: Emotionology, corporate environmentalism and climate change. *Human Relations, 65*(12), 1561–1587. https://doi.org/10.1177/0018726712457698.

York, J. G., Hargrave, T. J., & Pacheco, D. (2016). Converging winds: Logic hybridization in the Colorado wind energy field. *Academy of Management Journal, 59*(2), 579–610. https://doi.org/10.5465/amj.2013.0657.