\section{Discussion}

This chapter explores interdisciplinary collaboration and cumulative advantage through an in-depth analysis of a five-year grant application network using network visualizations, whole network metrics, and various \gls{ERGM} terms. The comprehensive analysis is designed to provide insights into the patterns, structures, and dynamics that characterize grant-proposing collaboration, with the ultimate goal of identifying opportunities for strategic enhancements to the network, thereby amplifying the impact and effectiveness of the \gls{GCs} initiative. The guiding hypotheses suggest a tendency towards cumulative advantage and short- or within-discipline collaborations. In other words, this thesis predicts that faculty members tend to collaborate with peers from their college and with scientific stars. Results indicate a preference for collaborations that do not span far across long-distance disciplinary boundaries and well-established experience collaborating on grant proposals results in more grant proposal collaborations. First, this discussion aims to unpack the foundational mechanisms influencing motivations for grant proposal collaboration before proceeding to discuss results on interdisciplinary collaborations and the equitable distribution of opportunities.

\subsection{Collaboration Motivation}

Motivations driving collaboration within the university's grant proposal network may be influenced by individual personalities or institutional structures such as workload policy. As LaRosa explained, ``Faculty can be corky, ego-driven, with a pinpoint of expertise. This makes it hard to allow someone else into your work and broaden your research. It's hard'' \citep[personal communication, September 25]{LaRosa2023}. The interviews and focus groups illuminated variations in workload policy, and support might result in researchers from different colleges collaborating on grant proposals at varying rates. Sociality, the `nodefactor' \gls{ERGM} term, underscores the propensity of colleges to engage in collaborative grant proposals.

With the College of Arts and Sciences serving as a reference point, it becomes evident that researchers in specific colleges, notably the College of Innovation and Design, exhibit a markedly higher inclination towards collaboration in grant applications. This finding aligns with Okraku et al. (2017) explanation that departmental policies and practices play a formative role in shaping the scientific community’s landscape, encompassing federal programs, funding opportunities, hiring practices, resource allocation, and graduate training.

The differential collaborative propensities observed across colleges underscore the inherent sociality within academic units, highlighting how specific colleges might be more actively seeking opportunities for collaborative grant proposals. This pursuit of collaboration is crucial for addressing the complex challenges that transcend the autonomy benefits of working alone. The findings from this analysis contribute to a nuanced understanding of how historical collaborative dynamics align with the university's strategic goals, emphasizing the importance of fostering a thriving community through enhanced research quality and scientific credibility \citep{BSUgoals2024}. Focus group participants propose solutions such as “Clear guidelines about time off and course buyouts that apply across campus” and “creating opportunity and space for the human connection” Moreover, the discussion on the need for tenure and promotion policy demonstrates the structural barriers to collaborative research. These restrictive policies often dictate faculty priorities and can inadvertently hinder the pursuit of innovative, collaborative projects.

Thus, the sociality of colleges, as determined by their propensity to co-propose, not only reflects their active engagement in the scientific community but also underscores the need for strategic policy adjustments to foster collaborative environments at \gls{Boise State}. Future research might investigate departments within a target college and that institutional structures might be preventing collaboration within the college and departments. While the sociality of colleges highlights the collaborative spirit within various colleges at \gls{Boise State}, the concept of cumulative advantage sheds light on the intricate dynamics of academic networks, exposing disparities that dictate the structure of these networks and their ability to broaden research opportunities.

\subsection{Cumulative Advantage}

Is there are inequality of opportunity to collaborate on grant proposals? The concept of cumulative advantage highlights the disparities in collaborative interactions and recognition within academic networks, serving as a crucial factor in the emergence of scientific stars and potentially challenging the objectives of the \gls{GCs} initiative to widen research opportunities (\citealp{Mali2012}; \citealp{Moody2004}. It suggests a hierarchical distribution of knowledge and resources across the academic landscape, raising questions about the equitable distribution of collaborative opportunities (\citealp{Vacca2015}; \citealp{BSUgoals2024}). Examining the degree distribution and Gini coefficient sheds light on these disparities, offering insights into the network's structural adaptations and the pivotal roles of specific individuals in directing collaboration patterns. Furthermore, analyses of the degree popularity term provide evidence of a move towards more inclusive and diverse collaboration patterns, as well as the importance of established relationships and social cohesion. Additionally, the exploration of differential homophily teases out patterns of preferential attachment, emphasizing the cycle of resource and recognition accumulation among established researchers and the pursuit of connections with scientific stars by less-established ones. The results highlight the importance of fostering a mentorship culture to mitigate the hierarchical distribution of expertise and promote a balanced collaboration landscape.

\subsubsection{Scientific Stars}

This thesis posits that most collaborating researchers have few co-proposers, and few have many. This unequal degree distribution suggests that there is an inequality of opportunity to collaborate on grant proposals. The analysis found a declining distribution of degree centrality. The Gini coefficient of this distribution was relatively high, indicating inequality. These results suggest that a smaller group of faculty members are involved in a larger share of co-proposers. This is concordant with \citet[p.~406]{Newman2001}, who found that few researchers have large numbers of co-authors, suggesting that individuals in authority gained joint authorship privilege due to their leadership role.

While this highlights the presence of inequality in collaboration opportunities, it is crucial to consider the underlying dynamics that may contribute to such disparities. A potential counterpoint to this observation is the notion that collaboration patterns are not solely dictated by existing inequalities but by the nature and requirements of the research itself. For instance, \citet{Newman2001} found that high-energy physics averaged nine authors per paper, whereas the study's average was about three. This suggests that some areas of research tend to have more collaborators. This does not undermine the importance of fostering inclusively by fostering collaborations among peripheral and code nodes. Understanding nuances between disciplines is essential when developing effective initiatives that encourage broader participation.

The network metrics highlight 2020 as the most connected network. The smaller size and fewer collaborative proposals compared to previous years might reflect an adaptive shift in response to the challenges posed by the COVID-19 pandemic. The Gini coefficient suggests that this year contained the highest concentration level of cumulative advantage. The observed shift towards a more connected network in 2020, with a reduction in size and the number of collaborative proposals, prompts a deeper inquiry. Specifically, it raises critical questions about the identity of the nodes that exited the network and whether the unique challenges of the COVID-19 pandemic disproportionately affected less prominent researchers' ability to engage in co-proposing activities. Although this analysis did not delve into these aspects, such questions underscore the importance of further research to understand the attributes influencing co-proposal participation, especially the potential impact on lower-frequency proposers.

\subsubsection{Degree Popularity}

The positive estimate of the \gls{GWD} term signifies edge dispersion across the network \citep{Levy2016}, suggesting a more equitable distribution of ties, where connections are spread out rather than centralized around specific scientific stars. This finding is unexpected as it contradicts the finding from the degree distribution and the Gini coefficient. The GWD interpretation, while indicative of dispersion, lacks a baseline or threshold against which to gauge the degree of dispersion or centralization effectively \citep[p.~83-85]{Harris2014}. The positive value underscores a tendency towards dispersed connections, yet without additional context or comparative metrics, it’s challenging to ascertain the extent of dispersion or its significance within the network’s overall structure \citep[p.~83-85]{Harris2014}. This scenario underscores the need for caution in drawing conclusions about network dynamics solely based on the sign and magnitude of GWD estimates without comparative analysis or benchmarks.

The \gls{ERGM} models the network structure, such as the degree of popularity, while controlling for individual attributes, such as differential homophily. Differential homophily also considers cumulative advantage within the network. The estimate of the \gls{GWD} may provide a different conclusion when not controlling for this attribute.

\subsubsection{Selective Mixing}

Selective mixing examines whether eminent scholars preferentially co-propose among themselves or if the structure of the grant proposal network reveals a pattern of preferential attachment wherein nascent researchers aspire to collaborate with these prominent figures. The analysis employs a node attribute delineated by quartiles, with the first quartile representing the lowest echelon of proposers and the fourth quartile the apex. Applying differential homophily (`nodemix') to the quartile attribute rigorously dissects the prevailing tendencies in selecting collaboration partners.

In analyzing the dynamics of collaborative behavior within the grant proposal network, the investigation delineates a reference group—comprising collaborations between members of the lowest and low quartiles—to contextualize the observed patterns of partnership formation. The analysis reveals a pronounced manifestation of cumulative advantage, particularly salient among the upper echelons of proposal activity yet spanning the continuum from lower to higher quartiles. This elucidates a dual trend: established researchers predominantly engage with contemporaries reflecting similar levels of proposal activity, whereas emerging researchers prefer co-proposing with highly esteemed scholars, thus perpetuating a cycle of resource consolidation and accolade accumulation.

Such a scenario aligns with the principles of preferential attachment described by \citet{Goodreau2009}, \citet{Mali2012}, and \citet{Vacca2015} and is reflected in the specialized interaction patterns identified by \citet{Lane2020} in academic settings. The disparity between the valuation and the pursuit of mentorship, as pointed out by \citet{Norton2017}, indicates that while mentorship is esteemed for fostering collaboration, it is less frequently an impetus among star scientists. This disconnect presents a compelling case for institutional policies to foster a mentorship culture that could help mitigate the hierarchical distribution of expertise and promote a more balanced collaboration landscape. \citet{Vacca2015} explains that the lack of familiarity with less prominent researchers drives emerging scholars to seek collaborations with scientific stars, recommending network treatments to introduce peripheral collaborators.

Future research could delve into the dynamics surrounding grant proposals involving collaborations among scientific stars to assess whether their participation augments the probability of securing funding. This inquiry would discern whether the enhanced success rate of these proposals is attributable to the sheer volume of applications submitted by these eminent figures or if their involvement intrinsically enhances the proposal's likelihood of being awarded. Specifically, it would be instructive to examine whether the presence of scientific stars acts as a magnet for resources due to their prolific proposal submissions or if their reputational capital and expertise fundamentally increase the proposal’s merit and appeal to funding bodies. Such investigations could illuminate the mechanisms through which scientific stars contribute to or benefit from the grant allocation process, thereby providing insights into the strategic composition of research teams and the allocation of research funds.

Examining the network's selective mixing, inequality of scientific stars, and degree popularity unveils grant-proposing disparities. The degree distribution of its application with the Gini coefficient showed an inequality of co-collaborators. An equitable distribution of ties, as indicated by the \gls{GWD} metric, may have been affected by controlling for cumulative advantage through selective mixing. Furthermore, the patterns identified through this differential homophily articulate the dynamics of cumulative advantage, where established researchers engage more with their contemporaries while emerging scholars navigate toward renowned scientific figures. This trend calls for policies to foster a more balanced and mentorship-focused collaboration landscape across campus.

Building on insights from network dynamics and collaborative patterns, the following section delves into interdisciplinary collaboration through network visualizations and Uniform Homophily.

\subsection{Interdisciplinary}

How do relationships and network structures contribute to developing interdisciplinary scientific work? The pursuit of enhanced interdisciplinary collaborations represents a foundational objective of the \gls{GCs} initiative, underpinned by the hypothesis that faculty members are predisposed to intra-college collaborations, thereby indicating a trend towards discipline-centric or short-distance interdisciplinary engagements. This analysis leverages network visualizations to elucidate the patterns of college clustering within the grant proposal network. Individuals with high betweenness are thought to be related to crossing disciplines \citep{Leydesdorff2019}. \gls{ERGM} terms that investigate transitivity and uniform homophily statistically evaluate a tendency of faculty to engage in co-proposal activities with their colleagues.

\subsubsection{Network Visualizations}

The network visualizations provide a vivid depiction of the collaborative landscape across different colleges within the institution, indicating varied levels of interdisciplinary engagement. The visual clustering of the College of Education affiliation suggests a strong potential for interdisciplinary collaboration, likely driven by overlapping research interests or goals. In contrast, the College of Engineering's central position underscores its pivotal role in fostering collaborative ventures, acting as a hub for interdisciplinary projects.

The peripheral position of the health sciences cluster hints at a more discipline-focused collaboration pattern, though with connections to the broader network, suggesting occasional interdisciplinary engagement. Meanwhile, the dual clustering of the College of Arts and Sciences nodes points to its versatility in serving as a connective tissue across various fields, especially in linking with the College of Engineering. This distribution and interaction of clusters underscore the dynamic interplay between insular disciplinary work and cross-disciplinary collaborations, highlighting areas of strong interdisciplinary synergy and potential gaps where further integration could be encouraged.

\subsubsection{Brokering Across Disciplines}

The distribution of Betweenness centrality in the historical grant proposal network suggests that, while the majority of faculty members are not frequently positioned as intermediaries in the network, there exists a small subset of individuals who hold considerable broker roles. The ideal scenario posits a network replete of few high-Betweenness brokers; instead, most faculty members are directly connected to the core network \textbackslash{}citep[p.\~236]\{Mali2012\}. \citet{Leydesdorff2019} determined the Gini coefficient from the distribution of betweenness to indicate the `balance' of interdisciplinary collaborations. Further research might investigate whether these betweenness outliers are indeed interdisciplinary collaborators.

\subsubsection{Transitivity}

Knowledge and resources are often exchanged within well-defined local triangles, indicating disciplinary research or thematic communities \citep[p.~236]{Mali2012}. The \textbackslash{}gls\{GWESP\} results signify a network where faculty members are substantially more inclined to co-propose with others who share mutual collaborators, reflecting a community that values established connections and potentially operates within well-defined disciplinary or thematic triangles. The statistically significant positive coefficient implies that the likelihood of tie formation between two individuals is higher than expected by chance, given all other factors are held constant. The significant \textbackslash{}gls\{GWESP\} term underscores the importance of social cohesion in the grant proposal process, suggesting that the network's structure is conducive to collaboration and knowledge exchange within established triangles. These results suggest that network treatments, as described by \citet{Vacca2015}, identify unconnected researcher dyads and triads and then assemble interdisciplinary research teams as a method of increasing Boise State's network connectivity, especially those who are less connected.

\subsubsection{Uniform Homophily}

Uniform homophily tests the hypothesis that researchers tend to collaborate with peers from their college. The analysis of the `nodematch' \gls{ERGM} terms uncovers a pronounced trend towards uniform homophily, highlighting a strong inclination among faculty members to collaborate within their colleges. This observed preference for shorter-distance interdisciplinary collaborations is evidenced by significant positive coefficients across all college categories. While intradisciplinary work continues to be a cornerstone of knowledge production within specific domains, the push towards interdisciplinary research is increasingly recognized as crucial for addressing complex societal challenges (\citealp{Huang2023}; \citealp{Lyall2013funding}). This transition underscores the imperative for academic institutions to foster environments conducive to interdisciplinary engagement, as emphasized by \citet[personal communication, September 25]{LaRosa2023} in the context of \gls{Boise State}'s strategic direction towards integrated research efforts.

However, the current state of collaboration, characterized by a marked preference for within-college partnerships, suggests potential barriers to the deep integration of disciplines advocated by funding bodies and institutional leadership. Results could reflect comfort in shared scholarly language, ease of communication, or possibly administrative and structural incentives within colleges that promote such shorter-distance collaborations, as the qualitative analysis suggested. Faculty discussions repeatedly emphasize the necessity of physical and strategic infrastructures that promote collaborative research. Statements like ``creating opportunity and space for the human connection.'' Network treatment, such as the IRA discussed in the following chapter, aids in creating this space for select research teams.

Future research might target investigations of departments within specific colleges. The significant homophily within the College of Business \& Economics, for instance, indicates a robust internal collaboration network but also hints at missed opportunities for cross-disciplinary research. The challenge, therefore, lies in bridging the gap between the existing practice of college-centric collaborations and the aspirational model of authentic, co-created interdisciplinary research that spans beyond superficial integration. This gap represents not only a methodological limitation but also a strategic one, as the success of interdisciplinary ventures is increasingly tied to their ability to synergize diverse disciplinary perspectives from the ground up. Addressing this challenge requires deliberate institutional strategies aimed at lowering the barriers to interdisciplinary research, enhancing the appeal of longer-distance interdisciplinary collaborations, and aligning with the evolving priorities of research funding landscapes.

In synthesizing the findings from the interdisciplinary evaluation, it becomes clear that existing patterns of uniform homophily and the specific clustering, as seen within network visualizations and transitivity results, indicate a preference for within-college collaborations and forming connections among members with shared collaborators. Those with high betweenness may engage in more cross-disciplinary co-proposals. To transcend these barriers and fully realize the initiative's interdisciplinary objectives, \gls{Boise State} must implement strategic, institution-wide measures to lower the hurdles to cross-disciplinary research, incentivize diverse scholarly cooperation, and nurture a culture that champions the integration of varied disciplinary insights. Such an inclusive and strategically focused approach to collaboration promises to not only augment the impact and caliber of the university's research endeavors but also ensure alignment with the overarching aspirations of the \gls{GCs} initiative, thereby cultivating a more dynamic and society-responsive research environment.

\subsection{Limitations and Further Research}

The statistical analysis in this thesis is a cross-sectional study analyzing only the cumulative five-year network. Therefore, there is no temporal relationship. Additionally, it is assumed that all faculty who proposed for a grant could have proposed each year. It is unknown which faculty entered or exited \gls{Boise State} during this time. Despite this limitation, this research provides a snapshot view of \gls{Boise State}'s collaborative grant proposal network. The combined network provides a comprehensive view of general trends and aids in highlighting potential areas of research that might have been more challenging to identify in a more involved yearly analysis.

There is an opportunity to extend this pilot investigation longitudinally. Leveraging these \gls{ERGM} methodologies will not only refine the temporal analysis but also enhance the exploration with the newly available data from 2021 to 2023. This extended analysis will not only provide a longitudinal perspective on the influence of the \gls{GCs} initiative but also allow for exploring new trends, challenges, and opportunities for enhancing interdisciplinary collaboration.

Building on the methodologies outlined in this thesis, future research may consider methods described by \citet{Sciabolazza2017}, which offer deeper insights into the shifts in disciplinary co-proposals over time. \citet{Sciabolazza2017} detail methods for longitudinal network comparison and clustering analysis to examine the evolution of research communities and interdisciplinary collaborations within a university setting over three years. They introduce a method that employs community-detection algorithms to identify consistent collaborative subgroups and utilize \gls{ERGM}s to explore the factors driving interdisciplinary collaborations \citep{Sciabolazza2017}. By detecting clusters in yearly networks and identifying researchers who consistently participate in the same collaborative groups, this method allows for examining shared attributes, offering insights into the dynamics in communities \citep[p.~2-3,214]{Borgatti2022}.

Additional node attributes could improve the \gls{ERGM} model. Attending team science training could be an attribute that aids in determining whether the \gls{CRCA}'s training alters collaborative practices. The \gls{CRCA} hosts a team science training each semester for any facility member to attend \citep[personal communication, September 25]{LaRosa2023}. The team science training roster is available and could underscore differences in faculty success, if any. The results would aid in understanding whether the training investments increase teaming.

Future research endeavors should explore partnerships with preeminent scholars to evaluate the likelihood of funding acquisition. This investigation should disentangle whether there is an observed higher success rate of such proposals stemming predominantly from the voluminous nature of submissions by these distinguished individuals or whether their direct participation substantively elevates the proposal's probability of success. A focal area of this research would be to ascertain if the allure of these scientific luminaries, through their extensive submission activities, serves as a beacon attracting resources or if, conversely, their esteemed reputational standing and specialized expertise inherently bolster the proposal's quality and attractiveness to funding agencies. Through such analytical endeavors, the research could shed light on the selection of research team leads and core members, aiming for grant proposal success while also expanding opportunities across campus.

Subsequent studies could also explore the hypothesis posited by \citet{Leydesdorff2019} regarding the role of researchers with high betweenness centrality as pivotal agents of interdisciplinary collaboration. This investigation would aim to validate the assumption that individuals occupying these central positions within the network serve as vital bridges between distinct academic disciplines. Should this hypothesis be corroborated, such insights could prove invaluable to \gls{Boise State} in its strategic efforts to bolster interdisciplinary research endeavors. This approach would not only enhance the university's research capacity but also significantly contribute to the science of team science and its utilization of SNA. Ultimately, by expanding the application of SNA principles to the study of interdisciplinary collaboration, this line of inquiry could pave the way for new methodologies and analytical tools designed to optimize collaborative networks within and beyond academic institutions.

Building on the observed sociability of various colleges, a more focused investigation into the sociability of targeted departments could reveal in-depth insights into motivations for collaborating. This knowledge could aid in narrowing down institutional structures that inhibit a department's sociability. Future research could focus on targeted college(s) deemed pertinent to promoting collaboration and targeted network treatments, teasing apart the sociability of various departments within the college.

While this study meticulously charts the terrain of collaborative grant proposal applications among \gls{Boise State} faculty, it operates with a notable limitation: the exclusion of collaborative endeavors beyond the institution, specifically those involving co-proposals with researchers from other institutions. However, this constraint, though significant, does not diminish the value of the study's findings. By focusing exclusively on intra-institutional collaborations, the research offers a concentrated view of the internal dynamics and cultural shifts within \gls{Boise State}, providing a detailed understanding of how the \gls{GCs} initiatives have sculpted the landscape of grant proposal networks within the university. This internal lens is crucial for assessing the initiatives' effectiveness and for identifying areas of strength and opportunities for growth within the institution's collaborative culture.

In conclusion, the \gls{CUPID} study's in-depth analysis of \gls{Boise State}'s grant proposal network from 2016 to 2020 provides a solid foundation for future research aimed at a year-by-year exploration using \gls{ERGM} and extending the dataset to include the years 2021 to 2023, future studies are poised to uncover the nuanced evolution of these networks. Integrating new node attributes, such as attendance at team science training, offers an innovative angle to enhance our understanding of the factors influencing successful interdisciplinary research. Also, the methodologies of \citet{Sciabolazza2017} represent a significant step towards identifying the patterns, shifts, and impacts of interdisciplinary efforts within the academic landscape statistically.

The adoption of longitudinal network comparison and clustering analysis methodologies not only promises to refine our temporal analysis but also sets the stage for a more comprehensive examination of the changing trends, challenges, and opportunities for enhancing interdisciplinary collaboration. Furthermore, a targeted investigation into the interdisciplinary interactions among specific colleges and the analysis of awarded grant networks could reveal more in-depth insights into the mechanisms of successful collaboration. Such focused research endeavors, coupled with exploring newly available data and innovative node attributes, will significantly advance our understanding of academic collaboration dynamics, ultimately fostering a more interconnected and interdisciplinary research environment at \gls{Boise State}.

\section{Conclusion}

The analysis presented in Chapter 4 examines the dynamics of grant-proposing collaboration at \gls{Boise State}, delving into which colleges motivate collaboration, the presence of inherent disparities among scholars, and the pursuit of interdisciplinary research within the grant proposal network. By analyzing sociality within colleges, the study highlights the critical role of supportive institutional frameworks in fostering collaborative dynamics. Examining cumulative advantage, facilitated by the degree distribution, Gini coefficient, degree popularity, and selective mixing, uncovers equitable distribution and a tendency towards forming established connections calls for mentorship-driven network treatments. Furthermore, the focus on interdisciplinary collaborations through network visualizations, brokerage, transitivity, and homophily illustrates a prevailing preference for discipline-centric partnerships, pointing to potential obstacles in achieving broad cross-disciplinary research. To fully realize the objectives of the \gls{GCs} initiative, the \gls{CRCA} can implement strategic interventions that reduce barriers to interdisciplinary research, encourage diverse scholarly interactions, and cultivate a culture that embraces the integration of varied disciplinary insights. These efforts are poised to not only enhance the quality and impact of the university's research but also align its pursuits with the dynamic societal needs and the ambitious goals of the \gls{GCs} initiative.