

Unique support from identity-based groups: Professional networks of women and LGBTQ+ physicists analyzed and compared by career sector

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Abstract: This paper presents a social network analysis of the professional support networks of 100 LGBTQ+ and/or women PhD physicists, comparing the networks based on the career sectors of academia, industry, and government/nonprofit. The methods for constructing and analyzing the ego networks, which are novel in many ways, are explained in greater detail in an earlier publication (Hatcher et. al., 2025). We use statistical tests of independence to explore differences between sectors in terms of whole network metrics, network composition based on alter characteristics, and support types. We find that alters associated with groups (like affinity groups and personal and professional interest groups) are more likely to provide identity-based and community building support, participants in Academia have fewer personal friends in their networks while those in Industry have more, participants in Government report less instrumental support, and those in Academia report less material support. These results and others lead to suggestions for employers in these sectors on how to better support these physicists, including continuing to promote participation in affinity and interest groups, providing more material support and/or personal time in the academic sector, and more instrumental support in the form of professional development or training in the government sector.

I. Introduction

Physics, as a field, has a well-documented history of being un-welcoming to gender and sexual minority scientists (GSM scientists, including anyone who is not a cisgender heterosexual man). Beyond statistics of who earns degrees at varying levels of physics education (more than three-quarters of all bachelors degrees were awarded to men in the US in recent years),¹ studies have shown that GSM physicists experience explicit discrimination and exclusion at all levels of

¹ “Number of Bachelor’s Degrees Earned in Physics, Classes 1987 through 2022 - AIP.ORG,” accessed June 19, 2024, <https://ww2.aip.org/statistics/number-of-bachelors-degrees-earned-in-physics-classes-1987-through-2022>.

physics education,^{2,3,4,5,6,7} which may be a reason why so many choose to leave the field. Such experiences are unfortunately also shared by physicists with other minoritized identities in physics, such as Black physicists and other Physicists of Color,^{8,9,10} physicists with disabilities,^{11,12} and others,¹³ but the current study focuses on GSM physicists, so our discussion will remain limited to their experiences.

² Ramón S. Barthelemy et al., “LGBT + Physicists: Harassment, Persistence, and Uneven Support,” *Physical Review Physics Education Research* 18, no. 1 (March 28, 2022): 010124, <https://doi.org/10.1103/PhysRevPhysEducRes.18.010124>.

³ Ramón S. Barthelemy, “LGBT+ Physicists Qualitative Experiences of Exclusionary Behavior and Harassment,” *European Journal of Physics* 41, no. 6 (October 2020): 065703, <https://doi.org/10.1088/1361-6404/abb56a>.

⁴ Ramón S. Barthelemy, Melinda McCormick, and Charles Henderson, “Gender Discrimination in Physics and Astronomy: Graduate Student Experiences of Sexism and Gender Microaggressions,” *Physical Review Physics Education Research* 12, no. 2 (August 1, 2016): 020119, <https://doi.org/10.1103/PhysRevPhysEducRes.12.020119>.

⁵ Lauren M. Aycock et al., “Sexual Harassment Reported by Undergraduate Female Physicists,” *Physical Review Physics Education Research* 15, no. 1 (April 22, 2019): 010121, <https://doi.org/10.1103/PhysRevPhysEducRes.15.010121>.

⁶ Ramón S. Barthelemy, Melinda McCormick, and Charles R. Henderson, “Understanding Women’s Gendered Experiences in Physics and Astronomy Through Microaggressions,” in *2014 Physics Education Research Conference Proceedings* (2014 Physics Education Research Conference, Minneapolis, MS: American Association of Physics Teachers, 2015), 35–38, <https://doi.org/10.1119/perc.2014.pr.005>.

⁷ Justin A. Gutzwa et al., “How Women and Lesbian, Gay, Bisexual, Transgender, and Queer Physics Doctoral Students Navigate Graduate Education: The Roles of Professional Environments and Social Networks,” *Physical Review Physics Education Research* 20, no. 2 (September 12, 2024): 020115, <https://doi.org/10.1103/PhysRevPhysEducRes.20.020115>.

⁸ Katemari Rosa, “Educational Pathways of Black Women Physicists: Stories of Experiencing and Overcoming Obstacles in Life,” *Physical Review Physics Education Research* 12, no. 2 (2016), <https://doi.org/10.1103/PhysRevPhysEducRes.12.020113>.

⁹ Rachel E. Scherr, Mike A. Lopez, and Marialis Rosario-Franco, “Isolation and Connectedness among Black and Latinx Physics Graduate Students,” *Physical Review Physics Education Research* 16, no. 2 (November 3, 2020): 020132, <https://doi.org/10.1103/PhysRevPhysEducRes.16.020132>.

¹⁰ Maria Ong, “Body Projects of Young Women of Color in Physics: Intersections of Gender, Race, and Science,” *Social Problems* 52, no. 4 (November 1, 2005): 593–617, <https://doi.org/10.1525/sp.2005.52.4.593>.

¹¹ Westley James et al., “Disabling Barriers Experienced by Students with Disabilities in Postsecondary Introductory Physics,” *Physical Review Physics Education Research* 16, no. 2 (August 19, 2020): 020111, <https://doi.org/10.1103/PhysRevPhysEducRes.16.020111>.

¹² Liam G. McDermott, “Developing and Operationalizing a Critical Disability Physics Identity Framework: Investigating the Experiences of Neurodivergent Physicists at Various Career Stages” (Ph.D., United States -- New Jersey, Rutgers The State University of New Jersey, School of Graduate Studies, 2024), <https://www.proquest.com/docview/3061501616/abstract/ED12A3EDB166417CPQ/1>.

¹³ D. K. Kehlbeck, K. Piatek-Jimenez, and C. Medina Medina, “Undergraduate Physics Students’ Experiences: Exploring the Impact of Underrepresented Identities and Intersectionality,” *Physical Review Physics Education Research* 20, no. 2 (September 27, 2024): 020120, <https://doi.org/10.1103/PhysRevPhysEducRes.20.020120>.

Researchers have found that retention of GSM physicists in physics, in many cases, comes down to being properly supported.^{14,15,16,17,18} Understanding what support looks like for gender and sexual minority physicists would help us understand what motivates people from marginalized backgrounds in physics to decide to stay anyway. It would also fill a gap in the physics community's understanding of its diversity problem by addressing the not-so-common question of, “why do GSM physicists stay?” rather than the more-often investigated question of, “why do GSM physicists leave?” We should be promoting diversity in physics not only on a moral basis of equitable access and inclusion for all, but also because diversity has been shown to lead to better science across the board.¹⁹

This study helps us understand how GSM physicists find professional success by providing a comprehensive understanding of their support networks using tools from social network analysis (SNA). Our team has interviewed 100 women and/or LGBTQ+ physicists about their career trajectories and their support systems, and during the interviews they created diagrams representing their professional support networks. By analyzing the interviews and support networks of these physicists, who span the career sectors of academia, government, and industry, we can get an idea for how their networks function and how support differs based on career sector and other dimensions of personal identity. With a better understanding of the support systems that GSM physicists have relied on to get to where they are now, we can provide recommendations to employers and professional societies and institutions on how to better support these scientists going forward.

This paper is meant to accompany and follow an earlier publication, Hatcher et al. 2025 (in review),²⁰ which explains our methods for constructing and analyzing participants' social networks and provides background on the subjects of critical theory and SNA that inform the work. We refer to the earlier publication as the “Methods Paper.” This paper briefly reviews key topics in the Methods Paper and then focuses on results of the analysis, split into general results for the full group and comparative results between participants in the three career sectors of academia, industry, and government. We conclude with a discussion of the results, their

¹⁴ Barbara L. Whitten et al., “What Works for Women in Undergraduate Physics?” 795 (October 1, 2005): 230–230, <https://doi.org/10.1063/1.2128388>.

¹⁵ Angela Johnson et al., “Common Challenges Faced by Women of Color in Physics, and Actions Faculty Can Take to Minimize Those Challenges,” *The Physics Teacher* 55, no. 6 (September 1, 2017): 356–60, <https://doi.org/10.1119/1.4999731>.

¹⁶ Karyn L. Lewis et al., “Fitting in or Opting out: A Review of Key Social-Psychological Factors Influencing a Sense of Belonging for Women in Physics,” *Physical Review Physics Education Research* 12, no. 2 (August 1, 2016): 020110, <https://doi.org/10.1103/PhysRevPhysEducRes.12.020110>.

¹⁷ Ramón S. Barthelemy et al., “Educational Supports and Career Goals of Five Women in a Graduate Astronomy Program,” *Physical Review Physics Education Research* 16, no. 1 (April 21, 2020): 010119, <https://doi.org/10.1103/PhysRevPhysEducRes.16.010119>.

¹⁸ Gutzwa et al., “How Women and Lesbian, Gay, Bisexual, Transgender, and Queer Physics Doctoral Students Navigate Graduate Education.”

¹⁹ Rachel D. Godsil, “Why Race Matters in Physics Class,” SSRN Scholarly Paper (Rochester, NY, January 1, 2016), <https://papers.ssrn.com/abstract=2933292>.

²⁰ Chase Hatcher et al., “Egocentric Mixed-Methods SNA: Analyzing Interviews with Women and/or Queer and LGBTQ+ Ph.D. Physicists” (arXiv, April 14, 2025), <https://doi.org/10.48550/arXiv.2504.10621>.

implications for the physics community, limitations of the study, and directions for future work. This paper provides a comprehensive understanding of our participants' professional support networks, differences that exist between them based on career sector, and what these results mean for supporting GSM physicists going forward.

II. Background & Theory

Careers in Physics

Research on the careers of professional physicists has commonly split their work into the career sectors of academia, industry, and government. These sectors are a refined version of the traditional division between employment in the public ("government," in our terminology, where compensation comes from taxpayers) and private sectors ("industry," where compensation comes from a private institution or individual). Academic institutions, which can be public or private, bridge the gap between these and represent an especially large employment sector for scientists, making it reasonable to treat it as a separate category. Examples of academic positions for physicists would be faculty (tenure-track or otherwise), research, administrative, or other appointments at universities or institutions of higher education. Examples of industry positions include a variety of job titles in engineering, tech, science communication, and consulting. Examples of government positions include those at national laboratories, federal agencies, and non-profits with government affiliations.

In 2024, The American Institute of Physics (AIP), using the same sector divisions, reported that nearly half of all new physics PhDs surveyed from 2021-2022 were initially employed in the academic sector (46%).²¹ About a third (34%) found initial employment in the private sector ("industry," in our terminology), and 16% found initial employment in government while 4% found initial employment in "other" sectors. They also divided positions into "postdoc," "potentially permanent," or "other temporary" and found that most postdoc positions were in academia (72%), most potentially permanent positions were in the private sector (73%), and most other temporary positions were in academia (63%).

AIP, through the work of Porter, also published a more extensive longitudinal study of the careers of physicists with PhDs.²² The results come from qualitative analysis of two open-ended survey questions related to success and barriers to success for mid-career physicists. They found that physicists in the private sector more often attributed success to skills and abilities (like interpersonal and computing skills), while those in academia and government attributed success to persistence, work ethic, and social support. Likewise, barriers in the private sector also

²¹ "Physics PhDs Initial Employment Booklet - Academic Years 2020-21 and 2021-22 - AIP.ORG," accessed February 18, 2025,

<https://www.aip.org/statistics/physics-phds-initial-employment-booklet-academic-years-2020-21-and-2021-22>.

²² Anne Marie Porter, "Physics PhDs Ten Years Later: Success Factors and Barriers in Career Paths. Results from the PhD Plus 10 Study," *AIP Statistical Research Center* (AIP Statistical Research Center, December 2019), <https://eric.ed.gov/?id=ED602755>.

involved skills as well as a lack of career opportunities, while barriers in academia and government were more often problems with the institutions themselves or social problems. This study also compared responses based on gender and found that men more frequently discussed their skills and women more frequently discussed social issues or support in terms of both successes and barriers to success. Men also discussed organization issues and women discussed gender bias in the context of barriers.

Other studies have variously looked at gendered power structures for physicists in the academic sector,^{23,24} careers of physicists in the private sector,²⁵ training for professional physicists,²⁶ and learning orientation as it relates to productivity for physics PhDs.²⁷ Many publications concerning careers for PhD physicists are focused on the job market (as bullish²⁸ or bleak²⁹), guidance on career pathways,^{30,31} or the promotion of a specific field.³² In other words, while there is research on the experiences of career physics PhDs, much writing on physics careers is directed towards physics students and takes a voice of guidance, whether it is encouragement or deterrence. This may speak to a larger trend in physics education research (PER) of studying physicists up to and until graduation and not so much afterwards.

This study adds to the physics community's limited knowledge of the experiences of professional physicists in their careers, focusing on those of GSM physicists. This work not only serves as a basis for making suggestions to employers for how to better support these physicists, but can also serve as a guide for aspiring physicists on what professional physics might entail.

Critical Theory

The larger project, of which this study is a part, is concerned with cultural and identity-based experiences in physics spaces and was conceived in light of a documented history

²³ Meytal Eran Jona and Yosef Nir, "4: The Academic Career in Physics as a 'Deal': Choosing Physics within a Gendered Power Structure," 2024, <https://bristoluniversitypressdigital.com/edcollchap/book/9781529222326/ch004.xml>.

²⁴ Ramón Barthelemy, Melinda McCormick, and Charles Henderson, "Barriers Beyond Equity: An Exploratory Study of Women Graduate Students' Career Pathways in Astronomy," *International Journal of Gender, Science and Technology* 7, no. 1 (February 7, 2015): 57–73.

²⁵ Roman Czujko and Garrett Anderson, "Common Careers of Physicists in the Private Sector," n.d.

²⁶ Steven J. Smith, Liane Pedersen-Gallegos, and Catherine Riegle-Crumb, "The Training, Careers, and Work of Ph.D. Physical Scientists: Not Simply Academic," *American Journal of Physics* 70, no. 11 (November 1, 2002): 1081–92, <https://doi.org/10.1119/1.1510884>.

²⁷ Zahra Hazari et al., "For the Love of Learning Science: Connecting Learning Orientation and Career Productivity in Physics and Chemistry," *Physical Review Special Topics - Physics Education Research* 6, no. 1 (May 21, 2010): 010107, <https://doi.org/10.1103/PhysRevSTPER.6.010107>.

²⁸ Kate Kirby, Roman Czujko, and Patrick Mulvey, "The Physics Job Market: From Bear to Bull in a Decade," *Physics Today* 54, no. 4 (April 1, 2001): 36–41, <https://doi.org/10.1063/1.1372112>.

²⁹ Kate Kirby and Roman Czujko, "The Physics Job Market: Bleak for Young Physicists," *Physics Today* 46, no. 12 (December 1, 1993): 22–27, <https://doi.org/10.1063/1.881392>.

³⁰ Guanyu Xu, "A Letter to HEP-TH Postgraduates on Career Prospects," n.d.

³¹ Barrett Ripin, "Preparing Physicists for Life's Work," *Physics Today* 54, no. 4 (April 1, 2001): 43–48, <https://doi.org/10.1063/1.1372113>.

³² T. Camporesi, "High-Energy Physics as a Career Springboard," *European Journal of Physics* 22, no. 2 (March 2001): 139, <https://doi.org/10.1088/0143-0807/22/2/306>.

of physics spaces being discriminatory and exclusive. To that end, we have used critical theory as a basis from which to investigate questions related to experiences of people with marginalized identities in physics. Critical theory is a mode of inquiry and body of sociocultural theory that has historically been oriented towards the betterment of life for oppressed groups.³³ Today, sub-research areas such as feminist studies, queer and gender studies, critical race theory, and ethnic studies are considered by some to exist under the umbrella of critical studies, even though these areas have distinct traditions and practices that separate them.

Underlying many works of critical theory is the rigorous examination of power and the way it functions in society to control behavior by normalizing some actions and attitudes and demonizing others.³⁴ Critical theorists have consistently demonstrated the socially-constructed nature of social norms, showing that deeply rooted sociocultural value systems (such as race,³⁵ patriarchy,³⁶ and heteronormativity³⁷) are constructed and maintained by the ruling classes to serve their interests rather than being universal or natural. Critical theories invite us to challenge widely held assumptions and beliefs to discover their origins and who they may serve, often leading to liberatory and revolutionary ideas for oppressed peoples.

Critical theories also shape research practices and methodologies. In the case of this study, the approach to network construction, network analysis, and reporting and interpretation of results are all designed to be aligned with guidance from critical theorists. The Methods Paper provides more background on critical theories relevant to this project and study (including critical work in PER) and the way that critical considerations have factored into the methodology. An earlier publication from this project, Gutwa et al. 2024, describes the role of critical theories in shaping the theoretical foundation of this project overall.³⁸ In short, our network construction procedures are based on a maximal amount of input from participants so that the networks we construct center the participant and their perspective and are as faithful as possible to those that actually exist for participants. We rely heavily on qualitative data sources so that the words of our participants are the primary means by which their experiences are depicted, something which is especially important for understanding experiences with discrimination and marginalization. Finally, our reporting process includes attention to the way that power is constructed and maintained socially in physics contexts and is guided by the overarching goal of improving the experiences of marginalized physicists.

³³ Robin Celikates and Jeffrey Flynn, “Critical Theory (Frankfurt School),” in *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta and Uri Nodelman, Winter 2023 (Metaphysics Research Lab, Stanford University, 2023), <https://plato.stanford.edu/archives/win2023/entries/critical-theory/>.

³⁴ Michael J. Thompson, ed., *The Palgrave Handbook of Critical Theory* (New York: Palgrave Macmillan US, 2017), <https://doi.org/10.1057/978-1-137-55801-5>.

³⁵ Richard Delgado and Jean Stefancic, “Critical Race Theory: Past, Present, and Future,” *Current Legal Problems* 51, no. 1 (1998): 467–91, <https://doi.org/10.1093/clp/51.1.467>.

³⁶ Judith Butler, “Performative Acts and Gender Constitution: An Essay in Phenomenology and Feminist Theory,” *Theatre Journal* 40, no. 4 (1988): 519–31, <https://doi.org/10.2307/3207893>.

³⁷ Riki Wilchins, *Queer Theory, Gender Theory* (Bronx, NY: Magnus Books, 2004), https://books.google.com/books/about/Queer_Theory_Gender_Theory.html?id=H_NpZ9YqFrUC.

³⁸ Gutwa et al., “How Women and Lesbian, Gay, Bisexual, Transgender, and Queer Physics Doctoral Students Navigate Graduate Education.”

Social Network Analysis

Social network analysis, or SNA, is a set of tools and techniques for analyzing groups of people based on their connections with one another, qualities of the people, and qualities of the connections themselves. It typically involves the creation of network visualizations (sociograms) with people represented by shapes like dots (called nodes) and lines between them representing connections (links or edges). It also usually involves the calculation of various metrics that describe characteristics of individuals or of the whole group. SNA can involve a mix of quantitative and qualitative techniques in constructing and then analyzing the networks and comes in a few modalities which are worth reviewing here.

Typically, and especially in PER, quantitative approaches to SNA are more common. As described in Traxler et al. 2024, also related to this project, quantitative approaches refer to a reliance on quantitative methods in the analysis of networks.³⁹ This often involves the calculation and comparison of various metrics that describe characteristics of networks. Alternatively, researchers could take a more qualitative approach to analysis, choosing instead to analyze networks based on descriptions from members, or they could take a mixed-methods approach, mixing quantitative and qualitative methods. Some researchers, including Traxler et al., have promoted mixed-methods SNA (MMSNA) as a best of both worlds approach that combines the analytical power and scalability of quantitative methods with qualitative methods' ability to capture nuance and provide mechanistic explanations for the networks.⁴⁰

SNA studies in PER (and more broadly) also typically take a sociocentric approach to network construction, meaning that they aim to represent a network that exists among a bounded group of people, usually based on all members' descriptions of their connections. Alternatively, we may take an egocentric approach to network construction, whereby one person (the ego) describes their relationships with others (alters), forming a network based around one person. There are advantages and disadvantages to each of these approaches, so their use would mostly depend on project goals and research questions.

The Methods Paper provides more background on SNA and how it has been used in PER and it includes a lengthier discussion of decisions made concerning available SNA modalities. In short, we chose to use MMSNA and egocentric SNA approaches because together they: (1) are more appropriate for our research questions which are based on our study participants' experiences in physics, (2) center our study participants in all aspects of their network, including its construction, and (3) allow for the exploration of complex sociocultural phenomena through the words and perspectives of our participants.

³⁹ Adrienne L. Traxler et al., "Person-Centered and Qualitative Approaches to Network Analysis in Physics Education Research," *Physical Review Physics Education Research* 20, no. 2 (October 21, 2024): 020132, <https://doi.org/10.1103/PhysRevPhysEducRes.20.020132>.

⁴⁰ Nick Crossley and Gemma Edwards, "Cases, Mechanisms and the Real: The Theory and Methodology of Mixed-Method Social Network Analysis," *Sociological Research Online*, May 31, 2016, <https://doi.org/10.5153/sro.3920>.

III. Methods

Network Construction, Analysis, and Visualization

Methods for constructing, analyzing, and visualizing participants' networks are described in detail in an earlier publication, Hatcher et al. 2025,⁴¹ or the "Methods Paper." We briefly summarize those methods here, but we encourage any reader interested in the methods to first read that paper.

The networks originate from interviews conducted with 100 women and/or LGBTQ+ PhD-holding physicists. The interviews served as both a source of qualitative data concerning our participants' professional experiences as well as a name generator (network construction tool) for their support networks. The interviews contained questions related to participants' career journeys and professional trajectories and the ways they were supported (or not) along the way. They included a sociogram construction component, wherein participants would add names to sticky notes on a Google Jamboard and place them on a set of concentric circles with a star in the center representing the interviewee (a sample sociogram is shown in Figure 1) These sociograms, combined with thematic coding of interview content relating to alters placed on the sociogram, comprised the data that went into our network construction.

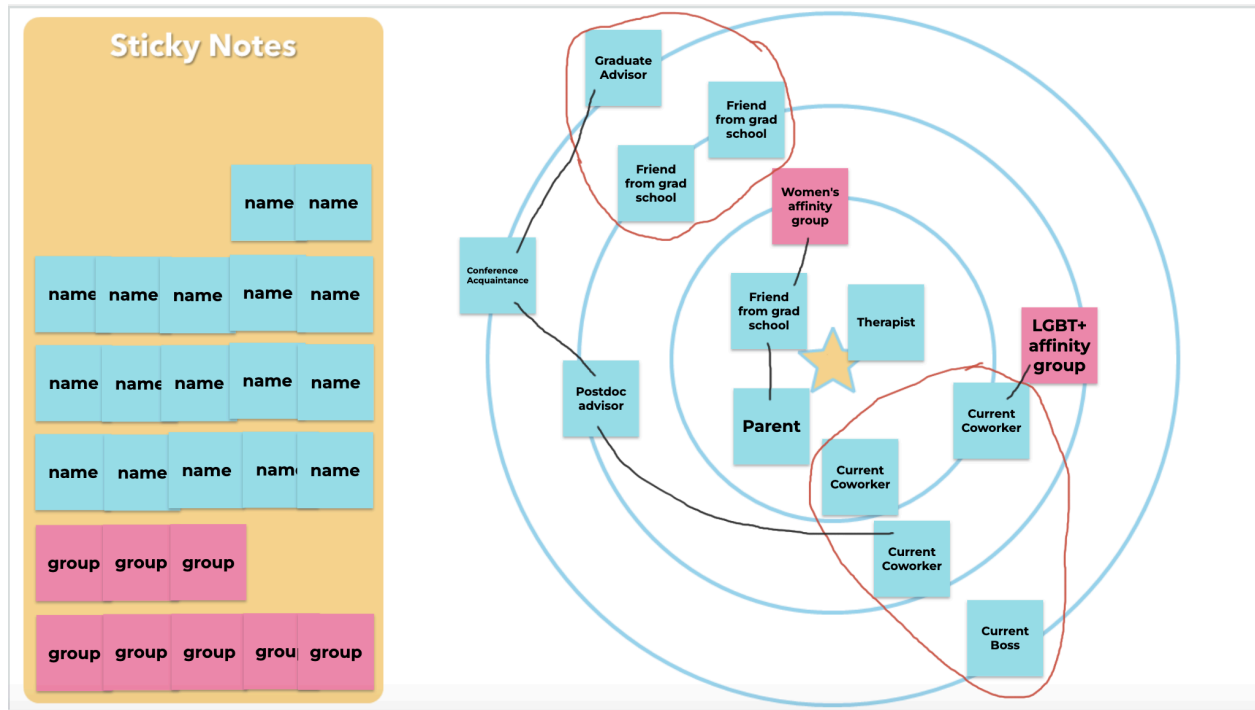


Figure 1: Fictionalized example of a sociogram showing alter connections.

After an initial round of thematic coding, which included coding for network data such as alter relationships and associated types of support (shown in Table 1), the interviews underwent a

⁴¹ Hatcher et al., "Egocentric Mixed-Methods SNA."

second round of network-oriented coding that further specified relationship and support codes for every mention of an alter. Ultimately, all coding led to a list of every alter placed on a sociogram specifying all professional and personal relationships that person had with the ego, all types of support (or gaps in support) they were associated with, the number of times they were mentioned in the interview (“Mentions”), their proximity to the center of the sociogram (“Proximity”), and whether they were ever associated with “Dissonance” or some sort of interpersonal tension or friction with the interviewee. We also created a list of “who to whom” connections among alters (and including connections between the ego and all alters) based on connections among alters indicated by participants on the sociograms.

Table 1: Network data codes, a subset of the full codebook available as Table 1 in Hatcher et al. 2025.

1st level	2nd level	3rd level
Connection Nodes	Individual	Partners Friends Family Other
	Group	Subfield Group/listserv Conferences Affinity group
	Institutional	Undergraduate program Graduate program Postdoc Past job Current job Future job
	Collegial & Supervisorial	Bosses/supervisors Mentors (professional) Mentees/direct reports Coworkers/peers
Nodal Support	Identity-based support Physical closeness Networking support Community building support Career advice support Emotional support Material support Instrumental support DEI initiatives/policies Gaps in support	

With a list of ego attributes from a pre-survey (including job title, career sector, gender identity, and more), alter attributes from thematic coding for network data described above, and

connections between any two nodes, we were able to construct networks in various ways using various libraries and packages in R.⁴² Some of these network visualization schemes included a maximal amount of information, including support encoded in edge color and thickness, while some simplified networks into uniform shapes or areas to make comparison easier. In addition to visualizing each network in various ways, we were also interested in comparing networks based on descriptive metrics. The metrics we calculated for each network are described in Table 2.

Table 2: Characteristics and metrics describing whole networks and their associated definitions.

All are calculated without ego included in the network. See the Methods Paper for more discussion on excluding ego from calculations.

Network characteristic or metric	Description
Total Nodes	Number of alters or groups
Total Groups	Number of groups
Percent Groups	Percent of Total Nodes which are Groups (Total Nodes divided by Total Groups)
Total Dissonance	Number of nodes carrying code for “Dissonance”
Percent Dissonance	Percent of Total Nodes carrying code for Dissonance (Total Nodes divided by Total Dissonance)
Average Proximity	Mean of Proximity, an integer value ranging 1 - 8 indicating how close an alter was placed to ego on sociogram with 1 being closest
Average Mentions	Mean of Mentions, a count of separate instances in which an alter is mentioned by ego in the interview
Total Support	Number of instances of support (each node could have up to 8 associated types of support, see Table 1)
Total Gaps in Support	Number of instances of gaps in support (each node could have up to 8 associated types of gaps in support)
Support to Nodes Ratio	Ratio of Total Support to Total Nodes
Gaps in Support to Nodes Ratio	Ratio of Total Gaps in Support to Total Nodes
Density	Global density, or total number of connections divided by total number of possible connections

⁴² R Core Team, *R: A Language and Environment for Statistical Computing* (Vienna, Austria: R Foundation for Statistical Computing, 2020), <https://www.R-project.org/>.

	(igraph's edge_density function)
Diameter	Largest separation between two nodes in the network as measured by number of linking edges (igraph's diameter function)
Components	Number of isolated nodes or groups of nodes (igraph's count_components function)
Largest Clique	Number of nodes in largest clique (fully-connected component, would be Total Nodes if Components = 1, found with igraph's clique_num function)
Cliques	Number of distinct cliques (fully-connected components) of three or more nodes (from igraph's max_cliques function; setting min = 3)
Transitivity	Global transitivity (sometimes called clustering coefficient), or the probability that adjacent nodes are connected (igraph's transitivity function)

Alter Classification

In order to compare participants' networks, it was helpful to classify alters into categories that served our comparison goals. Some of these classification approaches for alters were discussed in the Methods Paper, but we review them here in greater detail as they figure heavily in this analysis.

Career Stage

Alters were classified based on the career stage in which their associated ego first mentioned them ("Stage") and the primary nature of their relationship ("Relationship") with their associated ego. Classification based on stage was relatively straightforward as we had already coded each mention of an alter with their affiliation where appropriate (see Table 1 for a list of these codes). Since undergraduate, graduate, post-doctoral, past job, current job, and future job affiliations generally follow a linear and progressive path through someone's educational and career stages including a PhD program, we classified each alter's Stage based on the earliest role with which they were associated. We ended up using the codes "undergrad," "grad," "postdoc," "job," and "none." We combined the three phases of job codes into the single code because the time one might spend in any of these positions would vary more than the academic positions, and since they would all comprise a professional career stage. The "none" category included any alter with no affiliation codes, which was common for friends, family, and others with relationships to ego which were not based primarily in their professional/academic career.

Relationship

Classification based on relationship type was slightly more complicated, since the various types of relationships coded for in the Individual, Group, and Collegial & Supervisorial code categories (see Table 1) were not mutually exclusive and since there were too many of them (12) to allow for straightforward comparison. Instead of using these directly, we created 8 classes which we assigned to alters based on the logic described in Table 3. The inclusion criteria were determined during meetings of most of the authors and were meant to represent somewhat exclusive and common categories of relationships we observed in the interviews. We note that they are post-hoc classifications that are based on the words and indications of our participants but are assigned according to the perspective of the researchers.

Table 3: Relationship categories and their inclusion criteria.

Relationship category	Inclusion criteria
Peer	This is the default. Any alter that does not meet criteria for another category is defined as this.
Mentor	Coded as Mentors (Professional) and does not meet criteria for any following categories in this table.
Groups	Coded as Group/listserv or Affinity Group and does not meet criteria for any following categories in this table.
Friend - professional	Coded as Friends and does not meet criteria for any following categories in this table.
Friend	Coded as Friends and NOT coded as Subfield, Conferences, or Coworkers/peers, and does not meet criteria for any following categories in this table.
Family/partners	Coded as Family or Partners and does not meet criteria for any following categories in this table.
Mentees	Coded as Mentees/direct reports and does not meet criteria for any following categories in this table.
Boss	Coded as Boss/supervisor.

Network Comparison

Overall, we were interested in comparing our participants' networks according to several dimensions of personal and professional identity. This paper focuses on comparison on the basis of career sector, while subsequent papers will examine comparisons based on other dimensions of identity, such as race and LGBTQ+ status. In order to compare participants' networks in a comprehensive and rigorous way, we introduced and developed additional methods, which we describe here.

Violin Plots

Violin plots provide a way to visualize and compare multiple distributions of a variable for different populations.⁴³ Like a boxplot, which visualizes distributions by focusing on the relative location of means and quartiles within a dataset, a violin plot can show mean and quartile positions explicitly and/or implicitly by adding curves to reflect relative number of counts at each position. The result is a symmetric and curved shape that might resemble a violin body, especially for bi-modal distributions.

Violin plots are useful to us in that they can help us compare distributions of various whole-network metrics across different factors or categories of networks, like those belonging to participants in different career sectors. They can also help us compare distributions of more specific metrics, like counts of different types of alters for different classes of egos. In Section IV, we use violin plots to visually compare distributions of some parameters that are significantly different.

ANOVA and t-tests

ANOVA and t-tests are both widely used statistical tests of difference. ANOVA (or Analysis of Variance) is typically used to test if the means of an observable associated with more than two groups are significantly different from each other,⁴⁴ while a t-test (or Student's t-test⁴⁵) is used similarly for just two groups. Both have associated assumptions about the data they are being used with which are worth reviewing.

Although ANOVA tests are used to compare means of samples from different groups, they are based on variance insofar as they compare the variance of data between the different groups to the variance within the groups. This ratio, known as the F-test, when large, suggests a higher likelihood that the difference observed is real and not due to chance. ANOVA tests assume independence of observations (like most observational statistics tests), normality in the distributions of residuals for small ($n \leq 30$) samples, and homoscedasticity or equivalent

⁴³ Jerry L. Hintze and Ray D. Nelson, "Violin Plots: A Box Plot-Density Trace Synergism," *The American Statistician* 52, no. 2 (May 1, 1998): 181–84, <https://doi.org/10.1080/00031305.1998.10480559>.

⁴⁴ R. A. Fisher, "Statistical Methods for Research Workers," in *Breakthroughs in Statistics: Methodology and Distribution*, ed. Samuel Kotz and Norman L. Johnson (New York, NY: Springer New York, 1992), 66–70, https://doi.org/10.1007/978-1-4612-4380-9_6.

⁴⁵ Student, "The Probable Error of a Mean," *Biometrika* 6, no. 1 (1908): 1–25, <https://doi.org/10.2307/2331554>.

variances among the groups.⁴⁶ Student's t-test carries the same assumptions, except normality is expected for the samples themselves and not just their residuals. Both tests also expect to compare continuous quantitative data (the samples) based on discrete categorical factors (career sectors of egos, for example).

Chi-squared tests

Chi-squared tests (or Pearson's Chi-squared test⁴⁷) are used to test for independence between two or more variables based on the relative frequency or counts of different categorical factors composing one of them to a categorical separation of groups in the other. In other words, the tests analyze contingency tables, which tabulate the number of observations belonging to certain factors for separate groups, to determine whether group status could be at all related to the observations. Chi-squared tests require mutually exclusive categories in both variables, meaning that any observation could only be placed in one combination of categories. They also assume independence of the categories, as in ANOVA and t-tests, and are valid as long as at least 80% of cells in the contingency table have at least 5 counts.⁴⁸

Chi-squared tests involve calculation of the chi-squared statistic, which tells us whether and by how much an observation differed from its expected value, with any value greater than 1.0 indicating difference and scaling with how much greater than 1.0 it is. From the chi-squared statistic and the degrees of freedom in the test (calculated as number of rows in contingency table minus 1 times number of columns minus 1), a p-value is calculated, which provides guidance as whether or not to reject the null hypothesis, which is that there is no independence between groups. A sufficiently low p-value (a common threshold being under 0.05) tells us that the likelihood of the null hypothesis being true is sufficiently low, so a low p-value suggests that the groups are different in some way.

If the p-value is sufficiently low, depending on how many factors are considered for the test, it may then be necessary to run a post-hoc test to determine exactly which factors contribute to the low p-value. The result is a set of p-values (and residuals) for each factor, which allow us to identify which factor(s) is(are) different between the groups. The residuals, like the chi-squared statistic, represent the difference between the expected value of a cell and its observed value. A sufficiently high (or low, since residuals can be negative) value greater than 1.0 suggests a difference, the significance of which is reflected by the p-value for that cell.⁴⁹

⁴⁶ George W. Snedecor and William G. Cochran, *Statistical Methods*, 8th edition (Ames, Iowa: Iowa State University Press, 1989).

⁴⁷ Karl Pearson, "X. On the Criterion That a given System of Deviations from the Probable in the Case of a Correlated System of Variables Is Such That It Can Be Reasonably Supposed to Have Arisen from Random Sampling," *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* 50, no. 302 (July 1, 1900): 157–75, <https://doi.org/10.1080/14786440009463897>.

⁴⁸ Mary L. McHugh, "The Chi-Square Test of Independence," *Biochemia Medica* 23, no. 2 (June 15, 2013): 143–49, <https://doi.org/10.11613/BM.2013.018>.

⁴⁹ Donald Sharpe, "Your Chi-Square Test Is Statistically Significant: Now What?," *Practical Assessment, Research & Evaluation* 20, no. 8 (April 2015), <https://eric.ed.gov/?id=EJ1059772>.

P-values

Keeping with common practices of reporting p-values with asterisks to denote their significance, we will adopt and extend the widely used American Psychological Association (APA) code to: * for $p < 0.05$, ** for $p < 0.01$, *** for $p < 0.001$, **** for $p < 0.0001$.

IV. Results

We begin by reporting results for the full group, focusing on network metrics, alter composition, and support, then we move to a comparison of most of the same metrics on the basis of career sector.

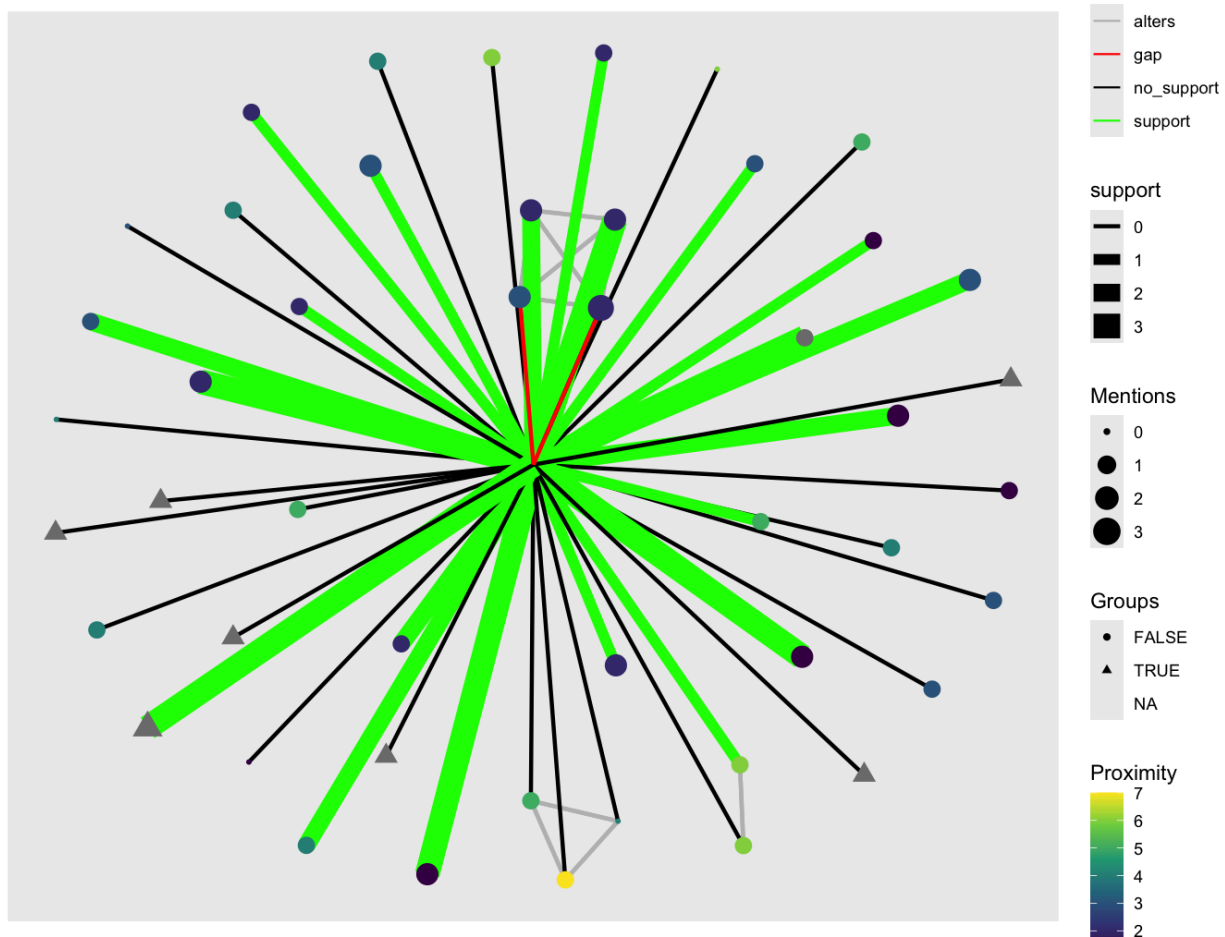
Full Group Results

Network Visualizations

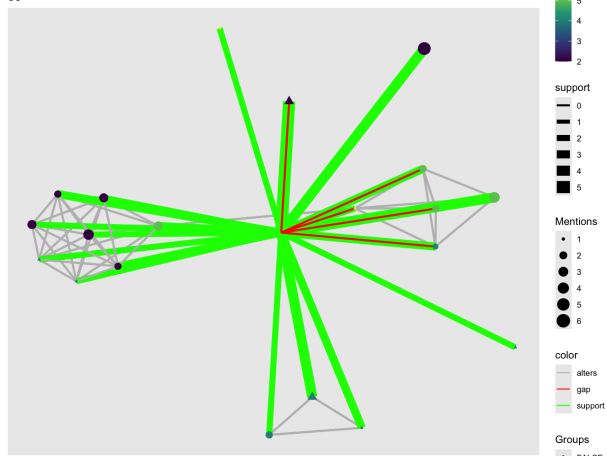
We used network data codes, connection codes, and qualities of the sociograms created during the interviews to re-visualize networks to highlight or display certain qualities and connections. As described in the Methods Paper, one way to do so in a maximally-informative way is to treat support as an edge attribute so that edge color reflects the presence (or absence) of support (or gaps in support) and edge thickness reflects number of different types of support. Node characteristics (like Proximity and Mentions) can be treated as node attributes, represented by node color and size, respectively. Since showing 100 sociograms in the body of this paper would be excessive, we selected a few sociograms to display in Figure 2. As described in Bidart et al. (2018),⁵⁰ a foundational step in egocentric network typology can be based on visual differences in the networks, which is our basis for choosing a few exemplary networks to represent different types we have observed in the full group. In our case, network size, clustering, and supportiveness were good visual parameters with which to distinguish. In Figure 2, the first network (number 9) represents both a large network and a network with isolated alters. Network 35 represents a very supportive and highly clustered network, while network 41 represents a very small network.

⁵⁰ Claire Bidart, Alain Degenne, and Michel Grossetti, “Personal Networks Typologies: A Structural Approach,” *Social Networks* 54 (July 2018): 1–11, <https://doi.org/10.1016/j.socnet.2017.11.003>.

9



35



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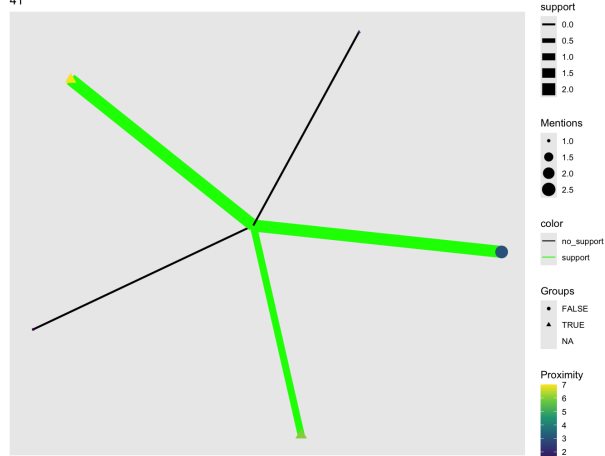


Figure 2: Selected sociograms, showing varying network sizes, support, and clustering tendencies among our participants.

Average Whole-network Metrics

For each network, we calculated the characteristics and metrics described in Table 1 and report their mean values and standard deviations for the whole group in Table 4. Histograms showing the distribution of a few of the metrics that we believe are most informative are shown in Figure 3. See “Selected Metrics for Comparison” later in this section for further discussion of our selections of certain metrics to highlight through the remainder of this paper.

Table 4: Mean values and standard deviations for all network metrics for the full group.

Network characteristic or metric	Mean	Standard Deviation
Total Nodes	16.8	7.28
Total Groups	3.46	2.75
Percent Groups	0.200	0.138
Total Dissonance	0.380	0.838
Percent Dissonance	0.022	0.047
Average Proximity	4.18	0.630
Average Mentions	1.84	0.459
Total Support	24.9	11.2
Total Gaps in Support	1.56	1.98
Support to Nodes Ratio	1.56	0.549
Gaps in Support to Nodes Ratio	0.109	0.169
Density	0.196	0.125
Diameter	2.83	1.34
Components	6.23	5.41
Largest Clique	4.82	1.98
Cliques	3.03	2.01
Transitivity	0.677	0.278

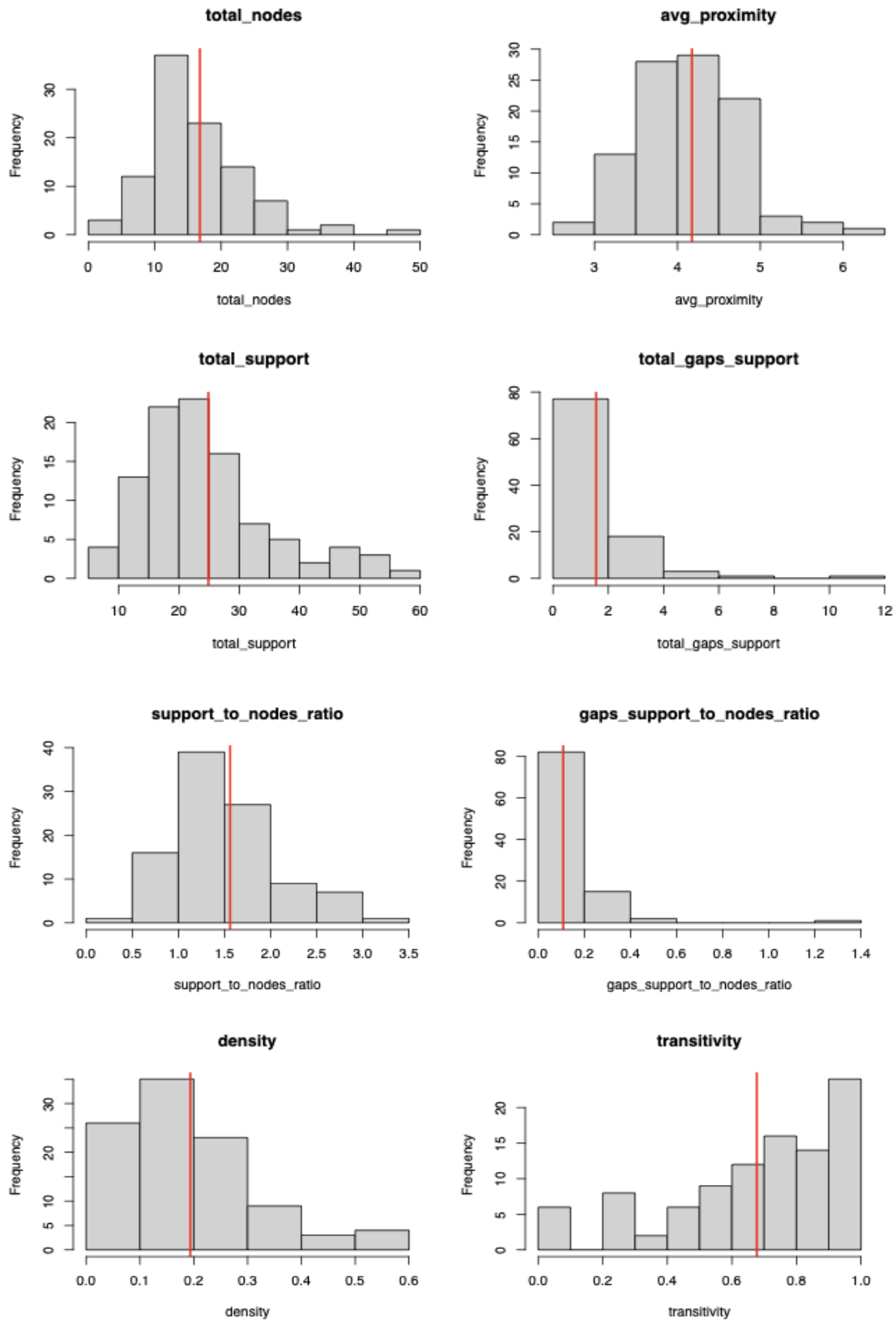


Figure 3: Histograms of selected network metrics with mean value indicated by red line.

Summary of Network Composition

All networks were composed of alters, each with a categorical description of their “Stage,” or the earliest career stage of the ego with which they are associated, and their “Relationship,” or a general description of the sort of relationship they have with ego. To represent network composition based on these qualities of alters, we show the total number of alters belonging to each class in the Stage and Relationship categories using pie charts, shown in Figure 4. Both pie charts show fractions of the 1680 total alters.

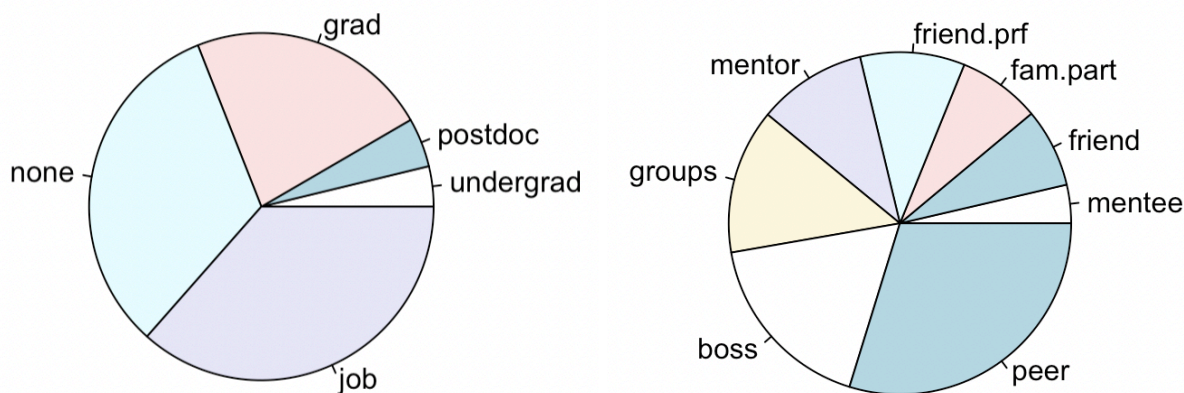


Figure 4: Pie charts showing network composition based on alter classification in two categories, Stage (left) and Relationship (right).

Since we also tracked how many times each alter was mentioned (the “Mentions” parameter), we also compare the relative sizes of each of these groups based on Mentions rather than number of nodes. These are shown in Figure 5, and should be understood as representing how often different types of alters were discussed in the interviews rather than how they showed up in the networks, which is what Fig. 4 shows. Both pie charts show fractions of the 2962.5 total Mentions, where a Mention prompted by the interviewer is counted as one-half of an un-prompted Mention (see the Methods Paper for more details on Mentions).

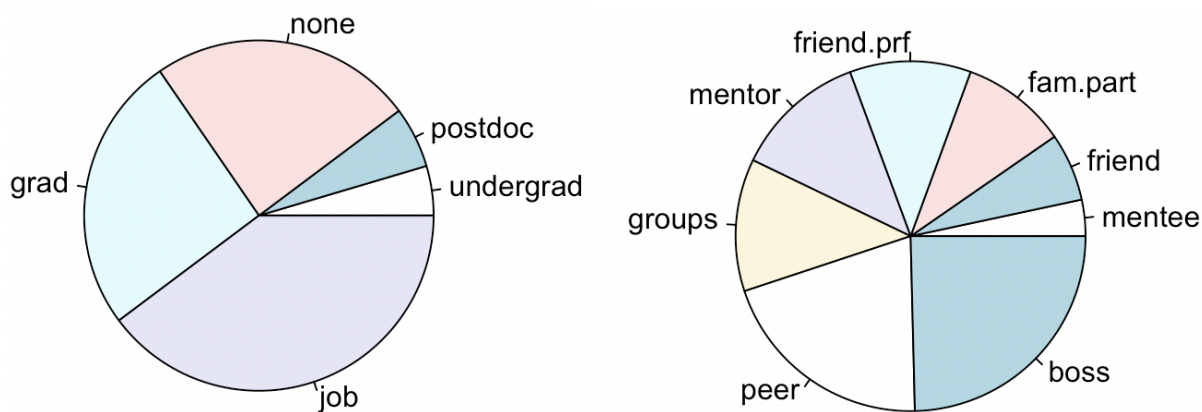


Figure 5: Pie charts showing network composition based on alter classification in two categories, Stage (left) and Relationship (right), and based on Mentions.

Summary of Support Types

Each alter was associated with anywhere from 0 - 9 of the 9 types of support for which we coded. We examined the relative prevalence of each type of support using pie charts of counts of nodes associated with each type across the full group, shown in Figure 6. The total number of support codes was 2490.

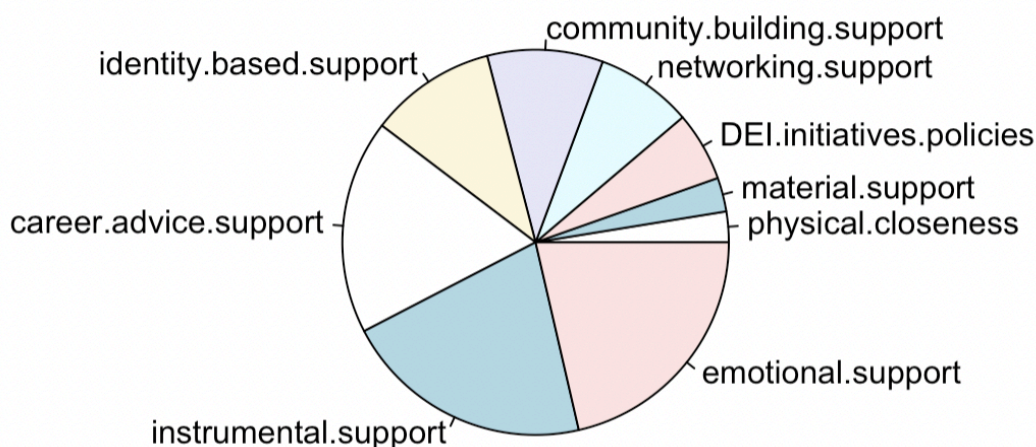


Figure 6: Pie chart showing counts of different support types for the full group.

Support by Alter Type

Based on alter classifications in the Stage and Relationship categories, we tested if certain types of alters were associated more or less often with the various types of support. Contingency tables showing counts of alters of different classes in the Stage and Relationship categories providing different types of support are shown in Tables 5 and 6. We note that, while some cells have few observations, both tables still meet the chi-squared test requirement of at least 80% of cells having at least 5 observations.⁵¹

Table 5: Counts of alters of different Stage classifications associated with different types of support.

Stage	Identity-based	Physical Closeness	Networking	Community-building	Career advice	Emotional	Material	Instrumental	DEI initiatives/policies
undergrad	15	6	8	14	27	30	3	19	3
grad	67	9	83	54	115	141	17	103	29
postdoc	8	7	15	16	35	21	5	30	8

⁵¹ McHugh, "The Chi-Square Test of Independence."

job	100	29	55	88	152	158	34	290	70
none	74	13	41	69	119	183	12	80	35

Table 6: Counts of alters of different Relationship classifications associated with different types of support.

Relationship	Identity-based	Physical Closeness	Networking	Community-building	Career advice	Emotional	Material	Instrumental	DEI initiatives/policies
boss	36	8	58	10	134	46	22	151	19
fam.part	13	4	5	12	37	88	15	17	0
friend	23	6	10	27	26	86	6	23	4
friend.pr f	22	19	22	37	53	107	5	63	9
groups	84	4	33	93	32	50	6	30	69
mentee	17	7	2	8	6	17	4	16	11
mentor	27	4	29	17	68	55	6	79	5
peer	42	12	43	37	92	84	7	143	28

A chi-squared test of independence of the alter classes within each of these two groups had the results shown in Table 7. Here, the low p-values suggest that we should reject the null hypotheses, which are that alters classed by their Stage and Relationship, respectively, are not different based on the types of support with which they are associated. These results called for a post-hoc analysis of both groups to determine exactly which combinations of classes of alters and types of support suggest differences within the groups. Since the results of the post-hoc tests are dense and large in table form, they are displayed in the Appendix in Table 1 and 2 but discussed in detail in Section V, along with all other results of statistical tests of difference.

Table 7: Results of chi-squared test of independence based on types of support provided by the classes of alters in each category of Stage and Relationship

Alter category	P-value	Chi-squared	Degrees of Freedom
Stage	<0.0001****	164.98	32
Relationship	<0.0001****	722.23	56

Sector Comparison Results

A primary research question guiding this project is concerned with differences in participants' experiences that are based on their career sector. In this section, we show results of comparisons of network metrics, network composition, and support types by career sector.

Sector Classification

Egos are classified into the three career sectors of Academia, Industry, and Government (capitalization indicating classifications in our dataset rather than the actual sectors) based on self-reported true/false answers to three survey questions about their belongingness to each of the sectors. This means that egos could be classified as belonging to any of 7 mutually exclusive combinations of 1 - 3 of the sectors. Counts of egos classified in each mutually exclusive sector (combination) are shown in Table 8.

Table 8: Number of egos classified as belonging to each mutually exclusive sector (combination).

Sector (combination)	Number of egos
Academia (A)	39
Industry (I)	19
Government (G)	14
Academia, Industry (AI)	0
Academia, Government (AG)	12
Industry, Government (IG)	14
Academia, Industry, Government (AIG)	2

We note the small number of egos classified as belonging to some of the combined sectors, which makes statistical tests of comparison less informative. In order to work with sufficiently large groups that our statistical comparisons are meaningful, we choose instead to compare on the basis of belongingness to each of the three sectors rather than the specific sector (combination) indicated. This means that each comparison we describe is based on belongingness to one sector, since the IN and OUT groups for each sector comprise the full group, just split in different ways. Counts of egos in or out of each sector, regardless of their belongingness to any other sector(s), are shown in Table 9.

Table 9: Number of egos classified as in or out of each sector.

Sector and counter-sector	Number of egos
In Academia (A_{IN}) / Out of Academia (A_{OUT})	63 / 37
In Industry (I_{IN}) / Out of Industry (I_{OUT})	35 / 65
In Government (G_{IN}) / Out of Government (G_{OUT})	32 / 68

Selected Metrics for Comparison

Rather than comparing networks by sector for every metric and characteristic calculated in Table 4, we selected a few for comparison by eliminating some based on informativity, redundancy, and variability. In general, we calculated the metrics in Table 4 because we thought they would be informative in some combination of quantitative or qualitative analysis on the basis of nodes or networks on scales large or small. Since this study focuses on large-scale quantitative analysis on the basis of nodes, we dropped metrics that would be more appropriate for other types of analysis on which other studies related to this project will focus.

Specifically, we dropped Total Groups and Percent Groups because our participants had varying criteria for marking nodes as groups (as opposed to making individual nodes for each/certain group members). We dropped Total Dissonance and Percent Dissonance because of the infrequency of the Dissonance code (most networks had no Dissonance codes). We dropped Average Mentions because it measures a similarly ambiguous degree of importance which Average Proximity does a slightly better job of capturing (since it is based on direct input from participants), and also because it is more informative when examining individual nodes rather than when averaged over all nodes in a network. We dropped Diameter, Components, Cliques, and Largest Clique because each of these, in some way, tell us about either the connectivity or the clustering tendencies in each network, which Density and Transitivity already tell us, respectively, in a more succinct and widely used way. Our selection of the remaining metrics was based on our expectations of where we would likely see differences between the sectors and where we would be able to interpret such differences in a meaningful way.

Network Metrics Comparison

Mean values and standard deviations of each selected metric for each sector (combination) are shown in Table 3 in the Appendix, along with the (null) results of ANOVA tests of difference. We placed this information in the Appendix because it was the only set of tests using sector (combination) we tried before we decided to engage in comparison on the basis of sector belongingness instead. Mean values and standard deviations of each selected metric for each group based on sector belongingness are shown in Table 10.

Table 10: Mean values and standard deviations (in parentheses) of selected metrics based on sector belongingness.

Sector	Total Nodes	Average Proximity	Total Support	Support to Nodes Ratio	Total Gaps in Support	Gaps in Support to Nodes Ratio	Density	Transitivity
A _{IN}	17.0 (7.81)	4.16 (0.644)	25.4 (12.2)	1.58 (0.576)	1.40 (1.62)	0.092 (0.122)	0.200 (0.131)	0.660 (0.277)
A _{OUT}	16.4 (6.37)	4.20 (0.614)	24.0 (9.41)	1.522 (0.505)	1.84 (2.47)	0.137 (0.226)	0.183 (0.116)	0.707 (0.281)
I _{IN}	16.1 (6.95)	4.15 (0.546)	24.0 (11.0)	1.56 (0.547)	1.57 (2.52)	0.117 (0.231)	0.213 (0.152)	0.684 (0.284)
I _{OUT}	17.2 (7.48)	4.19 (0.674)	25.4 (11.4)	1.56 (0.554)	1.55 (1.63)	0.104 (0.124)	0.183 (0.108)	0.674 (0.277)
G _{IN}	16.7 (6.12)	4.16 (0.683)	24.8 (11.9)	1.57 (0.654)	1.66 (1.60)	0.144 (0.234)	0.198 (0.120)	0.686 (0.270)
G _{OUT}	16.8 (7.81)	4.18 (0.609)	25.0 (11.0)	1.56 (0.497)	1.51 (2.14)	0.092 (0.125)	0.191 (0.128)	0.673 (0.284)

To test for differences between groups in or out of each sector, we used three separate T-tests per metric since we only wished to compare two groups each time, a sector's IN and OUT groups. The results of the T-tests (specifically the p-values) tell us the likelihood that the null hypotheses, that there are no differences between the IN/OUT group for each metric tested, are true. None of these tests resulted in P-values smaller than the common threshold of 0.05, meaning that we should not reject any of the null hypotheses and that no further post-hoc testing is needed.

Network Composition Comparison by Nodes

We compared network composition by sector belongingness in terms of the alter categories of "Stage" and "Relationship." Counts of alters classified in each category, split by belongingness to each sector, are shown in Tables 11 and 12.

Table 11: Counts of alters in different classes of the Stage category, split by belongingness to each sector.

Sector (N)	undergrad	grad	postdoc	job	none
A _{IN} (1074)	35	192	46	406	395
A _{OUT} (606)	28	189	31	208	150

I_{IN} (565)	16	170	33	184	162
I_{OUT} (1115)	47	211	44	430	383
G_{IN} (535)	26	132	25	199	153
G_{OUT} (1145)	37	249	52	415	392

Table 12: Counts of alters in different classes of the Relationship category, split by belongingness to each sector.

Sector (N)	boss	fam.par t	friend	friend.p rf	groups	mentee	mentor	peer
A_{IN} (1074)	177	80	59	109	143	49	105	352
A_{OUT} (606)	117	51	66	57	87	12	68	148
I_{IN} (565)	119	45	58	54	75	10	51	153
I_{OUT} (1115)	175	86	67	112	155	51	122	347
G_{IN} (535)	100	44	38	52	78	10	60	153
G_{OUT} (1145)	194	87	87	114	152	51	113	347

Since all networks were composed of alters that have some classification in both of these categories, the chi-squared test is appropriate for determining if any networks grouped by sector belongingness are different based on the relative frequency of the different classes of alter Stage and Relationship among nodes. Since chi-squared tests require mutually exclusive categorizations across the board, we ran three separate tests where each test compared a sector's IN group to its OUT group. In each case, results of these tests tell us the likelihood that the null hypothesis, that there is no difference between a sector's IN and OUT groups in terms of alter composition, is true. These results are shown in Table 13.

Table 13: Results of 6 chi-squared tests of independence for each of 2 alter categories and 3 sectors, based on each sector's IN/OUT groups.

Alter category	Sector	P-value	Chi-squared	Degrees of Freedom
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Stage	Academia	< 0.0001****	51.3	4
	Industry	0.00033***	32.9	4
	Government	0.244	7.63	4
Relationship	Academia	< 0.0001****	34.9	7
	Industry	< 0.0001****	27.0	7
	Government	0.106	9.12	7

Based on common thresholds, the tests for both Academia and Industry show significant differences in alter composition based on both Stage and Relationship. In order to determine exactly which factors were different, we ran 4 post-hoc tests for each alter category in Academia and Industry, the results of which are shown in Tables 14 and 15.

Table 14: Results of post-hoc tests to determine which classes of alters in the Stage category contributed to low p-values in chi-squared tests of difference between those in and out of Academia and Industry. P-values and residuals (in parentheses) are reported for the IN groups.

Sector	undergrad	grad	postdoc	job	none
Academia	1.00 (-1.41)	<0.0001**** (-6.27)	1.00 (-0.784)	1.00 (1.42)	<0.0001**** (5.06)
Industry	1.00 (-1.41)	<0.0001**** (5.16)	0.794 (1.75)	0.159 (-2.41)	0.189 (-2.35)

Table 15: Results of post-hoc tests to determine which classes of alters in the Relationship category contributed to low p-values in chi-squared tests of difference between those in and out of Academia and Industry. P-values and residuals (in parentheses) are reported for the IN groups.

Sector	boss	fam.par t	friend	friend.p rf	groups	mentee	mentor	peer
Academ ia	1.00 (-1.46)	1.00 (-0.710)	0.00083 *** (-4.05)	1.00 (0.490)	1.00 (-0.600)	0.11 (2.72)	1.00 (-0.936)	0.0052* * (3.60)
Industry	0.10 (2.74)	1.00 (0.182)	0.027* (3.14)	1.00 (-0.316)	1.00 (-0.353)	0.059 (-2.90)	1.00 (-1.22)	1.00 (-1.71)

Based on these results, we conclude that differences in alter composition by Stage between sector IN/OUT groups are for grad and none alters for Academia and just grad alters for

Industry. For the Relationship category, the differences are between friend and peer alters for Academia and just friends for Industry. More detailed discussion of these differences will follow, but we visualize these different distributions here in Figures 7 and 8.

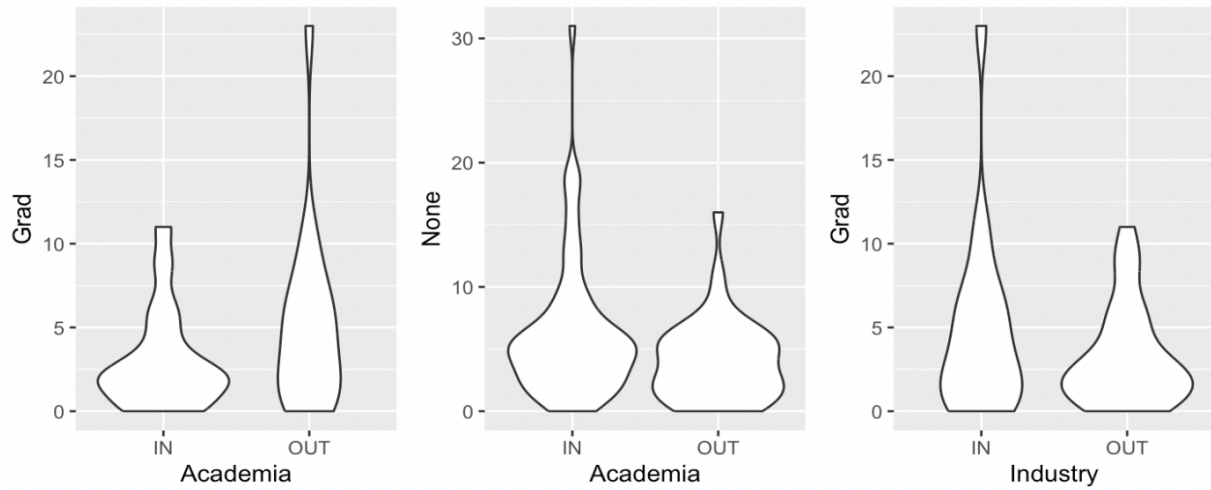


Figure 7: Violin plots comparing distributions of alter counts for groups found to be different based on p-values for the Stage category. Violins are normalized to have equal areas.

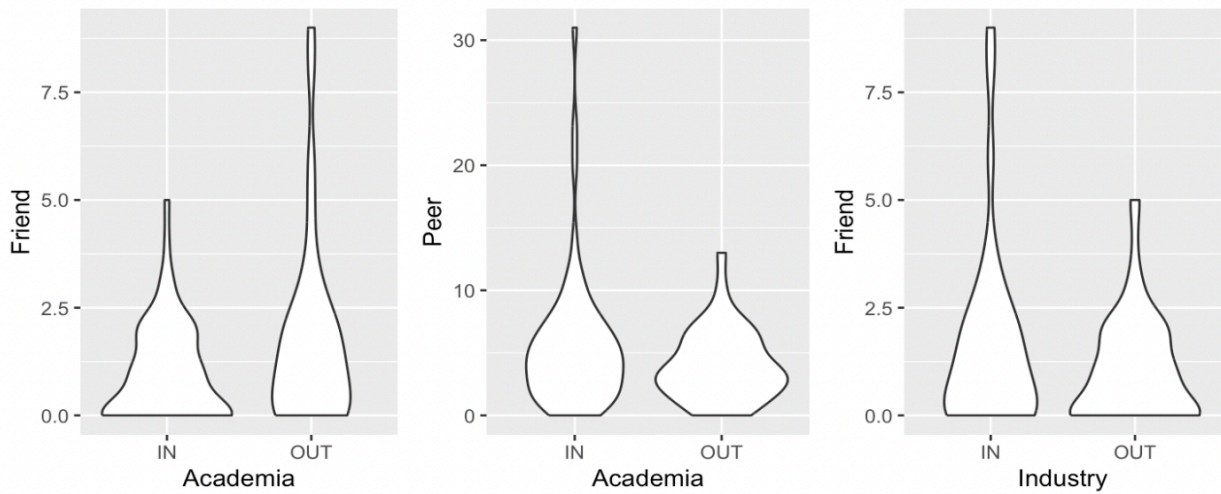


Figure 8: Violin plots comparing distributions of alter counts for groups found to be different based on p-values for the Relationship category. Violins are normalized to have equal areas.

Network Composition Comparison by Mentions

We also examined network composition based on the same two categories, Stage and Relationship, but from Mentions of alters in each class rather than counts of alters in each class. Again, the chi-squared test of independence was appropriate for determining if any networks grouped by career sector were different along these lines. Since this comparison followed the exact same procedure as the comparison in the previous section on the basis of node counts, we

display the results in the Appendix to save space in the body of the paper. The results are still discussed and interpreted in Section V.

Support Type Comparison

We compared counts of different support types based on sector belongingness. These counts are shown in Table 16.

Table 16: Counts of different types of support, split by belongingness to each sector.

Sector (N)	Identity-based	Physical Closeness	Networking	Community-building	Career advice	Emotional	Material	Instrumental	DEI initiatives/policies
A _{IN} (1074)	149	41	112	170	295	342	33	362	97
A _{OUT} (606)	115	23	90	71	153	191	38	160	48
I _{IN} (565)	105	20	90	66	144	172	23	160	59
I _{OUT} (1115)	159	44	112	175	304	361	48	362	86
G _{IN} (535)	91	23	76	75	140	171	33	131	52
G _{OUT} (1145)	173	41	126	166	308	362	38	391	93

The chi-squared test of independence is appropriate for comparing each sector's IN and OUT groups on the basis of counts of associated support types. In this case, results of the tests tell us the likelihood that the null hypotheses, that each sector's IN and OUT groups are not different from each other based on relative frequencies of support types, are true. Those results are shown in Table 17.

Table 17: Results of 3 chi-squared tests of independence for each sector's IN/OUT groups, based on frequency of association with different support types.

Sector	P-value	Chi-squared	Degrees of Freedom
Academia	< 0.0001****	34.6	8
Industry	0.00011***	25.9	8
Government	0.0026**	23.6	8

Based on common thresholds, the tests for all sectors showed significant differences in the support types commonly associated with the IN and OUT groups. In order to determine exactly which factors were different, we ran three post-hoc tests, the results of which are shown in Table 18.

Table 18: Results of post-hoc tests to determine which support type frequencies contributed to low p-values in chi-squared tests of difference between those in and out of the three sectors. P-values and residuals (in parentheses) are reported for the IN groups.

Sector	Identity-based	Physical Closeness	Networking	Community-building	Career advice	Emotional	Material	Instrumental	DEI initiatives/policies
Academia	0.087 (-2.82)	1.00 (-0.040)	0.11 (-2.74)	0.60 (2.13)	1.00 (0.757)	1.00 (-0.072)	0.027* (-3.18)	0.12 (2.71)	1.00 (0.673)
Industry	0.49 (2.21)	1.00 (-0.419)	0.011* (3.41)	0.53 (-2.18)	1.00 (-0.767)	1.00 (-0.784)	1.00 (-0.235)	1.00 (-1.65)	1.00 (1.84)
Government	1.00 (0.982)	1.00 (0.719)	1.00 (1.85)	1.00 (-0.241)	1.00 (-0.280)	1.00 (0.154)	0.13 (2.69)	0.0038** (-3.70)	1.00 (1.08)

Based on these results, we conclude that there are differences between IN and OUT groups in terms of material support for Academia, networking support for Industry, and instrumental support for Government. More detailed discussion on these differences will follow, but we visualize these different distributions here in Figure 9.

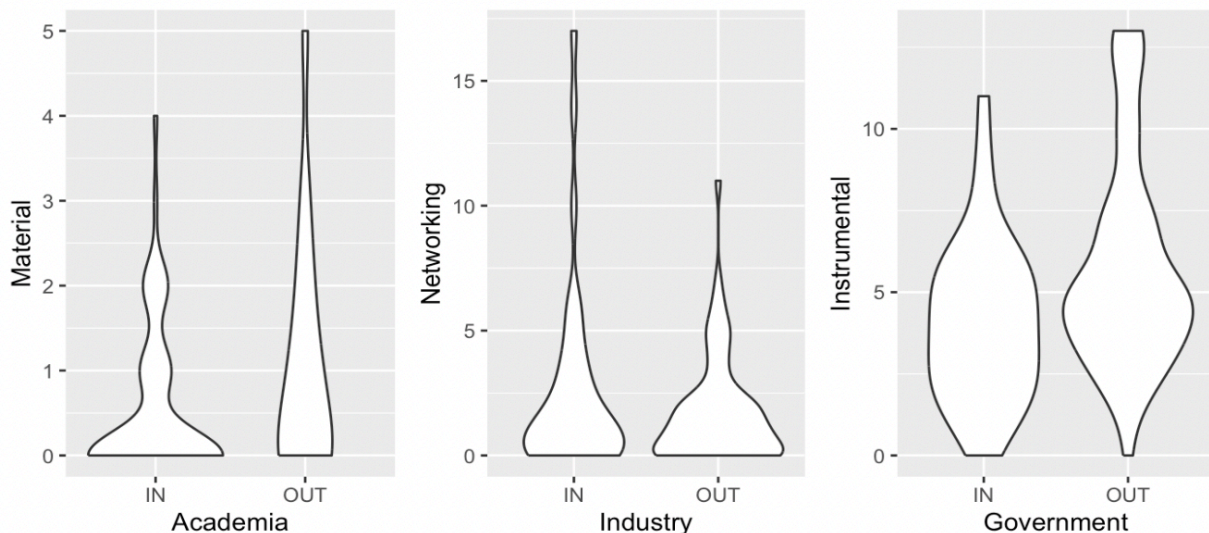


Figure 9: Violin plots comparing distributions of counts of support types for groups found to be different based on results of post-hoc testing. Violins are normalized to have equal areas.

V. Discussion

Interpretation and Discussion of Full Group Results

Networks and Metrics

Many aspects of participants' networks varied widely, which is apparent from the relative sizes of many standard deviation measures in Table 4. On average, each network had about 17 alters, but the number of alters ranged roughly normally from 4 to 47. About a fifth of these were groups rather than individuals. One quarter of our participants clearly indicated some type of dissonance with at least one alter in their network, while only a handful indicated dissonance with more than one alter. The average proximity of all alters was about 4, which is not surprising considering the proximity scale ranges from 1 - 8, and the average alter was mentioned in their associated interview twice.

Participants reported about 1.5 times as many instances of different types of support associated with different alters as the number of alters in their network, while they reported about one-tenth as many gaps in support as alters. Support measures varied, with some participants reporting more than three times as many support instances as alters while one participant reported more gaps in support than there were alters in their network. Interview questions were largely based on support (rather than gaps in support), so the abundance of support compared to gaps may not be surprising, but it is still worth noting that, overall, our participants were able to describe very supportive networks.

Participants' networks were generally not very dense—about one fifth of possible connections existed in their networks, on average. This may not be surprising since the only thing necessarily linking alters in any network was their connection to the ego. This relative scarcity of connections among alters is also reflected in an average components count of about 6 for the full group, which suggests that the networks typically have a handful of isolated individuals or groups of nodes. With an average of 3 cliques (cliques being groups of 3+ interconnected nodes) and an average largest clique size of about 5, we see that the networks tend to include well-defined clusters. This is also reflected by an average transitivity (also known as clustering coefficient) of 0.677, which suggests that groups of 3 nodes featuring at least two connections tend to have all 3 connections more often than not.

Transitivity had an unexpected non-normal distribution (see Figure 3) that suggested a large tendency towards clustering, which we believe may be partially explained by sociogram construction instructions. After participants placed alters on sociograms, they were asked to indicate which alters knew each other by drawing lines connecting them or circling groups of alters who knew each other. When alters were circled, we counted each person in the circle as being connected to every other person in the circle. With this instruction usually coming at the end of a long interview, in some cases, and especially when sociograms contained many alters, participants may have opted for circling as an easier alternative to drawing each and every

connection even if not all circled alters certainly knew each other. This is an example of a limitation of egocentric SNA described in the Methods Paper, where egos are an excellent source of information concerning their own connections but may be less reliable when it comes to their alters' connections.

Composition

In terms of career stage (the Stage category), participants' networks were mostly composed of alters they discussed first in the context of a job or who were not associated with a career stage ("none" career stage), about a third each. Many alters not associated with a specific career stage were personal friends, family, partners, or otherwise not formally associated with their ego's academic or professional careers. Participants also had many alters they first discussed in the context of graduate school (a little less than a quarter), but fewer alters first associated with their undergraduate education or with postdoc positions. The way that participants discussed alters of different Stage classifications (based on Mentions) roughly reflected the counts of alters, although job and grad alters were both discussed more and none alters discussed less.

In terms of general relationship type (the Relationship category), participants' networks were mostly composed of peers (over one quarter), bosses, and alters associated with groups (less than a fifth and a sixth, each, respectively). The remainder included roughly equal representations of friends, professional friends, mentors, and family/partners at a little less than 10% each, though mentees were less common at about 4%. The way that participants discussed alters in terms of Relationship roughly reflected counts of alters, though bosses and family/partners were discussed more and peers discussed less.

Support Types

Each alter could be associated with anywhere from 0 - 9 types of support. In considering total counts of different types of support for the full group, we found that emotional, instrumental, and career advice support were most common at about a fifth of total support counts each. This may not be surprising since the interview protocol included questions which asked somewhat directly about these types of support. Material support and physical closeness were less common, representing less than 3% each of total support counts.

We tested for differences in the way that different classes of alters (from the Stage and Relationship categories) were associated with different types of support. These differences are as follows for the Stage category, with asterisks indicating significance levels of each result:

- Grad alters were associated with more networking support.****
- Job alters were associated with more instrumental support**** and less emotional**** and networking* support.
- None alters were associated with more emotional support**** and less instrumental support.****

For the Relationship category:

- Boss alters were associated with more instrumental,**** career,**** and networking* support and less community building**** and emotional**** support.
- Family/partner alters were associated with more material** and emotional**** support and less instrumental** and DEI-related* support.
- Friend alters were associated with more emotional support**** and less instrumental support.*
- Professional friend alters were associated with more physical closeness** and more emotional**** support.
- Group alters were associated with more identity-based**** and community building**** support and DEI initiatives/policies**** and less career advice,**** emotional,*** and instrumental**** support.
- Peer alters were associated with more instrumental support.****

Interpretation and Discussion of Sector Comparison Results

Network Metrics

Based on ANOVA and T-tests, we found no statistically significant differences between any of the sectors based on mean values of network metrics. That is, career sector played no significant role in the size, the general connectedness, or the level of clustering or fragmentation of participants' networks.

Network Composition by Nodes

Based on contingency tables, p-values and chi-squared statistics from chi-squared tests of independence, and p-values and residuals from post-hoc chi-squared tests, we can draw a few conclusions about network composition by node count based on both alter Stage and Relationship for the IN/OUT groups of Academia and Industry. They are as follows for alter composition based on Stage:

- Participants in Academia had fewer grad**** alters and more none**** alters than those out of Academia.
- Participants in Industry had more grad**** alters than those out of Industry.

For alter composition based on Relationship:

- Participants in Academia had fewer friend*** alters and more peer** alters than those out of Academia.

- Participants in Industry had more friend* alters than those out of Industry.

Network Composition by Mentions

Based on contingency tables, p-values and chi-squared statistics from chi-squared tests of independence, and p-values and residuals from post-hoc chi-squared tests, we can draw a few conclusions about network composition of Mentions based on both alter Stage and Relationship for the IN/OUT groups of all three sectors. Since the Mentions parameter measures how often an alter was brought up in conversation, we refer to the results in terms of frequency of discussion. The results are as follows for alter composition of Mentions based on Stage:

- Participants in Academia discussed fewer grad**** alters and more job* and none**** alters than those out of Academia.
- Participants in Industry discussed fewer job** alters and more grad**** and postdoc*** alters than those out of Industry.
- Participants in Government discussed fewer none** alters and more grad**** alters than those out of Government.

For alter composition of Mentions based on Relationship:

- Participants in Academia discussed fewer friend**** and boss* alters and more mentee,** professional friend,* and peer** alters than those out of Academia.
- Participants in Industry discussed fewer mentee** alters and more friend**** and boss** alters than those out of Industry.
- Participants in Government discussed fewer mentee** alters than those out of Government.

Support Type

Based on contingency tables, p-values and chi-squared statistics from chi-squared tests of independence, and p-values and residuals from post-hoc chi-squared tests, we can draw a few conclusions about support types for the IN/OUT groups of all three sectors. They are as follows:

- Participants in Academia described less material support* than those out of academia.
- Participants in Industry described more networking support* than those out of Industry.
- Participants in Government described less instrumental support** than those out of Government.

We note that these conclusions apply in slightly different contexts. Overall, participants did not describe very much material support (less than half described any material support, let alone material support from multiple alters), so the first bullet should be read as those in Academia typically describe *no* material support while those out of Academia were more likely

to describe *some* material support. On the other hand, all but two participants described some instrumental support (with most describing multiple sources of instrumental support), so the last bullet should be read as those in Government describing less, but still *some* instrumental support, while those out of Government described more instrumental support. Networking support, or the middle bullet, should be read as somewhere between these two interpretations.

Implications and Suggestions

Implications Concerning the Full Group

Before discussing the implications of these results, we should note that the experiences of our participants may not be directly generalizable to the entire population of GSM physicists since our sample was not selected completely randomly. Furthermore, apart from comparisons for our sample made on the basis of career sector, our results do not allow us to make causal or correlational claims. However, we are able to comment on trends in our dataset, and with 100 physicists comprising that dataset, we believe that trends in their experiences may still reveal something about the experiences of GSM physicists more broadly. Also, since this sample consists entirely of people with physics PhDs working in physics (or physics-adjacent) fields, we see them as people that have found success as professional physicists and will interpret results in light of this assertion.

Considering the networks of the full group, perhaps the most striking feature is the presence of support. With an average of 1.5 times as many types of support recorded as nodes per network, we could say that our participants were able to describe ample support in their professional journeys, with emotional, instrumental, and career advice support being chief among them. Considering multiple studies which have stressed the importance of various types of support for the retention of GSM physicists in physics programs,^{52,53,54,55} we could see this as supporting the notion that professional GSM physicists do indeed need varying and ample avenues of support in order to find success, especially instrumental, emotional, and career advice support.

Considering the composition of these physicists' networks, we see that connections made during jobs, graduate education, and outside of academic and professional institutions are critical to the extent of their professional networks. Likewise, peers, bosses and mentors, and connections associated with groups are foundational in their networks. This is not to say that other types of connections like friends, family, and partners are not important, but the abundance

⁵² Whitten et al., "What Works for Women in Undergraduate Physics?"

⁵³ Barthelemy et al., "LGBT + Physicists."

⁵⁴ Erin M. Schipull, Xandria R. Quichocho, and Eleanor W. Close, "'Success Together': Physics Departmental Practices Supporting LGBTQ+ Women and Women of Color," 2020, 535–40, <https://www.per-central.org/items/detail.cfm?ID=15330>.

⁵⁵ Melinda McCormick, Ramon Barthelemy, and Charles Henderson, "Women's Persistence into Graduate Astronomy Programs: The Roles of Support, Interest, and Capital," *Journal of Women and Minorities in Science and Engineering* 20, no. 4 (2014), <https://doi.org/10.1615/JWomenMinorScienEng.2014009829>.

of these connections specifically suggests that they may be of extra importance to GSM physicists that find professional success in physics.

Finally, considering both support and alter composition, we see that bosses and connections made during graduate school were critical sources of networking support, meaning that those connections may have helped participants' networks grow and support them to the extent observed. Bosses, peers, and connections made at jobs were critical sources of instrumental support, which may not be surprising since instrumental support would most easily come from direct connections in the workplace. Family, partners, friends (both personal and professional), and connections made through groups were critical to providing emotional support, meaning that most emotional support comes from outside the professional sphere or from choice professional connections. Connections made through groups, which included identity-based affinity groups, personal and professional interest groups, and more, were uniquely associated with providing identity-based and community building support as well as support through DEI initiatives and policies. This may not be surprising, since these types of support are often among desired outcomes of such groups, but it confirms that these groups generally accomplish these goals for our sample of GSM physicists. The fact that group connections were the only connections providing a statistically significant share of these kinds of support also speaks to the unique and critical position of such groups in providing these kinds of support in general. It may be reasonable to then conclude that the elimination or diminishment of DEI-related programs, which describes many of the groups discussed by our participants, would result in less support for GSM physicists and a higher likelihood of their exit from the field.

Implications Concerning Career Sectors

Analysis of our dataset has allowed us to draw some conclusions about differences in participants' experiences in the three career sectors. As discussed earlier, these conclusions may extend beyond our sample or not. We discuss them here as a way for (aspiring) professional GSM physicists to have a better idea of what to expect in the different sectors and as a way for employers in these sectors to consider what they may or may not be providing to their employees.

Comparisons between those in and out of Academia (jobs include faculty, research administrative, and other roles at universities) suggest the importance and prevalence of mentorship and relationships with peers and professional friends, in most cases at a job, for those in academia. Personal friends, connections made in graduate school, and bosses may not feature as heavily in the support networks of those in academia, and material support may be lacking. This last point may support a notion that the work itself (rather than the pay) is the reward in academia. Other points may suggest that professional life may take precedence over personal life in academia, but that one has more ability to "be their own boss." We found the relative lack of graduate school connections surprising, since graduate school is often a critical time in the life of an academic, but believe it makes more sense if we consider the way that the networks of those in Academia seem to prioritize immediate working and professional connections.

For those in Industry (various jobs in engineering, tech, science communication, consulting, and other fields), results suggest that personal friends, bosses, and connections made in graduate school and postdoctoral positions are critical in the networks of successful GSM physicists. Mentorship is not as prevalent in their work, and they see more networking support than others. Unlike academia, then, industry may be seen as a sector that allows for more investment in personal life and long-lasting connections, but not for mentorship, which some may see as a good or bad thing. The relative abundance of networking support may be read as something that industry jobs provide, or it may be that those who received more networking support earlier on were better able to pivot out of academia and into industry after obtaining a PhD. We found the relative abundance of graduate school connections in Industry surprising, but believe it makes more sense when noted together with the relative abundance of networking support, some of which may have come from graduate school connections.

Participants in Government (positions at national labs, federal agencies, government-affiliated nonprofits, and others) tended to have more connections made in graduate school that persisted into their professional network, so we may see government also as a sector that is congruent with more investment in those relationships. Those in Government describe less instrumental support, suggesting that those in the sector may find that they fend for themselves in terms of their work.

Suggestions

The implications discussed above have their own implications for institutions that employ and support professional physicists. Generally, such institutions should recognize the ample and varying types of support described by these physicists and should consider how they can help connect their constituents with these types of support, especially instrumental, emotional, and career advice support. They should try to bolster workplace connections with supervisors and peers as effective means of receiving on-the-job support, perhaps through connection-building professional development or workplace social activities. They should recognize that emotional support, while not absent in professional environments, will largely come from the personal sphere and that constituents may need time and space away from work to access that sphere.

For institutions supporting and employing physicists across the three sectors, the importance of groups (like personal and professional interest groups, affinity groups, and identity-based groups) and the connections made therein can not be overstated. Our results show that, not only do these groups successfully meet their likely goals of providing identity-based and community building support to this sample of physicists, but they are the only entities and connections notable for these specific types of support. Depending on the groups, allocation of funding, time, space, and visibility may all be critical to the maintenance of these crucial support systems. Institutions should consider interest and affinity groups, whether professional or personal, as a necessary component in supporting GSM physicists. If considering eliminating or diminishing groups on the basis of DEI-relatedness, institutions should recognize that this would likely come at the expense of GSM physicists.

For sector-specific recommendations, we consider the implications of comparing participants' experiences in the three sectors. Employers in academia should continue to support connections within and across the institution (peers and professional friends), but they should also consider the effect of a lack of material support and of a professional life that may leave less room for personal relationships. If more material support (which would include pay, benefits, access to funding, or other necessary resources) for employees is not an option, academic employers should consider changing expectations around time spent at work or otherwise continue to support workplace flexibility, also found by Whitten et al. to be key in the retention of women physicists.⁵⁶ Mentorship is more prevalent in academia, which can be good or bad depending on the people involved, so academic institutions should be aware of the potential for mentoring as a uniquely rewarding experience or as a distractor. Employers in industry should continue to support networking for their employees and should consider that work in their sector may be difficult to access for PhD physicists. They should continue to allow space for personal relationships to flourish, and should consider providing more opportunities for mentorship if desired by employees. Employers in government should consider providing more support and perhaps mentorship that could help their employees with their day-to-day work, which may mean more training, detailed instructions, or bolstering connections with bosses and peers.

Limitations

In addition to limitations in the methods discussed in the Methods Paper (which included tradeoffs between qualitative descriptiveness and quantitative comparability, ambiguity in interview recordings, and variations in sociogram construction), this study is limited by a sample population that was not chosen completely randomly, which means we are unable to ensure generalizability to the larger population of GSM physicists. Still, by casting a wide net with invitations to join the study extended through national listservs and professional societies as well as social media advertisements, and with a relatively large sample, our results may at least be powerfully suggestive for the larger population of GSM physicists.

In some cases, we were limited by small population subsets when running statistical tests. Our need to base sector comparisons on sector belongingness rather than specific sector (combination) is an example of this. Consequently, our results are informative strictly on the basis of belongingness to the different career sectors and not necessarily on any participant's unique employment sector (combination). As with any meeting of qualitative description with statistical tools, there is a tradeoff between detail and nuance and explanatory power, and in this case we opted for explanatory power.

Finally, this study is limited throughout, though usually minimally, by the perspectives, biases, and subjectivities of the various researchers that have interacted with the participants and data. As described in more detail in the Methods Paper, this is an unavoidable reality for qualitative data collection and analysis, though we have taken steps to mitigate it. Still, minor

⁵⁶ Whitten et al., "What Works for Women in Undergraduate Physics?"

differences in interview techniques, thematic coding practices, and decisions regarding data classification have shaped our dataset in ways both predictable and not. As with any qualitative study, we do our best to account for these differences and we expect that they add some fuzziness, but not skew, to our results.

Future work

For other researchers, we see an opportunity to undertake similar studies of the experiences of marginalized professional physicists, but on the basis of identities other than gender and sexual identities, like perhaps race, nationality, and (dis)ability status, as we found differences in experiences along these lines as well in this dataset.

We also see opportunities to look more closely at the differences between career sectors revealed by this work, specifically the differences in personal/professional relationships in networks and the prevalence of different kinds of support. It would be interesting to know if such differences exist for all physicists working in these sectors or just the ones in our sample.

Much more work from this project is forthcoming, and much of it is qualitative. On the quantitative side, we plan to examine different groups in our dataset with similar comparison schemes, like LGBTQ+ participants, Participants of Color, and participants with disabilities. On the qualitative side, our team will look at professional physics identity, the experiences of international participants, the experiences of participants with disabilities, and participants' understanding of closeness, among other topics.

VI. Conclusion

We have presented the results of an extensive mixed-methods egocentric network analysis of the support networks of women and/or LGBTQ+ (gender and sexual minority, or GSM) PhD physicists, the methods for which are described in an earlier publication. We have reported descriptive results for the full group and comparative results for participants in or out of each of the three career sectors of academia, industry, and government. We have interpreted those results in light of what they suggest for our sample population and have made suggestions for institutions supporting and employing physicists.

The full group generally described supportive networks, suggesting that successful professional GSM physicists receive ample and varying support during their careers. Workplace connections like bosses and peers were more frequently associated with networking and instrumental support, while personal connections like family, partners, and friends were more frequently associated with emotional support. Institutions should continue to nurture professional relationships as they are linked to professional success in this sample, but they should leave room for personal relationships as these are the best way to ensure emotional support. Connections made with or within groups (like affinity groups and personal and professional interest groups) were uniquely linked to community-building and identity-based support. Institutions should

continue to promote participation in and should consider expanding such groups as they are able as they are indispensable to this sample of GSM physicists.

Comparisons based on career sector revealed that those in our sample in academia had plenty of professional connections like mentees, peers, and professional friends but fewer personal friends and bosses in their networks. They also described less material support. Employers in academia should continue to support flexibility in the workplace (being one's own boss) and should consider what resources constituents are lacking, or if a tradeoff in expectations around work-life balance can be made when greater allocation of resources can not. Those in industry had more connections with friends and bosses and longer-lasting connections from graduate education and postdoctoral positions. They described more networking support, meaning their jobs have done a good job connecting them with others in their field or that their strong connections helped them land a job in industry in the first place. Participants working in government described less instrumental support, meaning that employers in that sector should consider ways to support constituents with their day-to-day work, perhaps by strengthening ties with or allowing for more interaction with peers and bosses.

This study and its results may serve as a guide for aspiring professional physicists, especially GSM physicists, on what they might expect when working in any of these sectors. It also may serve as a guide on the qualities of the networks of successful GSM physicists. This study also provides guidance and suggestions for institutions and organizations that support and employ professional physicists, particularly with regard to what types of support and what types of connections are important for professional GSM physicists. Ultimately, this work can help marginalized physicists make better decisions about their continued work in physics and can help physics institutions better support them.

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References

- Aycock, Lauren M., Zahra Hazari, Eric Brewe, Kathryn B. H. Clancy, Theodore Hodapp, and Renee Michelle Goertzen. "Sexual Harassment Reported by Undergraduate Female Physicists." *Physical Review Physics Education Research* 15, no. 1 (April 22, 2019): 010121. <https://doi.org/10.1103/PhysRevPhysEducRes.15.010121>.
- Barthelemy, Ramón, Melinda McCormick, and Charles Henderson. "Barriers Beyond Equity: An Exploratory Study of Women Graduate Students' Career Pathways in Astronomy." *International Journal of Gender, Science and Technology* 7, no. 1 (February 7, 2015): 57–73.
- Barthelemy, Ramón S. "LGBT+ Physicists Qualitative Experiences of Exclusionary Behavior and Harassment." *European Journal of Physics* 41, no. 6 (October 2020): 065703.

- <https://doi.org/10.1088/1361-6404/abb56a>.
- Barthelemy, Ramón S., Melinda McCormick, and Charles Henderson. “Gender Discrimination in Physics and Astronomy: Graduate Student Experiences of Sexism and Gender Microaggressions.” *Physical Review Physics Education Research* 12, no. 2 (August 1, 2016): 020119. <https://doi.org/10.1103/PhysRevPhysEducRes.12.020119>.
- Barthelemy, Ramón S., Melinda McCormick, and Charles R. Henderson. “Understanding Women’s Gendered Experiences in Physics and Astronomy Through Microaggressions.” In *2014 Physics Education Research Conference Proceedings*, 35–38. Minneapolis, MS: American Association of Physics Teachers, 2015. <https://doi.org/10.1119/perc.2014.pr.005>.
- Barthelemy, Ramón S., Melinda McCormick, Charles R. Henderson, and Alexis Knaub. “Educational Supports and Career Goals of Five Women in a Graduate Astronomy Program.” *Physical Review Physics Education Research* 16, no. 1 (April 21, 2020): 010119. <https://doi.org/10.1103/PhysRevPhysEducRes.16.010119>.
- Barthelemy, Ramón S., Madison Swirtz, Savannah Garmon, Elizabeth H. Simmons, Kyle Reeves, Michael L. Falk, Wouter Deconinck, Elena A. Long, and Timothy J. Atherton. “LGBT + Physicists: Harassment, Persistence, and Uneven Support.” *Physical Review Physics Education Research* 18, no. 1 (March 28, 2022): 010124. <https://doi.org/10.1103/PhysRevPhysEducRes.18.010124>.
- Bidart, Claire, Alain Degenne, and Michel Grossetti. “Personal Networks Typologies: A Structural Approach.” *Social Networks* 54 (July 2018): 1–11. <https://doi.org/10.1016/j.socnet.2017.11.003>.
- Butler, Judith. “Performative Acts and Gender Constitution: An Essay in Phenomenology and Feminist Theory.” *Theatre Journal* 40, no. 4 (1988): 519–31. <https://doi.org/10.2307/3207893>.
- Camporesi, T. “High-Energy Physics as a Career Springboard.” *European Journal of Physics* 22, no. 2 (March 2001): 139. <https://doi.org/10.1088/0143-0807/22/2/306>.
- Celikates, Robin, and Jeffrey Flynn. “Critical Theory (Frankfurt School).” In *The Stanford Encyclopedia of Philosophy*, edited by Edward N. Zalta and Uri Nodelman, Winter 2023. Metaphysics Research Lab, Stanford University, 2023. <https://plato.stanford.edu/archives/win2023/entries/critical-theory/>.
- Crossley, Nick, and Gemma Edwards. “Cases, Mechanisms and the Real: The Theory and Methodology of Mixed-Method Social Network Analysis.” *Sociological Research Online*, May 31, 2016. <https://doi.org/10.5153/sro.3920>.
- Czujko, Roman, and Garrett Anderson. “Common Careers of Physicists in the Private Sector,” n.d.
- Delgado, Richard, and Jean Stefancic. “Critical Race Theory: Past, Present, and Future.” *Current Legal Problems* 51, no. 1 (1998): 467–91. <https://doi.org/10.1093/clp/51.1.467>.
- Fisher, R. A. “Statistical Methods for Research Workers.” In *Breakthroughs in Statistics: Methodology and Distribution*, edited by Samuel Kotz and Norman L. Johnson, 66–70. New York, NY: Springer New York, 1992. https://doi.org/10.1007/978-1-4612-4380-9_6.
- Godsil, Rachel D. “Why Race Matters in Physics Class.” SSRN Scholarly Paper. Rochester, NY, January 1, 2016. <https://papers.ssrn.com/abstract=2933292>.
- Gutzwa, Justin A., Ramón S. Barthelemy, Camila Amaral, Madison Swirtz, Adrienne Traxler, and Charles Henderson. “How Women and Lesbian, Gay, Bisexual, Transgender, and Queer Physics Doctoral Students Navigate Graduate Education: The Roles of

- Professional Environments and Social Networks.” *Physical Review Physics Education Research* 20, no. 2 (September 12, 2024): 020115.
<https://doi.org/10.1103/PhysRevPhysEducRes.20.020115>.
- Hatcher, Chase, Lily Donis, Adrienne Traxler, Madison Swirtz, Camila Manni, Justin Gutzwa, Charles Henderson, and Ramón Barthelemy. “Egocentric Mixed-Methods SNA: Analyzing Interviews with Women and/or Queer and LGBT+ Ph.D. Physicists.” arXiv, April 14, 2025. <https://doi.org/10.48550/arXiv.2504.10621>.
- Hazari, Zahra, Geoff Potvin, Robert H. Tai, and John Almarode. “For the Love of Learning Science: Connecting Learning Orientation and Career Productivity in Physics and Chemistry.” *Physical Review Special Topics - Physics Education Research* 6, no. 1 (May 21, 2010): 010107. <https://doi.org/10.1103/PhysRevSTPER.6.010107>.
- Hintze, Jerry L., and Ray D. Nelson. “Violin Plots: A Box Plot-Density Trace Synergism.” *The American Statistician* 52, no. 2 (May 1, 1998): 181–84.
<https://doi.org/10.1080/00031305.1998.10480559>.
- James, Westley, Caroline Bustamante, Kamryn Lamons, Erin Scanlon, and Jacquelyn J. Chini. “Disabling Barriers Experienced by Students with Disabilities in Postsecondary Introductory Physics.” *Physical Review Physics Education Research* 16, no. 2 (August 19, 2020): 020111. <https://doi.org/10.1103/PhysRevPhysEducRes.16.020111>.
- Johnson, Angela, Maria Ong, Lily T. Ko, Janet Smith, and Apriel Hodari. “Common Challenges Faced by Women of Color in Physics, and Actions Faculty Can Take to Minimize Those Challenges.” *The Physics Teacher* 55, no. 6 (September 1, 2017): 356–60.
<https://doi.org/10.1119/1.4999731>.
- Jona, Meytal Eran, and Yosef Nir. “4: The Academic Career in Physics as a ‘Deal’: Choosing Physics within a Gendered Power Structure,” 2024.
<https://bristoluniversitypressdigital.com/edcollchap/book/9781529222326/ch004.xml>.
- Kebblbeck, D. K., K. Piatek-Jimenez, and C. Medina Medina. “Undergraduate Physics Students’ Experiences: Exploring the Impact of Underrepresented Identities and Intersectionality.” *Physical Review Physics Education Research* 20, no. 2 (September 27, 2024): 020120.
<https://doi.org/10.1103/PhysRevPhysEducRes.20.020120>.
- Kirby, Kate, and Roman Czujko. “The Physics Job Market: Bleak for Young Physicists.” *Physics Today* 46, no. 12 (December 1, 1993): 22–27. <https://doi.org/10.1063/1.881392>.
- Kirby, Kate, Roman Czujko, and Patrick Mulvey. “The Physics Job Market: From Bear to Bull in a Decade.” *Physics Today* 54, no. 4 (April 1, 2001): 36–41.
<https://doi.org/10.1063/1.1372112>.
- Lewis, Karyn L., Jane G. Stout, Steven J. Pollock, Noah D. Finkelstein, and Tiffany A. Ito. “Fitting in or Opting out: A Review of Key Social-Psychological Factors Influencing a Sense of Belonging for Women in Physics.” *Physical Review Physics Education Research* 12, no. 2 (August 1, 2016): 020110.
<https://doi.org/10.1103/PhysRevPhysEducRes.12.020110>.
- McCormick, Melinda, Ramon Barthelemy, and Charles Henderson. “Women’s Persistence into Graduate Astronomy Programs: The Roles of Support, Interest, and Capital.” *Journal of Women and Minorities in Science and Engineering* 20, no. 4 (2014).
<https://doi.org/10.1615/JWomenMinorScienEng.2014009829>.
- McDermott, Liam G. “Developing and Operationalizing a Critical Disability Physics Identity Framework: Investigating the Experiences of Neurodivergent Physicists at Various Career Stages.” Ph.D., Rutgers The State University of New Jersey, School of Graduate Studies,

2024.
<https://www.proquest.com/docview/3061501616/abstract/ED12A3EDB166417CPQ/1>.
 McHugh, Mary L. “The Chi-Square Test of Independence.” *Biochemia Medica* 23, no. 2 (June 15, 2013): 143–49. <https://doi.org/10.11613/BM.2013.018>.
 “Number of Bachelor’s Degrees Earned in Physics, Classes 1987 through 2022 - AIP.ORG.” Accessed June 19, 2024.
<https://ww2.aip.org/statistics/number-of-bachelors-degrees-earned-in-physics-classes-1987-through-2022>.
 Ong, Maria. “Body Projects of Young Women of Color in Physics: Intersections of Gender, Race, and Science.” *Social Problems* 52, no. 4 (November 1, 2005): 593–617.
<https://doi.org/10.1525/sp.2005.52.4.593>.
 Pearson, Karl. “X. On the Criterion That a given System of Deviations from the Probable in the Case of a Correlated System of Variables Is Such That It Can Be Reasonably Supposed to Have Arisen from Random Sampling.” *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* 50, no. 302 (July 1, 1900): 157–75.
<https://doi.org/10.1080/14786440009463897>.
 “Physics PhDs Initial Employment Booklet - Academic Years 2020-21 and 2021-22 - AIP.ORG.” Accessed February 18, 2025.
<https://ww2.aip.org/statistics/physics-phds-initial-employment-booklet-academic-years-2020-21-and-2021-22>.
 Porter, Anne Marie. “Physics PhDs Ten Years Later: Success Factors and Barriers in Career Paths. Results from the PhD Plus 10 Study.” *AIP Statistical Research Center*. AIP Statistical Research Center, December 2019. <https://eric.ed.gov/?id=ED602755>.
 R Core Team. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing, 2020. <https://www.R-project.org/>.
 Ripin, Barrett. “Preparing Physicists for Life’s Work.” *Physics Today* 54, no. 4 (April 1, 2001): 43–48. <https://doi.org/10.1063/1.1372113>.
 Rosa, Katemari. “Educational Pathways of Black Women Physicists: Stories of Experiencing and Overcoming Obstacles in Life.” *Physical Review Physics Education Research* 12, no. 2 (2016). <https://doi.org/10.1103/PhysRevPhysEducRes.12.020113>.
 Scherr, Rachel E., Mike A. Lopez, and Marialis Rosario-Franco. “Isolation and Connectedness among Black and Latinx Physics Graduate Students.” *Physical Review Physics Education Research* 16, no. 2 (November 3, 2020): 020132.
<https://doi.org/10.1103/PhysRevPhysEducRes.16.020132>.
 Schipull, Erin M., Xandria R. Quichocho, and Eleanor W. Close. “‘Success Together’: Physics Departmental Practices Supporting LGBTQ+ Women and Women of Color,” 535–40, 2020. <https://www.per-central.org/items/detail.cfm?ID=15330>.
 Sharpe, Donald. “Your Chi-Square Test Is Statistically Significant: Now What?” *Practical Assessment, Research & Evaluation* 20, no. 8 (April 2015).
<https://eric.ed.gov/?id=EJ1059772>.
 Smith, Steven J., Liane Pedersen-Gallegos, and Catherine Riegle-Crumb. “The Training, Careers, and Work of Ph.D. Physical Scientists: Not Simply Academic.” *American Journal of Physics* 70, no. 11 (November 1, 2002): 1081–92.
<https://doi.org/10.1119/1.1510884>.
 Snedecor, George W., and William G. Cochran. *Statistical Methods*. 8th edition. Ames, Iowa: Iowa State University Press, 1989.

- Student. “The Probable Error of a Mean.” *Biometrika* 6, no. 1 (1908): 1–25.
<https://doi.org/10.2307/2331554>.
- Thompson, Michael J., ed. *The Palgrave Handbook of Critical Theory*. New York: Palgrave Macmillan US, 2017. <https://doi.org/10.1057/978-1-137-55801-5>.
- Traxler, Adrienne L., Camila Mani Dias Do Amaral, Charles Henderson, Evan LaForge, Chase Hatcher, Madison Swirtz, and Ramón Barthelemy. “Person-Centered and Qualitative Approaches to Network Analysis in Physics Education Research.” *Physical Review Physics Education Research* 20, no. 2 (October 21, 2024): 020132.
<https://doi.org/10.1103/PhysRevPhysEducRes.20.020132>.
- Whitten, Barbara L., Shannon R. Dorato, Suzanne R. Foster, and Margaret L. Duncombe. “What Works for Women in Undergraduate Physics?” 795 (October 1, 2005): 230–230.
<https://doi.org/10.1063/1.2128388>.
- Wilchins, Riki. *Queer Theory, Gender Theory*. Bronx, NY: Magnus Books, 2004.
https://books.google.com/books/about/Queer_Theory_Gender_Theory.html?id=H_NpZ9YqFrUC.
- Xu, Guangyu. “A Letter to HEP-TH Postgraduates on Career Prospects,” n.d.

Appendix

Support by Alter Type Post-hoc Chi-squared Results

Table 1: Results of post-hoc analysis showing p-values and residuals for each support type by alter class in the stage category.

Stage	Identity-based	Physical Closeness	Networking	Community-building	Career advice	Emotional	Material	Instrumental	DEI initiatives/policies
undergrad	1.00 (0.521)	1.00 (1.62)	1.00 (-0.720)	1.00 (0.590)	1.00 (1.08)	1.00 (0.726)	1.00 (-0.311)	1.00 (-1.62)	1.00 (-1.68)
grad	1.00 (0.223)	1.00 (-2.02)	<0.0001 **** (5.58)	1.00 (-0.912)	1.00 (0.460)	1.00 (0.986)	1.00 (-0.173)	0.11 (-3.03)	1.00 (-1.38)
postdoc	1.00 (-2.05)	1.00 (1.77)	1.00 (1.01)	1.00 (0.569)	1.00 (1.99)	1.00 (-2.09)	1.00 (0.445)	1.00 (-0.084)	1.00 (-0.162)
job	1.00 (-0.464)	1.00 (1.02)	0.013* (-3.64)	1.00 (-0.897)	0.52 (-2.52)	<0.0001 **** (-5.10)	1.00 (1.52)	<0.0001 **** (8.61)	0.94 (2.31)
none	1.00 (1.14)	1.00 (-0.902)	1.00 (-1.66)	1.00 (1.31)	1.00 (0.766)	<0.0001 **** (5.52)	1.00 (-1.62)	<0.0001 **** (-5.81)	1.00 (-0.287)

Table 2: Results of post-hoc analysis showing p-values and residuals for each support type by alter class in the relationship category.

Relationship	Identity-based	Physical Closeness	Networking	Community-building	Career advice	Emotional	Material	Instrumental	DEI initiatives/policies
boss	0.85 (-2.52)	1.00 (-1.42)	0.037* (3.48)	<0.0001 **** (-6.31)	<0.0001 **** (6.19)	<0.0001 **** (-7.11)	0.91 (2.49)	<0.0001 **** (6.16)	1.00 (-1.99)
fam.part	1.00 (-1.77)	1.00 (-0.433)	0.27 (-2.89)	1.00 (-1.65)	1.00 (0.517)	<0.0001 **** (8.65)	0.0011* * (4.32)	0.0015* * (-4.26)	0.025* (-3.58)
friend	1.00 (0.147)	1.00 (0.262)	1.00 (-1.88)	1.00 (1.60)	1.00 (-2.24)	<0.0001 ****	1.00 (-0.001)	0.013* (-3.75)	0.78 (-2.55)
friend.pr f	0.65 (-2.61)	0.0093* * (3.83)	1.00 (-1.15)	1.00 (0.868)	1.00 (-1.16)	<0.0001 **** (4.99)	1.00 (-1.62)	1.00 (-1.10)	0.57 (-2.66)
groups	<0.0001 **** (7.35)	1.00 (-2.17)	1.00 (0.093)	<0.0001 **** (9.99)	<0.0001 **** (-5.70)	0.00014 *** (-4.76)	1.00 (-1.78)	<0.0001 **** (-7.24)	<0.0001 **** (10.6)
mentee	0.49 (2.70)	0.083 (3.25)	1.00 (-2.04)	1.00 (-0.190)	0.39 (-2.78)	1.00 (-0.486)	1.00 (0.972)	1.00 (-0.653)	0.47 (2.72)
mentor	1.00 (-0.760)	1.00 (-1.36)	1.00 (1.25)	1.00 (-2.34)	0.72 (2.57)	1.00 (-1.08)	1.00 (-0.852)	0.37 (2.79)	0.11 (-3.17)
peer	1.00 (-1.60)	1.00 (-0.173)	1.00 (0.631)	1.00 (-1.75)	1.00 (0.552)	0.85 (-2.52)	1.00 (-2.10)	<0.0001 **** (5.05)	1.00 (-0.900)

Network Metrics Comparison by Sector (Combination)

We used ANOVA to test for differences in the mean of each selected network metric for each sector (combination) since it is preferred for testing for differences between more than two groups. Results of these tests are shown in Table 3.

Table 3: Mean values and standard deviations (in parentheses) of selected metrics for specific sector (combinations).

Sector	Total Nodes	Average Proximity	Total Support	Support to Nodes	Total Gaps in Support	Gaps in Support to	Density	Transitivity
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		ty		Ratio	t	Nodes Ratio		
A	17.2 (8.42)	4.24 (0.679)	25.9 (12.1)	1.57 (0.472)	1.41 (1.71)	0.092 (0.125)	0.183 (0.112)	0.664 (0.294)
I	17.6 (7.31)	4.10 (0.534)	26.3 (10.3)	1.58 (0.563)	2 (3.09)	0.107 (0.145)	0.168 (0.103)	0.698 (0.285)
G	15.6 (4.09)	4.25 (0.640)	22.7 (7.62)	1.48 (0.466)	1.64 (1.50)	0.119 (0.111)	0.175 (0.096)	0.715 (0.278)
AG	18.8 (7.40)	3.96 (0.706)	26.9 (13.2)	1.64 (0.863)	1.92 (1.56)	0.128 (0.140)	0.192 (0.115)	0.654 (0.233)
IG	13.9 (6.50)	4.21 (0.609)	18.6 (6.45)	1.46 (0.465)	1.21 (1.63)	0.149 (0.328)	0.272 (0.192)	0.676 (0.281)
AIG	18.5 (3.54)	4.19 (0.269)	39.5 (26.2)	2.04 (1.02)	0 (0)	0 (0)	0.229 (0.148)	0.617 (0.501)

Results of ANOVA tests of difference among specific sector (combinations) for each metric included no p-values below a common threshold of 0.05, so we do not reject the null hypotheses, that there are no differences between sector (combinations) based on these metrics, and no further testing is needed.

Network Composition Comparison by Mentions

Following the exact same procedure as for the network composition comparison by nodes, here we compare network composition based on classes of alters in the Stage and Relationship categories but by Mentions rather than counts of nodes. Mentions is the number of separate instances in which an alter is discussed by the ego. Mentions that were prompted by the interviewer are counted as one-half of an un-prompted Mention. For more information on this parameter, see the Methods Paper. Tables 4 and 5 show Mentions for alters classified in both the Stage and Relationship categories, split by sector belongingness.

Table 4: Number of Mentions associated with alters in different classes of the Stage category, split by belongingness to each sector.

Sector (N)	undergrad	grad	postdoc	job	none
A _{IN} (1074)	78.5	398	101	789.5	511.5
A _{OUT} (606)	57	361	66	389	211

I _{IN} (565)	38.5	303	81	347.5	212
I _{OUT} (1115)	97	456	86	831	510.5
G _{IN} (535)	46.5	292.5	51.5	366.5	190.5
G _{OUT} (1145)	89	466.5	115.5	812	532

Table 5: Number of Mentions associated with alters in different classes of the Relationship category, split by belongingness to each sector.

Sector (N)	boss	fam.par t	friend	friend.p rf	groups	mentee	mentor	peer
A _{IN} (1074)	428.5	181	84	238.5	219.5	80	227.5	419.5
A _{OUT} (606)	300.5	109	102	93.5	143	19.5	134.5	182
I _{IN} (565)	283	94.5	97.5	93.5	112.5	16.5	106	178.5
I _{OUT} (1115)	446	195.5	88.5	238.5	250	83	256	423
G _{IN} (535)	255	93.5	58.5	87	136.5	14.5	122	180.5
G _{OUT} (1145)	474	196.5	127.5	245	226	85	240	421

The chi-squared test is appropriate for determining if any networks grouped by sector belongingness are different based on the number of Mentions of the different classes of alter Stage and Relationship. Since chi-squared tests require mutually exclusive categorizations across the board, we ran three separate tests where each test compared a sector's IN group to its OUT group. In each case, results of these tests tell us the likelihood that the null hypothesis, that there is no difference between each sector's IN and OUT groups in terms of alter Mentions, is true. These results are shown in Table 6.

Table 6: Results of 6 chi-squared tests of independence for each of 2 alter categories and 3 sectors, based on each sector's IN/OUT groups.

Alter category	Sector	P-value	Chi-squared	Degrees of Freedom
Stage	Academia	< 0.0001****	65.3	4

Relationship	Industry	< 0.0001****	46.7	4
	Government	< 0.0001****	26.3	4
	Academia	< 0.0001****	67.8	7
	Industry	< 0.0001****	64.3	7
	Government	0.00015***	28.9	7

Based on common thresholds for p-values showing significance, the tests for all three sectors show significant differences in alter Mentions based on both Stage and Relationship. In order to determine exactly which factors are different, we ran 6 post-hoc tests for each alter category in all sectors, the results of which are shown in Tables 7 and 8.

Table 7: Results of a post-hoc test to determine which classes of alter Mentions in the Stage category contributed to low p-values in chi-squared tests of difference between those in and out of all three sectors. P-values and residuals (in parentheses) are reported for the IN groups.

Sector	undergrad	grad	postdoc	job	none
Academia	1.00 (-1.35)	< 0.0001**** (-7.28)	1.00 (-0.809)	0.010* (3.29)	< 0.0001**** (4.74)
Industry	1.00 (-1.20)	< 0.0001**** (4.60)	0.00014*** (4.34)	0.0058** (-3.44)	0.12 (-2.50)
Government	1.00 (0.596)	< 0.0001**** (4.49)	1.00 (-0.327)	1.00 (-0.839)	0.0020** (-3.72)

Table 8: Results of a post-hoc test to determine which classes of alter Mentions in the Relationship category contributed to low p-values in chi-squared tests of difference between those in and out of all three sectors. P-values and residuals (in parentheses) are reported for the IN groups.

Sector	boss	fam.par t	friend	friend.p rf	groups	mentee	mentor	peer
Academ ia	0.045* (-2.99)	1.00 (-0.371)	< 0.0001* *** (-5.34)	0.011* (3.38)	1.00 (-1.21)	0.0055* * (3.58)	1.00 (-0.238)	0.0049* * (3.61)
Industry	0.0029* *	1.00 (-0.214)	< 0.0001*	0.65 (-2.05)	1.00 (-0.912)	0.0057* *	1.00 (-1.67)	0.68 (-2.03)

	(3.75)		*** (5.77)			(-3.57)		
Government	0.73 (2.00)	1.00 (0.099)	1.00 (-0.161)	0.27 (-2.40)	0.22 (2.47)	0.0024* * (-3.79)	1.00 (0.748)	1.00 (-1.16)