EXPLORING EMERGENT NETWORKS ACROSS UNDERGRADUATE STEM EDUCATION REFORM NETWORKS: THE STEM REFORM HYDRA

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ABSTRACT

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Over the last 30 years, formally structured inter-organizational networks have risen in popularity as a strategy for addressing large-scale and complex societal problems. Within higher education, many inter-organizational networks organize to reform undergraduate science, technology, engineering, and mathematics (STEM) education to promote the quantity, quality, and diversity of STEM graduates. While formal networks in undergraduate STEM education reform play a role in officially linking higher education institutions, literature points to the existence of an unstructured informal network emerging from the connections established by connecting organization in reform. This sequential quan-Qual mixed methods study highlights a small, informal inter-organizational network of leaders in formal STEM networks. Implications underscore emergent network roles in the facilitation, maintenance, and sustainability of the formal networks, and larger impacts of this group in undergraduate STEM education reform efforts. Broader impacts speak to a greater role of informal networks in innovation, organizational sense-making, and systemic change, and invites critical constituents in reform efforts to utilize emergent networks more intentionally.

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KEY TO ABBREVIATIONS

ASCN: Accelerating Systemic Change Network

AAC&U: Association of American Colleges and Universities

AAU: Association of American Universities

APLU: Association of Public Land-Grant Universities

BOSE: Board on Science Education

CoT: Communities of Transformation

DBER: Discipline-Based Education Reform

Emergent Network: Emergent Collaborative Inter-Organizational Network

FIPSE: Fund for the Improvement of Postsecondary Education

HHMI: Howard Hughes Medical Institute

Network: Collaborative Inter-Organizational Network

Formal Network: Formal Collaborative Inter-Organizational Network

NASEM: National Academies Roundtable for Systemic Change in Undergraduate STEM Education Reform

NSF: National Science Foundation

PLC: Professional Learning Communities

QAP: Quadratic Assignments Procedure

Sloan: Alfred P. Sloan Foundation

SOTL: Scholarship on Teaching and Learning

STEM: Science, Technology, Engineering, and Mathematics

USER: Undergraduate Science, Technology, Engineering, and Mathematics Education Reform

Chapter 1: Introduction

In the last 40 years, higher education institutions have become increasingly beset by complex and systemic challenges. Although higher education institutions have always mirrored societal problems (Thelin, 2011), the last four decades saw growing disillusionment with higher education as a public good (Marginson, 2011; Singh-Kagisano, 2001; Tilak, 2008). Dramatic increases in public scrutiny through reduced appropriations (Kezar, Chambers, & Burkhardt, 2015), greater accountability (Friedman, 2007; Hillman, Tandberg, & Gross, 2014; Tandberg & Hillman, 2014), and increased perceptions of education as a private investment have progressively plagued post-secondary education since the 1990s. Compounding these public concerns were increasing distrust and political polarization of institutions and a "crisis of confidence" in the ability of universities to serve the public interest, with one Gallup poll finding a decrease in higher education confidence by almost 10% between 2015 and 2018 (Jones, 2018). Each of these challenges required higher education institutions to respond with organizational changes (Thelin, 2011), increases in tuition (Tandberg & Hillman, 2014), and even public relations campaigns to "win back the hearts" of the public (Jones, 2018, para 8).

Countless authors have identified the societal problems plaguing U.S. higher education as "wicked problems" (Hutchings & Quinney, 2015; Krause, 2012; Ramley, 2014; Watson, 2000Rittel & Weber, 1973). Defined as systemic, complex, and unstructured problems, "wicked problems" are cross-sector challenges to which single organizations are poorly suited to address (Rittel & Weber, 1978; Weber & Khademian, 2008). Mentioned frequently with research on climate change (Hulme, 2009), U.S. healthcare reform (Council of Accountable Physician Practices, n.d.), public health (Peterson, 2016), and higher education (Armstrong, 2017; Krause, 2012; Masten, 2016; Ramley, 2014), wicked problems require expertise from disparate fields to

cooperatively construct feasible ways to address the complexities inherent in society's complex and often implicit challenges (Conteh, 2013; Isett et al., 2011; Rittel and Weber, 1973). This research explores one strategy employed by colleges and universities in higher education to address the wicked problem of undergraduate science, technology, engineering, and mathematics (STEM) education reform.

Inter-Organizational Networks

In attending to wicked problems, institutions in varying domains rely heavily on the role of inter-organizational networks (networks). Although there is considerable discussion about definitions, these networks are generally defined as a cross-sectional group of individuals who link organizations through their relationships and share information regarding a common problem (Bryson, Crosby, & Stone, 2006; Provan, Fish, & Syndow, 2007; Weber & Khademian, 2008). Networks are a response to market failures in the face of complexity, de-legitimization, and lack of innovation posed by wicked problems (Isett et al., 2011). Networks are often seen by institutions as viable alternatives when both bureaucracies and markets fail (McGuire 2006; O'Toole & Meier, 2004).

The benefits of networks are commonly cited as cross-fertilization among experts, organizations, and domains (Berry et al., 2004). Bringing together different perspectives provides the platform to collaboratively address the problems at-hand. Several authors highlighted the benefits of networks as access to shared resources (Bryson et al., 2006; Huxam & Vangen, 2005), shared risk (Casebeer, Popp, & Scott, 2009), advocacy (Provan & Lemaire, 2012), increased organizational learning capacity (Bryson et al., 2009; Kenis & Provan, 2009; Weber & Khademian, 2008), innovation (Provan & Lemaire, 2012; Turrini, Cristofoli, Frosni & Nasi, 2010), and nimbleness relative to traditional organizations (Isett et al., 2011; Provan &

Lemaire, 2012). More importantly, the involvement of multiple actors (both individual and organizational) allows for "synchronization" —or a logical and organized approach—to addressing the wicked problems (Popp et al., 2014, p. 200). Similarly, networks provide a clearer avenue for beneficial involvement from actors who may not be directly affected by the complex problems.

Although inter-organizational networks are defined as a cross-sectional group of individuals linking organizations through relationships, there is considerable variation in how networks are applied in the literature. Authors bifurcate their nature among the roles of governance, structures, formation, and accountability into two forms: formal networks (also referred to as mandated networks) and emergent networks (commonly referred to as *informal networks*) (Isett, et al., 2011; Popp et al., 2014). Although the degree to which collaboration can be *formal* is speculative (Chisholm, 1998; Provan & Lemaire, 2012), formal networks are "consciously created with some sort of binding agreement for participation" (Isett et al., 2011). These organizations typically have some form of charter, commission or bylaws, and financial resources dedicated to their common goals (McPherson, Popp, & Lindstrom, 2006). Formal networks are often commissioned by governments or other societal institutions that encourage participation through varying incentives (Popp et al., 2014). Interestingly, Carboni and Milward (2012) argued formal networks generally lack organization power or legitimacy and are not attuned to systemic problems their mandating body created them to address. These formal networks exist as a mechanism for institutions to "off-load" complex and dense organizational problems with little support other than a charge (Network Leadership Symposium, 2013, p. 7). Concerns with formal networks also call into question the efficacy of artificial relationships whose flourishment are simply left up to chance (Popp et al., 2014).

Compared to formal networks, emergent networks are complex groupings of "organically derived" relationships which occur through an out-growth of organizational contingencies (Isett et al., 2011, p. 162). In absence of a charter, these networks are based in voluntary social relationships and require considerable exchanges to establish common understandings of concepts (Rodriguez, Langley, Beland, & Denis, 2007). Provan and Lemaire (2012) argued those criteria are necessary, but not sufficient conditions, for defining emergent networks. They contended 1) homophily in interest, 2) physical proximity, 3) heterophily in approach, 4) prior relationships, 5) legitimacy in the market, and 6) market-dependence management as six critical components of emergent networks (p. 641). Regardless of how their characteristics are subdivided, emergent networks are pervasive and often embedded within formal networks as a grouping of individuals who work "behind the scenes" to ensure work is accomplished (Rodriguez et al., 2007, p. 152). These networks contribute to creating culture, shared meaning, and *the network way of working* which simply implies a level of collaboration that differentiates itself from traditional organizational work and engages participants in trusting, reciprocal relations.

The Wicked Problem: Undergraduate STEM Education Reform

Science, technology, engineering, and mathematics (STEM) curricular reform is among many of the wicked problems facing contemporary higher education. Increasingly, high profile organizations are calling to increase the quantity, diversity, and quality of undergraduate STEM education in the United States (ASEE, 2009; NAE, 2004; NSF, 1996; PCAST, 2012). With concerns of global competitiveness and meeting future labor markets, government and industry leaders have pushed for business practices like greater institutional accountability, performance-based funding, or other outcomes-based approaches (Friedman, 2007).

Despite the demands for undergraduate STEM education reform (USER), systemic change in higher education has proven difficult, if not *wicked* (AAU, 2018; Austin, 2011; Fairweather, 2009; Kezar & Gehrke, 2015). Many authors (AAU, 2018; Austin, 2011; Fairweather, 2009; Kezar, Gehrke, & Bernstein-Sierra, 2018) lamented the challenges of idiosyncratic and complex systems nested within colleges and universities. For example, most change initiatives have not been able to scale up teaching innovations due to (1) a strong focus on individual classroom teaching practice (Dancy & Henderson, 2008; Fairweather, 2009; Kezar, 2011a); (2) the lack of attention to additional variables that could affect the adoption of teaching practices (Austin, 2011; Fairweather, 2009); and (3) the inability of research communities that study undergraduate STEM instruction to communicate and coordinate efforts (Beach, Henderson, & Finkelstein, 2012). Indeed, individual higher education institutions must contend with coordinating reform among different disciplines within their organization; incentivizing faculty to adopt reform efforts, and successfully recruiting and retaining students within their STEM programs. Each of these complex reform tasks must be completed within a context which does not reward reform. The systemic nature of USER, nevertheless, means a single university successfully reforming undergraduate STEM education on their campus will not successfully resolve undergraduate STEM education at all institutions.

Shortcomings in systemic adoption of USER led many to push for greater collaborative approaches that emphasize interconnectivity between colleges and universities (AAU, 2014; Austin, 2011; Coalition for Reform of Undergraduate STEM Education, 2014; Elrod & Kezar, 2015; Henderson, Beach, and Finkelstein, 2011). One of the more popular responses to addressing USER concerns has been the development and use of inter-organizational networks to link institutions of higher education (AAU, 2018; AAU, 2015b; Bryson, Crosby, & Stone, 2006).

Indeed, various funding agencies (both private and public) have contributed close to a billion dollars to establish inter-organizational networks addressing change in STEM education (Kezar & Gehrke, 2015). These networks encourage faculty and administrators to engage in large-scale reform efforts, learn pedagogies, develop new skills, and share ideas across institutional barriers.

Over the last 30 years, dozens of networks have begun operating in USER. Each network has different missions, memberships, governance structures, and each targets a different aspect of the "wicked problem" of USER. Some focus on cultural or structural concerns within member institutions, while others focus on promoting better pedagogy (Fairweather, 2009; Kezar & Gehrke, 2016). Despite the heavy investment of resources, relatively little is available on networks or how they operate.

Problem Statement and Research Questions

Undergraduate STEM education reform is a complex, systemic, and wicked problem plaguing higher education improvement. Institutional collaborations through formal networks are one of the most pervasive strategies employed by institutions to combat the systemic nature of USER. Most research on inter-organizational networks comes from public administration and public health literature bases, with only a few authors taking on the mantle in higher education. Indeed, scholars across education, sociology, public administration, and anthropology all name the increased use of inter-organizational networks to address complex problems, and lament their scholarship considerably lags networks' deployment and use (Isett et al., 2011). "Networks have assumed a place of prominence in the literature on public structures, gradually nudging bureaucracies and markets as the foremost means to organize to address complex problems, share resources, and achieve collective goals" (Weber & Khademian, 2008, p. 334). As such,

"many networks have moved ahead without the benefit of a well understood and easily available research base" (Popp et al., 2014, p. 16).

Although some studies are beginning to emerge on the role and efficacy of formal networks in USER (Hill, 2016; Kezar, 2014; Kezar & Gehrke, 2016) , the existence and role of emergent networks is relatively unknown. Given the necessity of institutional collaborations in addressing "Wicked Problems," (Rittel & Weber, 1978), more empirical research on emergent networks will better inform funding organizations, formal networks administrators, and universities to collaborate more thoughtfully. With this imperative, I posed the following research questions and sub-questions to further explore the presence of an emergent network across formal networks in USER.

1. How do formal and informal leaders across formal networks in USER serve as an emergent network?
    1a). How interconnected are leaders across formal networks?
    1b). How do leaders engage in knowledge diffusion regarding their networks?
    1c). How do leaders engage in network learning?
2. How does this emergent network affect USER formal networks?

The first research question seeks to understand if an emergent network exists in USER. Each sub-question following the first question draws from existing public health and business literature on the structure, functions, and roles of emergent networks. Question (1a) enquires into the social structure and connectivity of leaders in the space. Unlike their formalized counterparts, emergent networks do not have an organizational chart, bylaws, or charter. Instead, these amorphous groups rely on relationships or acquaintances. If members do not know one another, there is little chance they will engage in emergent network behavior. Concepts such as power and trust are linked to the sharing of organizational problems (Katz and Tushman, 1979) making it unlikely for an emergent network to exist among complete strangers. Although social

connectivity is foundational to establishing the existence of an emergent network, it is insufficient in determining how the leaders may serve as an inter-organizational conduit. Questions (1b) and (1c) ask more specifically about the functions of emergent networks. The former poses a question to understand both how knowledge is shared among the formal USER networks and how leaders qualify network *knowledge* in the space. The latter (1c) probes how the collection of leaders engage in network learning across their affiliations. Aspects of socialization, consensus, and coalition building are all inherent within the question. Finally question 2 begins to investigate a more tangible impact of the emergent network in USER. These may be new bylaws, or structures to aid formal networks, or new opportunities for formal networks to utilize.

Dissertation Organization and Conclusion

This chapter discussed the increased reliance on inter-organizational networks by different social institutions as a result of "wicked problems" (Rittel & Weber, 1973). Specifically, wicked problems in higher education's ability to reform undergraduate STEM education were highlighted as an impetus for the explosion of various networks in higher education. The surge and subsequent scaling of these networks consequently requires the use of more tacit emergent networks to build capacity. The second chapter explores the literature related to inter-organizational networks in education, public policy, business, and sociology. With the intention of outlining the existing research on emergent network, the literature review highlights the forms of formal (formal) networks operating in the USER space, and explains scholarship on emergent network functions, structures, and governance.

Following the literature review, the third chapter outlines the research design, research paradigm, methods, data management, and ethical considerations accompanying the inquiry.

Given emergent networks are often latent or imbedded with other social relationships, this study employed a sequential quan-Qual mixed methods research design to examine the nuances of those networks. First participants were surveyed to draw socio-metric data about the relationships of the participants. Then, some participants were interviewed about their experiences with others in the study. The fourth and fifth chapters detail the findings from both of those methods respectively, and the sixth integrates the findings from both previous strands. The final chapter concludes by directly addressing each of the research questions posed in this introduction with evidence garnered through the research.

Chapter 2: Literature Review

Despite wide-spread use of formal networks in undergraduate STEM education reform (USER), there is little investigation into how these organizations impact one another. Indeed, most research targets how formal networks advance their missions and affect their affiliated higher education institutions (AAU, 2014a; AAU, 2018; Gehrke & Kezar, 2016; Henderson, Beach, & Finkelstein, 2011; Hill, 2016). Whereas the previous chapter situated the rationale for creating various collaborative inter-organizational networks, this literature review aims to further contextualize formal networks and delve deeper into emergent network functions, structures, and roles. Drawing from empirical research in public administration, education, and sociology, I argue for the conceptual existence of an emergent network built through relationships and established across formal networks in the USER space. These relationships, moreover, serve USER goals through the benefits attributed to emergent networks through the literature. The overview begins with (1) a brief discussion of different formal networks operating in USER, and (2) the impetus for formal networks in creating (in-part) emergent networks, before (3) summarizing research on the functions, leadership, structures and benefits of emergent networks in advancing organizational change.

Formal Collaborative Networks in Undergraduate STEM Education Reform

For years scholars argued for USER efforts to be undertaken by faculty networks, professional learning communities, or other inter-organizational conglomerates. These various groups relied on their collective knowledge base and positional power to build consensus and inspire change in undergraduate STEM education reform. Indeed, many scholars have called for the use of collectivist movements to leverage systemic change in higher education (Austin, 2011; Fairweather, 2009; Kezar; 2011). As stated, these calls were answered by individuals and

organizations interested in improving practices in higher education. The rise and study of formal networks in USER is critical in similarly understanding the rise of emergent networks, as formal networks provide the forum for the relationship-building of otherwise disparate actors. This relationship-building created the potential rise of emergent networks. The following sections briefly outlines various formal network forms operating in USER.

Drawing from previous literature on networks, communities of practice, and other communal interest groups, Kezar and Gehrke (2015) introduced "community of transformation" (CoT) as a distributed group of individuals in education who employ a targeted philosophy to create new practices in undergraduate STEM education (p. 20). Kezar and Gehrke (2015) stressed the importance of the driving philosophy, or "coalescing feature to drive innovation" (p.18), as a guiding factor in the work of CoTs. They stated, "philosophies play an important role to these communities because the practices they espouse…challenge the status quo" (Kezar & Gehrke, 2015, p. 19). CoTs are situated to deliver information to institutions of higher education through affiliated faculty and are typically composed of members who share interests in reform (i.e., pedagogy, faculty incentive structures, multiculturalism, etc.). Communities of transformation are situated outside the boundaries of colleges or universities. Given this independence CoTs rely on members to share resources, including STEM-related knowledge, inside and outside the network (Kezar & Gehrke, 2015).

Since CoT's naming, Kezar, Gehrke, and Bernstein-Sierra (2018) expanded the communities of transformation definition to include tenants of Mezirow's transformational learning theory (1991), arguing the CoT's philosophies push members to reflect on their individual professional development. Similarly, authors found CoTs' driving philosophies to be a strong uniting factor in their formation and functioning (Kezar & Gehrke, 2017). Although this

written philosophy remained unchanged, it was continually re-interpreted to establish consensus when new members were added. This process of consensus building drove stronger personal relationships and established more positive and sustainable collaborative relationships (Gehrke & Kezar, 2016; Kezar, Gehrke, & Bernstein-Sierra, 2018).

Similar to communities of transformation, professional learning communities (PLCs) are another network-driven initiative commonly cited in the literature as driving undergraduate STEM education reform. PLCs stress the importance of individual professional capacity-building through association with others in similar organizational positions (Astuto, Clark, Read, McGree & Fernandez, 1993). Louis, Kruse, and Bryk (1995) emphasized the importance of members' structural equivalence as a defining feature of a PLC's community. They indicated similar positions facilitated a greater capacity for knowledge diffusion because individuals did not need to use time understanding other roles at their home institutions. Beyond members' structural equivalence as a precursor for involvement, PLCs share many traits with CoTs. Those participating in a PLC often have 1) a shared value or vision for their profession, 2) a sense of collective responsibility, 3) inclination to collaborate, and 4) a promotion for learning (Stoll, McMahon, & Thomas, 2006). In this regard, they resemble CoTs by appealing to a specific community, domain, and practice, but are generally more hierarchically structured and member-exclusive when compared to other formal networks (DuFour, DuFour, & Eakers, 2008; Huffman & Hipp, 2001).

Professional learning communities are often found in secondary education. Drawing from shared structural equivalence, PLCs incorporate teachers into networks to address pedagogy, policy implementation, or student concerns (Mulford & Silins, 2003; Stoll, McMahon, & Thomas, 2006) and principal PLC's often share administrative techniques (McLauglin & Talbert,

2001). Vescio, Ross, and Adams (2007) found PLCs to be a driving force for pedagogical improvement in English and Humanities at a research university. Arguing instructors relied on one another to better frame open-ended questions for their classes, PLCs aided members to establish these questions and facilitated feedback. Outside of the classroom, PLCs are commonly limited to leadership and administrative roles in higher education (Bond & Lockee, 2014; Stoll et al., 2006). These communities allow for administrators of similar roles (e.g., associate vice provosts for undergraduate affairs or student affairs) to gather and discuss major issues within their domain (i.e., student success, retention, policy-changes, etc.) (DuFour, DuFour, & Eaker, 2008; Kezar & Gehrke, 2015).

In addition to the aforementioned formal networks, new research is beginning to address formal networks of higher education institutions. Rather than relying on networks of individuals, organizational change networks rely on entire organizations to leverage systemic change in higher education (ASCN, 2018). These networks utilize many of the same principles of the other formal networks, however the actors within the collaborations serve as representatives, or delegates, from their higher education institutions. Although few conclusions have been reached about the degree to which network interactions benefit their member organizations, organization change networks appear to share many properties with the other formalized networks including the role of community and domain.

Importance of relationships. Formal networks are a medium for disparate actors across the country to interact, share ideas, collaborate, and advocate for change. Undeniably, a formal network's *success* (i.e., as the network defines it) is determined by the ability of its members to work together (Provan & Kenis, 2008). Provan and Kenis (2008) noted the capacity to collaborate is qualitatively different than 'being friends' or even liking one another. Each of the

formal networks (i.e., CoPs, CoTs, and PLCs) and their corresponding literatures rely heavily on individual relationship-building, and relationship-maintenance for success. Formalizing networks by creating bylaws and governing structures provides an avenue for networks to organize, apply for funding, and begin to share their strategies in USER. In many instances, however, the concepts of increasing a formal network's impact require increasing network size. Although formal governance structures are viewed as complementary to concepts of network trust (Provan & Lemaire, 2012), relationships "become less densely distributed throughout the network as the number of participants get larger" consequently a network's ability to reach consensus declines (Provan & Kenis, 2008, p. 237);

A decline in trust and supplementation with governance fundamentally changes the role of the network (Network Leadership Symposium, 2013). With a decrease of interpersonal trust and increase in formal governance, the network shifts away from innovation (albeit, not completely) to reproduction and diffusion (Bryson et al., 2006). Provan and Lemaire (2012) coined this stage as network *maturity and sustainability* and marked it as a shift of network priorities away from internal capacity building to the development of external legitimacy.

Nevertheless, formal networks still require guidance, innovation, and trust in their organizations as they shift their focus to the external environment. In serving that end, individuals may lean on their relationships with others engaged in similar network-like work in the USER space. These informal relationship networks may represent a greater force for innovation within formal networks as they are organically created and are not limited by formal networks scope or mission (McLaughlin & Mitra, 2002).

Longstanding literature links organic relationships, organizational change, individual sustainability, and motivation to high-functioning emergent networks (Healey & Destafano,

1997; McLaughlin, & Mitra, 2002; Samoff, Sebante & Dembele, 2003). Despite this literature conceptually pointing to the existence of high-functioning informal networks in USER, the existence of multiple organizational barriers, differences in capital, and other factors prevent a wholesale adoption of the theoretical base. Simply put, are USER reformers *conference buddies* who only interact at conferences? At current no research empirically indicates the interconnectedness of individual actors within the USER. Although conceptually present, more exploration is needed to understand the web of relationships among people in USER before more research can begin.

Emergent Collaborative Networks

In contrast to formal networks, emergent networks are based in voluntary relational ties (Isett, et al., 2011). Often termed *informal* networks, they are organically derived, have high degrees of interconnectedness, trust, support, consensus, homophilic goals, and many heterophilic tendencies (Isett, et al., 2011). Unfortunately, available literature detailing emergent networks in any domain is relatively sparse. Indeed, Isett et al. (2011) stated "there is no distinct body of literature on informal networks. Consequently, there has been very little advancement of our understanding of this pervasive mechanism" (p. 165). Although connections within emergent networks may be friend networks, the latter does not necessarily predict the former.

Emergent networks, rather, serve as a conduit for information within a specific domain. Dawes (1996) argued in-network information-sharing occurred tacitly as a way to reinforce valued relationships. Indeed, understanding the role of emergent networks is critical as they have a significant impact on what, when, and with whom information is shared. In addition to information sharing, emergent networks often arise for the purpose of exploring ambiguous phenomena such as personal network capacity-building, collaborative problem solving, and

better network service delivery to key stakeholders (Arganoff, 2007; Imperial, 2005; Provan & Milward, 2001). The following sections condenses the available literature on emergent network to first describe their (1) theoretical implications, before exploring their (2) functions, (3) implicit governance and leadership, (4) and structure.

Theoretical interpretations. Several theoretical understandings aid in providing context to how emergent networks operate. First, Burt's (2000) structural hole theory is easily apparent in the network functions. Based in sociology, structural hole theory explains the origin and differences in social capital through position within a social network of relationships. Burt (2000) suggests all placements in a social network hold certain advantages and disadvantages. *Network closure* refers to several individuals who are highly connected and exhibit increased degrees of trust, support, and risk aversion (Burt, 2000, Coleman, 1988). A dense web of interconnected relationships lends itself to the conferring of tacit and technical information in a manner that cannot be replicated easily by individuals who are acquaintances (Burt, 2000). Network closure is also associated with maintaining established group dynamics, upholding the status-quo and provides little incentives for group disruption (including innovation) (Coleman, 1988).

Compared to closure, *structural holes* provided the amount of status-quo disruption that could lead to creativity and innovation (Burt, 2000; Burt & Celotto, 1992). Defined as people within a network who do not share high levels of interconnectivity with others, structural holes provide "an opportunity to broker the flow of information between people, networks, and projects" (Burt, 2000, p. 353). Individuals who occupy structural holes maintain information flow advantages as they are often linked to other individuals who are not connected to other

unique individuals (Burt, 2000; Granovetter, 1973). These individuals are often source points for new information entering and exiting the network.

Another theory used to interpret the function of emergent networks is Rogers' (2003) diffusion of innovation theory. Defined as "the process by which an innovation is communicated though certain channels" (p. 147), diffusion theory provides structure as to how, why, and at what rate new technologies are spread through a social system. Rogers (2003) argued innovation diffusion is a normally distributed curve comprised of five sequential groups: 1) innovators, 2) early adopters, 3) early majority, 4) late majority, and 5) laggards. These zones represent groups of people who adopt an innovation at roughly the same time. In addition to these groupings, Rogers introduced four main elements that influence the spread of an innovation: 1) the innovation itself, 2) communication channels, 3) time, and 4) a social system. In essence, an innovation relies on individuals using their acquaintances to talk about a new technology for an innovation to spread through a system. Conceptually, one function of emergent networks is to serve as innovators and early adopters.

Another social theory regarding relationships pertains to inter-organizational boundary spanning. Tied closely with Burt's (2000) structural holes, boundary spanner refers to individuals who have membership in multiple tangential organizations. Boundary spanners are individuals who connect their organization to resources in the external environment. They use their social connections to gain valuable knowledge to support local organizational performance (Aldrich & Herker, 1977; Brion, Chauvet, Chollet, & Mothe, 2012; Katz & Tushman, 1981; Leifer & Delbecq, 1978). This action requires boundary spanners to interpret, translate, and adapt external resources to a useable form in the organization (Brion et al., 2012; Katz & Tushman, 1981). Given the import and translation of new resources, boundary spanner roles also include many

functions of organizational learning, increased social capital, and norm development (Brands, 2013; Brown & Duguid, 1991; Gherardi, Nicolini, & Odella, 1998; Hill, 2016; Phelps, Heidl, & Wadhwa, 2012; Tsai, 2002).

Finally, Weick (1969) presented the concepts of sensemaking to interpret how individuals organize for the purposes of consensus. Weick defined organizing as "the resolving of equivocality in an enacted environment by means of interlocked behaviors embedded in conditionally related processes" (p. 91). This approach situates organizations at an individual imperative and sets the base rationale for organizing as a process for removing ambiguity from the environment and uncertainty from individuals' lives. The larger role of organizations thus becomes a pursuit of establishing a "workable certainty" for members, and by extension, the organization itself (p. 40). Establishment of workable certainty in an organization translates to a set of mutually defined behaviors which allow members to perceive and interact with their environment. Weick (1969) goes on to note that workable certainty is not a fixed goal, but flexes with changes in the environment and membership. In order to survive in perpetuity, "organizations must maintain a balance of flexibility and stability" (Weick, 1979, p. 215). The process of establishing workable certainty centers on participant interactions (Weick, 1969). Through interactions, participants reflect and "make sense" of their involvement before engaging with other members to establish common meanings.

Network functions. Within the larger scholarly discussion on emergent networks, there is a strong drive to understand network functions, and differentiate them from other social networks (McGuire, 2006). Isolating emergent network functions allows for greater interrogation of their impacts in the social world, most notably, with the organizations in which they are affiliated. These functions are often linked to the sectors in which the networks belong (e.g.,

USER), and commonly associated with the networks' intended outcome (Feiock, Lee, & Park, 2012). While these functions are often broad and overlapping, Popp et al. (2014) provided three macro-functions specific to emergent networks. The following sections provide an overview to the primary emergent network functions.

Function one: information diffusion and knowledge exchanges. The first major function of emergent networks is information diffusion and knowledge exchange (Popp et al., 2014). Given the increased pressure for organizational performance to address larger problems, emergent networks are often seen as a mechanism for spreading ideas and practice (Hartley & Bennington, 2006). Research on knowledge sharing suggests knowledge is not simply *transferred* from one context to another, but is rather continuously reviewed, taken into new settings, and redefined with that context (Hartley & Bennington, 2006). Information sharing therefore is socially mediated by network members who help determine how it is framed, understood and mobilized within the network and their respective organizations. Similarly, emergent networks are built on trust. Trust and relationships within networks are associated with transfer of tacit knowledge (Burt, 2000; Granovetter, 1973), and are often seen as more effective at diffusing technical or esoteric information to respective groups as network members have a better understanding of the knowledge being distributed.

Despite information-sharing practices of a network, there remain barriers to appropriate diffusion. Organizations external to the network may not exhibit readiness for change or occupy a proximal zone outlined by Rogers (2003). Additionally, Huang (2015) discussed the role of power, politics, and the awareness of the environment. Network members must be cognizant of the political impacts of their innovations in order for their outputs to take hold.

Function two: network learning. Closely aligned to diffusion and exchanges, network learning refers to the capacity for networks to learn how to address problems single organizations cannot (Popp et al., 2014). The concepts of network learning are drawn from literature on organizational learning, which posits the organizational gains of individuals learning is greater than the sum of learning done by its members (Stoyko, 2001). Organizational learning is associated with increased performance and efficiency (Montgomery, 1996; Nelson, Rashkind-Hood, Galvin, Essien, & Levine, 1999). Beyond organizational learning, "network learning" is learning "completed by a group of organizations acting as a group" (Knight, 2002, p. 427). This definition moves network learning beyond the specific individual or organizational members to a system-level function where information is acquired and negotiated by network members until consensus of interpretation is established for further dissemination to members outside the network (Knight & Pye, 2005).

Beyond consensus, network learning is also regarded by its place of origin, namely internal or external to the network. Internal network learning refers to learning generated by network members, and external originating outside the network but applied through emergent network consensus building. Eisenhardt and Martin (2000) referred to networks leveraging their internal connections as a resource for network learning. This "dynamic capability" relies on the individuals, their expertise, and collaboration to create new knowledge for trial and eventual diffusion to member organizations. The more internal resources at the network's disposal, the more likely the network can create and disseminate more knowledge (Casebeer, Reay, Dewald, & Pablo, 2006). Similarly, a network can absorb information from members outside the network and assimilate, transform, and use the information for network development (Zahra & George,

2002). This form of learning relies on the social connections of members and organizations to access the necessary information in the environment.

Function three: innovation. Innovation is a critical function in networks, as it is often one of the main reasons networks are formed (Keast et al., 2004; Provan & Huang, 2012). Defined as the "capacity of a network to change given conditions" within the environment, networks use their internal and external resources to filter information to their members and affiliated organizations (Turrini, Christofoli, Frosini, & Nasi, 2010, p. 533). Innovations within networks can either be derived or refined from existing knowledge or generated through new creative actions from network interactions (Kuhn, 1985). "In stable conditions, network learning tends to be a narrowing and converging process of testing, divergence, and discovery, thus setting the stage for innovation" (Popp, et al., 2014, p. 35). The functions of innovation relate to knowledge exchanges and network learning in that learning and knowledge exchange contribute to innovation (Popp et al., 2014). Factors which appear to enhance a network's capacity for innovation include: financial support (Thorgren et al., 2009), diversity of network members (Provan & Kenis, 2008), conflict-resolution oriented environment (Reay, Goodrick, Casebeer, & Hinings, 2012), formal or informal mechanisms for encouraging participation, and transparency or trust (Human & Provan, 2000).

Similar to cautions associated with information sharing and diffusion, research indicated networks consider political ramifications of their innovations. Network members are advised to carefully consider the reception of their innovations by those outside the network, as "innovations usually replace an existing structure or process" (Popp et al., 2014, p. 36). If the innovation is not perceived to be relatively advantageous to the existing process, network

members risk their reputation and legitimacy, and the reputation and legitimacy of those with whom they are affiliated.

Network governance and leadership. Although emergent networks are primarily founded in relationships and social structures, regulative structures are embedded in social interactions which guide and shape how those interactions occur (Milward & Provan, 2006). Indeed, explicit bylaws or other regulative structures generally are reserved for formal networks or the organizations from which the networks are affiliated. "Some authors have the view that you simply cannot govern networks, and that in trying to do so you will destroy everything that is good about them" (National Leadership Symposium, 2013, p. 10). In spite of formal structures, factors such as trust and human capital all govern how individuals interact with one another (Bryson, et al., 2006; Provan & Kenis, 2008). These factors also shape the concept of leadership among members in the network. Keast, Mandell, Brown, and Woolcock (2004) stated "some members of a network, as in other organization forms, may have more formal power to their position, education, resources, or political clout which affect how those in the network interact with them" (p. 40). This formal power, however, cannot be wielded without conscientious understanding of the network's relationships and interdependence (Keast et al., 2004). Given the role of environmental influences and cultural markers' effect on the network, the following sections outline various forms of human capital and how they may influence how individuals interact in emergent networks.

Human capital. Broadly, human capital (capital) refers to a set of assets capable of generating a future benefit for at least some individuals within society (Bourdieu, 1987; Burt, 1992; Coleman, 1988; Ostrom, 2009). Enacted capital primarily confers various manifestations, influence, or power in a social setting to an individual (Bourdieu, 1987). This influence becomes

a quality of an individual who can wield it to produce desire returns (Bourdieu, 1987, p. 243). Human capital is a renewable individual resource within a domain, which can only be lost by changes within the domain (Bourdieu, 1987).

Social capital. Given the social space of emergent networks, social capital remains a critical component to consider in how these networks are socially shaped, and how they communicate with organizations in the environment. Putnam (1993) defined social capital as "those features of social organizations, such as networks, norms, and trust that facilitate coordination and cooperation for mutual benefit." (p. 36). Some authors view social capital as conduits aiding someone to access influence power or other resources in the environment (Bourdieu, 1987; Burt, 2000). Other authors argued social capital is embedded within the relationships and contribute to building mutual trust and collective identity (Coleman, 1990; Fukayama, 1997; Putnam, 2000). This collectivist perspective articulates how individual self-interests is overridden through relationships, shared meaning and goals. Thus, social capital serves as a "social glue," which binds individuals together who might otherwise fragment (Putnam, 2000, p. 19). Social capital is unique to other forms of capital as it inherently connects people to others, thus enhancing the role of all other human capital forms (Putnam, 1993). Regardless of the differing definitions, Burt (1992) summarizes social capital as simultaneously "the structures of contacts in a network and the resources they each hold" (p. 61).

Relationships and relationship-building form the foundation to emergent networks (Isett, et al., 2011). Participation and flourishment of these networks are driven by voluntary social arrangements and sustained by renewed interest and commitment to other. With regards to governance, individuals who are considered to have high levels of social capital may hold more influence in shaping the language, norms, or behaviors simply because they may initially bridge

individuals together. Similarly, individuals with social connections outside the network may provide power and influence in shaping the conversations and leadership of the emergent network. Additionally, the collective emergent network could be viewed as an influential group of people due to their trust, collective identity, and collective connections to other influential people and organizations.

Cultural capital. A second form of human capital concerns societal markers, socialization, and social appeal. Based on concepts by Bourdieu (1977), "cultural capital" refer to the social assets of a person that promote social mobility and desirability (p. 244). Taking four separate but overlapping sub-forms, cultural capital is an individual's composite cultural marker of social status, mobility, and power. First, the category of the "embodied state" includes power drawn from proper, positive socialization within a given society (Bourdieu, 1987, p. 245). This form is acquired over a lifetime, and unlike other forms of capital cannot be given to others. "Much like the acquisition of muscular physique or a suntan, [embodied capital] cannot be done second hand" (Bourdieu, 1987, p. 244). Although originally included in *the embodied state*, "linguistic cultural capital" was further clarified as a distinct individual asset associated with socialization and refers to person's mastery of language and its relation to others within a given domain (Bourdieu, 1990).

Another sub-form of cultural capital addresses a person's property that can be mobilized for individual return. The "objectified state" exists as an individual's accumulation of personal property, knowledge, skills, and work (Bourdieu, 1987, p. 247). Although this may include economic assets, the objectified state chiefly refers to the cultural symbolism associated with possessing something valued by society. This may be a priceless collection of fine art, an expensive car, or the ability to dunk a basketball. From this perspective, wealth importance is

derived from the cultural significance of its possession, that is, being *considered* wealthy by others. Finally, the fourth form of cultural capital is referred to as "the institutionalized state" (p. 248). This type of cultural capital is comprised of power and influence granted to an individual through institutional affiliations. Another symbolic representation of power and influence, affiliations with education (i.e., degrees, credentials), place of employment, religious affiliations, or awards received from organization may serve as cultural markers of capital.

With the emergent network, cultural capital provides understanding to the actors as they exist in the social world and offers more depth to interpreting why actors seek out one another. Whereas social capital may be conceptualized as an individual or group asset, cultural capital is distinctly situated as an individual quality. Cultural markers and institutional affiliations signal other actors of the potential for a social bond to form. This form of capital can be derived from networks' organizational affiliations (institutionalized), previous research they conducted (objectified), their ability to engage in the nuanced language of USER (linguistic), or simply their charismatic and congenial disposition (embedded). Regardless of an individual cultural capital's origin, its symbolism drives social connection and enables the flows of communication throughout a social network.

Intellectual capital. Intellectual capital concerns the possession of content knowledge. Although originally used in business literature as a means of human resource accountancy (Nahapiet & Ghoshal, 1998; Stewart, 1998), intellectual capital recently has been applied in the higher education setting (Gappa, Austin, & Trice, 2007; Khan, Arafat, & Raushan, 2019; Rowlands, 2013). Despite the increased use in higher education, few authors applied intellectual capital as an individualized quality, choosing more to quantify the role of organizational knowledge as an intellectual asset. For the purposes of informal networks of undergraduate

STEM education reformers, intellectual capital is defined as the amount of knowledge an individual possesses in a specific domain, which can be leveraged to create more knowledge or further increase understanding of an existing concept (Stewart, 1998). This contrasts from the various forms of cultural capital, as it pertains specifically to the asset of possessing unique or esoteric knowledge and not the cultural significance of *being smart*.

In considering the members of the emergent networks, intellectual capital introduces the concepts of knowledge domains and the influence they bestow. As emergent networks meet, they encounter complex problems which require expertise from disparate fields and cross various boundaries (e.g., disciplinary, organizational, formal networks, etc.). Although individuals may have expertise in one area, they will encounter different areas in which they may not possess capital. These expertise asymmetries inform governance and leadership by potentially informing strategies, language, approaches, or agenda-setting for the network. Intellectual capital can be identified both as an individual property of someone in the network, and to describe the information exchanges occurring. Bridging social networks to incorporate an individual with intellectual capital in a specific domain will produce social and cultural capital for network members and provide the opportunity for more intellectual capital generation.

Organizational capital. Another form of capital speaks to the power of institutional affiliation. Organizational capital refers to the resources, power, influence, authority, communication systems, granted to organizational members for exerting power and influence both inside and outside organizational boundaries (Morgan, 1998; Scott, & Davis, 2007). Although organizational capital may be inclusive of other forms of capital (most notably, cultural capital), this form is primarily comprised of symbolic and economic power (Scott & Davis, 2007). Similarly, organizational capital is not evenly distributed to all members within an

organization (Fullan, 2002; Scott & Davis, 2007). Their access rather is mitigated by formal positions, expertise, experience, or even other forms of capital (Amey, Eddy, & Campbell, 2010). For various reasons organizational members may be more or less able to harness their organizational capital, depending on purpose alignment, environmental, or contextual factors. This distinguishes the varying levels of power associated with specific organizational affiliation(s).

Given individuals engaged in emergent *inter-organizational* networks inherently come from other organizations, their position, expertise, and experience within those organizations can convey power in social networks. These organizations also often provide financial resources to networks giving another dimension to capital provided by organizational affiliation. The number of affiliated organizations actively engaging the network's arena may provide affiliated individuals with necessary economic capital to cultivate power and influence. Beyond the symbolism of cultural capital and intellectual capital, organizational capital often provides the economic driver which impacts how individuals act within a social network.

Servant leadership. In addition to the role of capital in governing networks, several authors point to the values of servant leadership in networks (Holley, 2012; Mays & Scutchfield, 2010). Servant leadership refers to a basic premise that leaders put the needs of their followers ahead of their own needs, trying to make sure that other people's highest priority needs are being served (Block, 1993). Wheatley and Frieze (2011) asserted effective leaders needed to view their role as a "host" and not a "hero" (p. 2), which resonated with the tenets of servant leadership. When the principles of servantship, roles of human capital, and fluid nature of interpersonal relationships are held in tandem, leadership becomes a contextualized and amorphous entity

within an emergent network. In this setting different individuals exert influence and leadership in spaces where they have comparative marginal influence on others within the space.

Network structure. Given relationships form the core of emergent networks, their structures are particularly important to practitioners who seek to more purposely design formal networks and other organizations (Isett et al., 2011). "Studying the connections between [individuals] of emergent networks can provide information about the network structure and its relationship with network effectiveness" (Popp et al., 2014, p. 55). Provided knowledge and information exchange is a key function of many networks, their structure is critically important to understand how exchanges are achieved. The area of emergent network structure and how it may translate to effectiveness is largely unexplored. The studies which do exist rely heavily on the tools of social network analysis. Network structures refer to "the nodes in a network, the ties that connect nodes, and the patterns that result from these connections" (Ahuja, Soda, & Zaheer, 2012, p. 435). Drawing from Burt (2000) and Granovetter (1973), Provan and Lemaire (2012) argued for a mix of both strong and weak ties within a network to achieve efficiency.

Existing Literature Gaps

Despite the synthesized review presented in this chapter, the area of collaborative networks is essentially uninvestigated. Nevertheless, the need for more information into how networks work is critical, especially when their financial commitments and deployment in practice far exceeds a strong, supportive evidence base. These concerns are magnified when applied to networks in the USER space, where one estimate places total financial contributions nearing one billion dollars (Gehrke & Kezar, 2016). While the literature highlighted in this chapter begins to characterize emergent networks as an informal organization situated to address systemic problems, the research-base falls considerably short in three critical areas.

Existing research on emergent networks is primarily theoretically based, with most of the literature coming from studies on social capital theory. This work centers on an individual's experience within an emergent network and how individuals activate their social capital to achieve goals. While this work is important in understanding the lived experience of an emergent network, it fails to capture any of its organizational qualities. Indeed, Popp et al. (2014) argued the focus on an individual's experience in an emergent network is indistinguishable from that of a formal network or any other organization. The focus on social capital also ignores the intersections of other forms of human capital. While social connections are important in establishing the structure of a network, other qualities (i.e., cultural capital, intellectual capital, and organizational capital) affect how those individuals interact. More investigation into the areas of human capital are critical to understanding how individuals cooperate and what social markers are significant in emergent network contexts.

Another gap in the existing literature relates to how few research disciplines study them. At the time of this study, emergent networks are only recognized as social phenomena in public administration, public health, and criminal justice. Authors in public administration inquired into emergent networks developed across city governments, and those in public health investigated linkages across different hospitals. Although those studies recognize the social power of emergent networks, their applicability to higher education is suspect. Within higher education research there are few examples of research on formal networks and no known research on emergent networks. While the existing literature in public administration, public health, and criminal justice may help guide formal and emergent networks in higher education, more research is needed to address how networks operate in the higher education sector.

Despite authors bifurcating inter-organizational networks into formal and emergent groupings, no known research investigates how these two network forms interact with one another. Most authors singularly identified and examined the efficacy of formal networks or the formation of emergent networks. These two types of networks, nevertheless, undoubtedly co-exist. Indeed Isett et al. (2011) argued emergent networks may be the seminal place for innovations within formal networks. Recognizing this gap in the literature, the second research question sought to recognize and detail how the two forms of networks affect one another.

Conclusion

This chapter targeted the differing forms of formal collaborative networks as they exist within the USER space. Highlighting the contrasting amounts of structures associated with the formal networks, this review posited the role of relationships and lifecycles in the scaling and search for external legitimacy of formal networks. As networks grow, they shift their focus from internal capacity building to production and diffusion. Following the review of the more formal networks, this chapter offered a deeper examination of emergent networks, their functions, governance, leadership and potential structures.

Given the use of networks in USER and impetus from scaling reform (AAU, 208; Kezar & Gehrke, 2015), there stands an imperative need to know more about how formal and emergent networks operate in tandem. How do networks establish their internal processes while shifting their focus to the external environment? What role do emergent networks play in the scaling of formal networks? How do emergent networks differ from a simple collection of friends operating in the same USER space? Are emergent networks a stronger mechanism for innovation when compared to their formal counterparts? Each of these questions is important and equally valid

however, this study investigates the social networks of the leaders in formal networks in order to ascertain if they work as an emergent network.

Chapter 3: Research Methods

The extensive deployment of different networks in USER has resulted in large investments of human and financial resources. Although some literature is available to guide the committed resources, almost all understanding is derived from work in public administration and limited almost exclusively to the functioning of formal networks (Bryson et al., 2006; Isett et al., 2011; Popp et al., 2014). This relative dearth in research is not due to a lack of imperative as emergent networks often operate *behind closed doors* of formal networks or as primordial formal networks (Bryson et al., 2006). The difficulty in inter-organizational network study rather is owed to the amorphous nature of networks across all domains and disciplines (Isett et al., 2011). The fluidity of '*what constitutes a network?'* is compounded when interrogating emergent networks, which often double as friendship, colleague, or peer networks (Gilchrist 2006). Popp et al. (2014) contended difficulty is not a legitimate excuse when emergent networks hold the "potential to increase our knowledge and understandings of formal inter-organizational networks evolution, function, and support" (p. 29). Despite the articulated difficulty, the following chapter outlines the research approach I took to map and interpret the functions of an emergent network operating across formal networks in undergraduate STEM education reform.

As described in the opening chapter, my research questions sought to explore the existence of an emergent inter-organizational network in USER. Specifically, I set out to explore the following research questions:

1. How do formal and informal leaders across formal networks in USER serve as an emergent network?
    - 1a). How interconnected are leaders across formal networks?
    - 1b). How do leaders engage in knowledge diffusion regarding their networks?
    - 1c). How do leaders engage in network learning?

2. How does this emergent network affect USER formal networks?

Each sub-question inquired into a different aspect of emergent networks as described in the literature review. Question 1a) inquired into the social structures embedded in the emergent network, while questions 1b) and 1c) inquired into different articulated functions of an emergent network as described in the literature review (i.e., knowledge diffusion and networked learning). The final research question explored the impact of the emergent networks on both formal networks and USER altogether.

Philosophical Grounding

Given the intricacy and potential confounding nature of investigating emergent networks, I approached these research questions pragmatically. Unmarried to any particular methodology or ontology, a pragmatist research approach centers on answering research questions by the best suited tools. Powell (2001) argued

> The pragmatist epistemology stands in contrast to prevailing positivist and anti-positivist views of scientific discovery. Whereas positivism emphasizes the objective, law-like properties of a brute reality independent of observation, anti-positivism emphasizes the creative role of active, subjective participants, none of whom owns a privileged claim on truth. Pragmatism, on the other hand, rejects positivism, on grounds that no theory can satisfy its demands (objectivity, falsify-ability, the crucial experiment, etc.); and rejects anti-positivism, because virtually any theory would satisfy them. (p. 884)

Epistemologically, pragmatism's leading ideas are defined as *belief, doubt,* and *habit* (Pierce, 1877). Social reality and knowledge are based on beliefs and habits which are constructed through processes of institutionalization, legitimation, and socialization (Berger & Luckmann, 1967; Yefimov, 2003). Berger and Luckmann (1967) argued it is impossible to understand an institution adequately without an understanding of the historical process in which it was produced. In this regard, research is always embedded in social, historical, and political contexts. Ontologically, "pragmatism asserts reality exists in an external world as well as that lodged in the mind" (Creswell, 2009, p. 11).

However, “we need to stop asking questions about reality and the laws of nature” and focus on increasing the human condition. What is real or true “is simply the name of whatever proves itself to work.” (James, 2000, p. 201).

With regards to methods of inquiry, pragmatism embraces all tools espoused by positivists and interpretivists (Creswell, 2009). Rather than selecting a methodology to guide the methods and data collection, pragmatism emphasizes the research problem and uses all available approaches to understand that problem (Rossman & Wilson, 1985). This approach fronts the importance of the questions posed and allows the researcher to confront the questions unbounded by the limits of one particular methodology. Paramount to this approach, however, is understanding the questions posed (Morgan, 2006). In order to fully engage in the work, the researcher must know their questions and a multitude of different methods to know which tool may be the best to examine the phenomena.

Research Approach

From this perspective, I utilized a mixed-methods approach for collecting, analyzing and mixing both quantitative and qualitative data (Tashakkori & Teddlie, 2003). “The rationale for mixing both types of data are that neither quantitative nor qualitative methods are sufficient by themselves to capture the trends and details of complex situations” (Ivankora & Stick, 2007, p. 97). Given the articulated difficulty of researching emergent networks, a single methodological approach is insufficient. An approach solely utilizing surveys may uncover frequencies of interactions or topical conversations among network members, but survey data lacks the richness needed to uncover how networks operate or the experiences of those found therein. Similarly, qualitative approaches may provide data on how a network operates but provides little information beyond the individuals experience. If the methods are used in tandem though, their

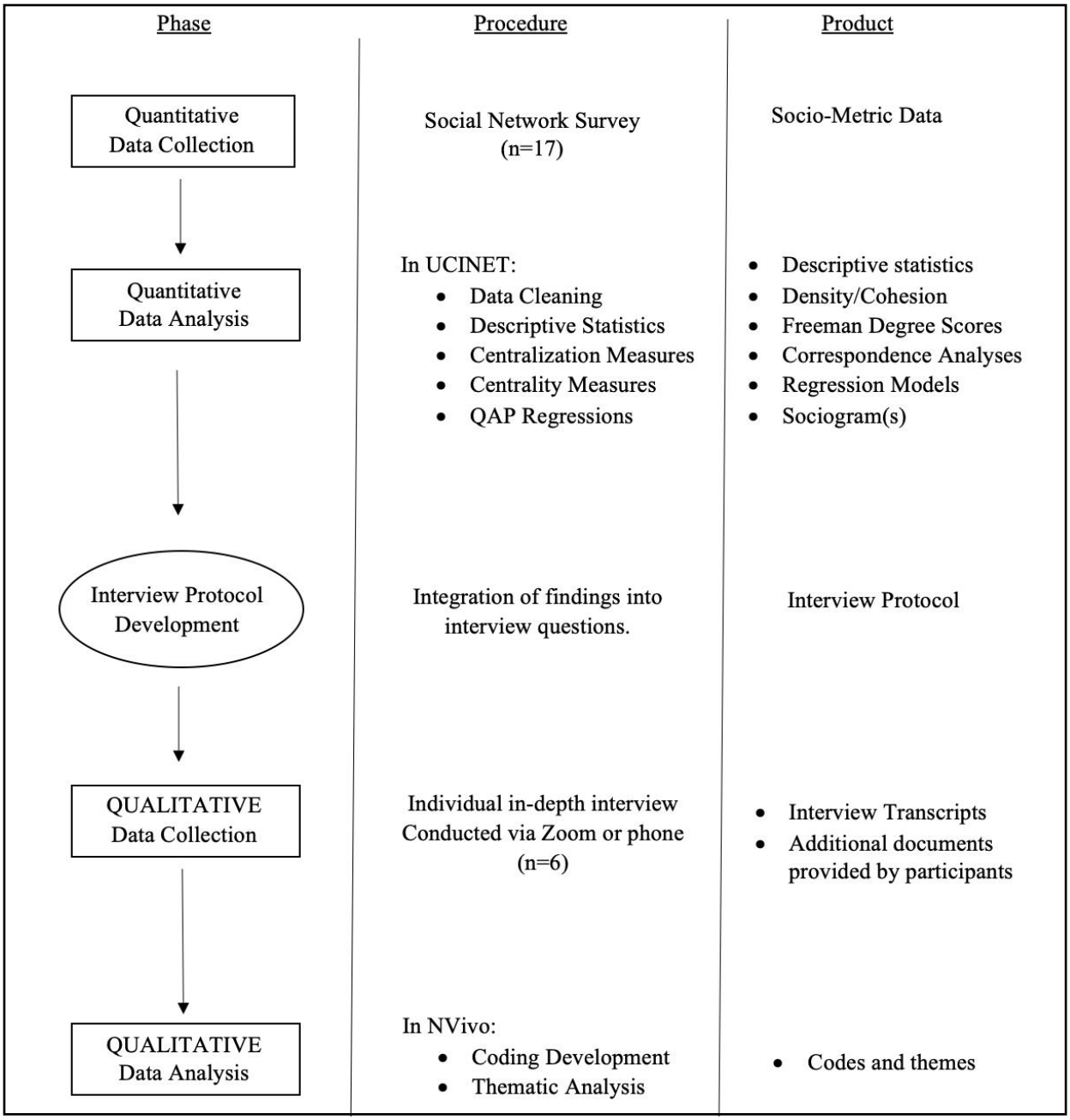
complementarity gives a more complete and nuanced understanding of the phenomena (Creswell & Plano-Clark, 2011; Green, Caracelli, & Graham, 1989; Johnson & Turner, 2003; Tashakkori & Teddlie, 2003).

Provided this rationale, I employed a sequential explanatory quan-Qual mixed method design, comprised of two separate strands (Creswell & Plano-Clark, 2011; Creswell, Plano Clark, Guttman, & Hanson, 2003). This design was *sequential* as I collected quantitative data first before collecting any qualitative data (as opposed to collecting both simultaneously), and *explanatory* as I used quantitative to inform the qualitative approach. The work began with surveying participants to gather quantitatively-oriented socio-metric data, which was collected, analyzed, and used to inform an interview protocol and qualitative data collection. In this study, the quantitative data were employed to establish the social interconnectedness of participants in formal USER networks and help to identify the types of relationships which exist. Following the survey, interviews were conducted to further explain and contextualize the relationships beyond the social network statistics. In total, quantitative data were used to understand the connections of leaders, and the interviews further described those data by exploring the participants lived relational experiences in more depth.

Priority in this work was centered on conducting and coding interviews, as it focused on in-depth explanations of the quantitative socio-metric data (Creswell & Plano Clark, 2011, Creswell et al., 2003). This emphasis is signified by the capitalization of *Qual* in the research design description. The quantitative and qualitative strands were connected by using quantitatively ascertained network structure, participant placement within the network, and network homophilic/heterophilic tendencies to inform the interview protocol. Initial data integration was completed during the analysis of the quantitative data, but prior to qualitative

data collection. Secondary data integration took place at the conclusion of qualitative data analysis, when quantitative findings were reinterpreted for more detailed meaning (Figure 1). Given the explanatory nature herein, the ethos driving the design focused first on understanding the emergent network dimensions before exploring the experiences of relationship-building and engaging in conversations regarding the future of USER.

Figure 1. *Quan-QUAL Sequential Explanatory Mixed Methods Design*



Participant selection. Given thousands of individuals participate in some form of USER, participant selection was a critical component in identifying which leaders could be a part of an emergent network across formal STEM networks. Research in public health found organizations nominate *leaders* in many ways including self-nomination, nomination by members of a group, nomination by formal leaders, or expert nomination (Valente & Davis, 1999; Valente & Pumpuang, 2007). Each of these strategies, nevertheless, was accompanied by its own variation of selection bias (Valente & Pumpuang, 2007). Provided the bias limitation, the first step of participant selection was structured around a consensus building approach called the Delphi Method. This method required a group of pre-established nominators to confidentially recommend a group of individuals whom they believed fit preset criteria (Avella, 2016). By collecting and corroborating the disparate set of nominees, the researcher may draw a set of participants from those who are present on multiple lists. Most importantly, proponents of the Delphi Method encourage using multiple rounds of nominations to ensure nominator fidelity and reliability (Avella, 2016).

For the purposes of identifying formal and informal leaders in USER formal networks, I conducted a combined Delphi process across two comprehensive USER formal networks. The first group of nominators were taken from the leadership teams of the National Academies of Science, Engineering, and Medicine Roundtable on Systemic Change in Undergraduate STEM Education (National Roundtable). The second group of nominators were drawn from the Accelerating Systemic Change Network (ASCN). These groups served as the ideal starting point for nominators as their missions both seek to convene leaders from across STEM policy, research, and implementation communities (About ASCN, 2019; NASEM, 2018).

Nominator profile. For the purposes of participant selection and identification, I conducted the first round of the nomination process with six leaders within the National Roundtable and ASCN. Three nominators represented each of the organizations. To avoid any potential bias from the start of the process, diversity was sought among the initial nominators. These individuals had served in multiple leadership capacities stretching across multiple domains in USER (e.g., policy, funding, faculty, higher education advocacy, university administration, etc.). Four of the nominators were women and two were men. Four nominators' primary responsibilities were at a post-secondary institution, while 2 nominators worked for different STEM-affiliated non-profit organizations. Geographically, the nominators were located in all major regions of the United States with two nominators representing the mid-Atlantic/Northeast, and one nominator located in the Central Plains, Midwest, South, and West Coast respectively. Reflecting the lack of racial diversity in the STEM fields, five of the nominators were white and one identified as Latino/a.

In August 2019, the selected nominators were asked to confidentially identify 15 – 30 formal or informal leaders in USER networks through a Qualtrics survey (Appendix A). All nominators were provided a sample list of USER formal networks to aid in their nomination process and were advised to include individuals from additional groups if they felt it appropriate. Self-nominations were not included. Following the initial nominator submissions, their lists were provided to a second group of two reviewers for validation and consolidation. A second group was used as many of the nominated names in the initial lists included the nominators in the first round. The second group helped to avoid any conflicting interests. In the second round of review, no additional names were added or subtracted from the list

Participants. All six nominators returned a list of names between 19 and 30 names with a total of 128 nominees, representing over 20 different USER formal networks. Of the 128 total nominations, there were 86 unique individuals. Nineteen of the individuals nominated appeared on three or more of the nominator lists, and nine names appeared on five or more lists. Those nineteen individuals were validated by the second set of nominators as being preeminent leaders in USER and were invited to participate in the study. No names were excluded by the second nominators. Provided the social network survey required participants to disclose their names to others in the study, participation consent was sought prior to the survey distribution. Consent was elicited to all 19 of the initial participants in mid-September 2019 with 17 consenting to participate.

Quantitative Methods: Social Network Analysis

After finalizing the participants for the study through the nomination process, data collection began with the social network survey. The purpose of the survey and subsequent analysis were two-fold. First, asking participants to map their social connections among other leaders in USER networks provided an initial understanding to the interconnectedness of those leaders in formal USER networks. Social network analysis relies on metrics of centrality and cohesion as measures of brokerage, structural holes (i.e., Burt, 2000), and trust and collective identity (i.e., Borgatti, Everett, & Johnson, 2018; Putnam, 2000). Mapping the social components of this social network aided in identifying potential structural components (e.g., central or peripheral actors, isolated actors, boundary spanners, etc.) of the network. Second, collecting and analyzing the social network data provided information to be included in subsequent interviews described in subsequent sections.

Data collection. In late September 2019, participants were sent the survey populated with the other nominated names from the nomination exercise (Appendix A). Prior to completion of the survey, each participant received specific direction on how to complete the survey and a worksheet providing additional context to the study (Appendix B). Socio-metric data were collected through a Qualtrics survey, distributed online to participants, with the aforementioned attachments. Participants had two weeks to complete the survey with one reminder relayed through email after one week, and a final reminder sent when 24 hours remained in the survey. An extension was granted to one participant to accommodate the critical need for a high response rate.

In the survey, participants were asked to provide basic demographic and education information and to list any USER networks in which they are currently affiliated. Previous USER network affiliations (within the last 5 years) were collected. Following the basic survey questions, each participant was asked to denote relational connections with other members in the pre-populated list of participants. Socio-metric data were collected across three vectors loosely reflecting the literature on the functions of emergent networks. Corresponding the knowledge-sharing function of emergent networks, participants were asked to indicate with which of the other participants they regularly spoke about their USER network business (*Business*). Reflecting network learning and consensus building, participants were polled to indicate which of the other participants they periodically discussed their network problems (*Problems*) or sought advice (*SoughtAdvice*). Note, the innovations function of emergent networks was not directly interrogated in this process, as social network surveys are not situated to specifically ask about outputs or products of relationships. Following the social network aspects of the survey,

participants could nominate, at most, two names of individuals they speak to regularly about USER related networks who were not included on the list.

Data cleaning. Upon the conclusion of data collection, all responses were downloaded from the Qualtrics collection software and moved to fit with a Microsoft Excel file. Individual responses were reformatted from their raw responses to three unique 17x17 adjacency matrices for each network, and one 17x15 two-mode adjacency matrix to capture USER network affiliations. All participants were assigned a unique and randomized participant identification number and all categorical data were recoded to numeric identifiers. Any missing demographic, education, or network responses were populated using open and publicly available information found on the internet; however, participants who selected *prefer not to respond* for specific questions did not have any publicly sourced information included in the dataset.

Following the recoding and categorical cleaning, all three networks were loaded into UCINET for further cleaning and adjustment. The *Business* and *Problem* networks were assumed to be comprised of reciprocal dyads. These networks were symmetrized using UCINET software. Using this function filled in any missing unreciprocated ties. Essentially, this process identified when individual, *i*, identified they spoke with another individual, *j*, but the *j* did not indicate the *i* as a connection. Borgatti, Everett, and Johnson (2018) indicated symmetrizing was a common aspect of data cleaning when no directionality is assumed in information flows (p. 86). Both (spoke about) *Business* and (discussed) *Problems* networks assumed multi-directionality in the network, as one does not speak or discuss uni-directionally in a conversation. Symmetrizing the data allowed for the inclusion of consenting participants who did not respond the survey. This reduces data waste by using data other participants provided about non-

respondents. Both the *Business* and *Problems* networks include data on all 17 consenting participants.

SoughtAdvice was not assumed to be reciprocal given information asymmetry inherent in each of the dyads. Plainly, an individual may seek advice from another, but one cannot assume the latter will seek out former for advice. Given the inability to assume reciprocity in this network, only socio-metric data for the 15 contributing participants were included in this network. Although I could not assume reciprocity in network ties, I did assume individuals who sought advice did, in fact, receive it. I based this assumption on the prompt "sought advice" being elicited in the past tense. Provided this assumption, I transposed *SoughtAdvice* data to represent a new network. This new network was called *GaveAdvice.* Transposing networks of directed ties reverses the information flow and direction of the ties (Borgatti, Everett, & Johnson, 2018). I transposed this *SoughtAdvice* for two reasons. First, I switched the direction of ties to match the flow of information (in this case, advice) to ease with the interpretation of centrality measures and sociograms. Second, transposing directed ties allows for more inclusion of consenting participants in the study. This translation also reduces data waste by including those who did not respond and relying on the responses of advice-seekers. Despite having 17 nodes, the *GaveAdvice* network has only 15 participant responses.

Data analysis. Data collected from the social network survey were used in four strategies. First, measures of centralization were taken. Centralization measures "are properties of a network as a whole" (Borgatti, Everett, & Johnson, 2018, p. 173). These measures aid to understand the network density, cohesion, and to recognize the presence of subgroups. Although measures of centralization are almost always used in network comparison, these measures provide insight into the cohesiveness of the emergent network in relation to their sharing of

formal USER network information. Importantly, centralization measures provide interpretations into subgroups and core-periphery structures, which provide theoretical interpretations to how the social network functions.

Second, individual respondent centrality measures were taken to understand how central members are to the emergent network. Compared to centralization measures, centrality refers to the structural properties of an individual person within a greater network (Borgatti, Everett, & Johnson, 2018). Measures of centrality are typically understood through the number of relationships (or *ties*) an individual has within a given network and their betweenness. Betweenness is a measurement of how central of a role an actor plays in transferring information through the network. Centrality statistics have many other forms, and most are used to represent direct relationships or indirect relationships (Borgatti, Everett, & Johnson, 2018).

Centralization and centrality statistics independently reveal little about the network beyond *who talks to whom*. Nevertheless, when held in tandem with known literature on social capital, the network structures begin to elicit more meaning. Concepts such as structural holes (Burt, 2000), closure (Coleman, 1990), and bridging-bonding tendencies (Putnam, 2000) provide an additional lens to understand what position within the network may translate to practice. Applying statistics to measures of centralization provides a crucial first-step to understanding the presence of an emergent network. The amount of interconnectedness among the individuals in the network can inform how (and to what degree of depth) they communicate. For preliminary social network analysis, I used the Valente, Palinkas, Czaja, Chu, and Brown (2015) "Goldilocks Principle" as a guide for interpreting centralization and centrality measures (p. 7). With regards to statistical measures within the network, the Goldilocks Principle regards normalized centralization and centrality scores below 0.30 to be low, 0.30 to 0.60 moderate, and levels above

0.60 to be high. These measurements can be applied to both centralization measures for the whole network (i.e., centralization and cohesion), and individual centrality scores. The authors stressed the Goldilocks Principle is a loose interpretation of network data, and factors such as network size, context, and domains should be considered in full network analysis.

In addition to network specific statistics, I tabulated Quadratic Assignments Procedure (QAP) regressions and QAP correlations to recognize prominent factors within the network. QAP methods are calculations used specifically in social network analysis, as social networks violate foundational tenants of traditional regression methods (Borgatti, Everett, & Johnson, 2018). The QAP methods aid in identifying specific personal characteristics or other variables which lead to relationships forming. These methods were used to identify homophilic tendencies within the network, and how *closed* the network is to difference.

Many authors highlighted the value of understanding homophily and heterophily within an emergent network. Arguing homophily (along some variable) was a driving force in emergent network formation, Provan and Lemaire (2012) indicated homophily has value in the beginning stages of a network but heterophily is necessary for emergent networks to thrive. Isett et al. (2011) stated homophilic tendencies were unsustainable and greatly limited the networks ability to innovation. Similarly, homophily is linked with network closure and increased levels of trust, support, and relationships. Putnam (2000) called this the "social glue" bonding individuals together.

Finally, individual respondents were charted into a map to visually represent network structure. Commonly referred to as a *sociogram*, this visual is a map of the different anonymized individuals and their connectedness provides a collective view of the network. Four sociograms were graphed with the data and are located in Chapter 4. Three of the sociograms visualized the

individual participants and their connections to one another. The fourth sociogram incorporated 2-mode of data and charted the interconnectedness of participants and their network affiliations. This will allow for the charting of formal network representation and connectedness. Admittedly, a sociogram does not provide much utility beyond visual clues for the researcher. Drafting the sociogram will solely be for use in interviews with the participants.

Qualitative Methods: Semi-Structured Interviews

Although social network analysis is a valuable tool in mapping emergent networks, it does not fully capture the many dimension and contexts of relationships. In short, interpersonal relationships cannot be fully represented with a statistic or line. While helpful in establishing network boundaries and connections, social network analysis is a crucial first step in interpreting emergent networks. Indeed, several authors argued qualitative investigation of emergent networks are critical to bounding and operationalizing the relationships (Casebeer, Huerta, VanderPlaat, 2006; Keast et al., 2004; Popp et al., 2014). “It is all too easy to simply make attractive pictures and tell stories that could have been told without network data...the problem is that these easy presentations tend to bake in all kinds of assumptions that should always be questioned" (Frank, Kim, & Belman, 2010, p. 223). In order to avoid *making attractive pictures* and *baking assumptions,* I conducted six semi-structured interviews with participants to discuss their experiences working with others identified in the study.

Data collection. Following the social network data initial analysis, six participants were selected from the existing group of participants and interviewed about their experiences with other participants. All six individuals successfully completed the initial social network survey. The two participants who did not complete the survey were not considered for interview. Criteria for selection in the interview process was based solely on composite centrality measures drawn

directly from the social network data. Standardized composite centrality measures were compiled through averaging (1) number of ties, (2) closeness, and (3) betweenness for each participant. Given that each participant represented a nominated leader in formal USER networks, diversity in these scores was sought to understand how different aspects of the social network were experienced. Two participants with the lowest and two participants with the highest standardized composite centrality scores were invited to interview. Additionally, the two participants with the centrality scores closets to the group averages were invited to participate in interviews. Their selection resulted in three groups of two interviewees representing high, average, and low connectivity to others within the group.

Interviews began in mid-November 2019 and concluded in mid-December 2019. Each interview session lasted between 46 and 83 minutes with a unique semi-structured protocol derived, in part, by data drawn from the social network survey. A template for the interview protocol can be found in Appendix C. At the beginning of each session, the research project was briefly described before each interviewee was asked to discuss their background in USER and affiliations to formal USER networks. Following their USER backgrounds, each interviewee was asked to elaborate on their social network responses with others in the survey. Participants were prompted to discuss how they met the individuals they signified in the survey, and how they would characterize their relationship. Following a re-introduction to other participants in the study, interview questions pivoted to emergent network functions derived from the literature review. Paying particular attention to how participants share information about their formal network functions, how individuals "make sense" of this information, and how this information is codified to outcomes or deliverables, the interviews focused on individual relationships or

chains of relationships and the role these relationships played in formal network-organizational needs.

Participants with median and high centrality composite scores were shown anonymized sociograms comprised of the social network data gathered in the first strand. These participants had their placements in the network revealed to them in the interview and were asked their initial reactions and interpretations of the social network. Those with low centrality scores had the sociograms described to them but were not physically shown any visuals. Their low centrality scores were also not revealed to them. This protocol was informed by literature on ethical considerations in social network analysis (Borgatti & Molina, 2003) and driven by reducing unintended harm to those who believed themselves to be more central actors. Near the end of the interviews, participants were asked about any additional nominations (if applicable) they added to the survey. The interviewees were specifically asked why they nominated certain individuals, and where they believed the nominated individuals belonged in the network.

Data preparation. After each recorded interview the audio files were transcribed verbatim within three days by the researcher. During transcription, all personal identifying information was removed and recoded with either a participant-selected or researcher-assigned pseudonym. The pronouns used for each interviewed participant were also randomized to further protect the participant confidentiality. All references or citations to other participants in the study were reassigned to either a pseudonym (if they were interviewed) or their participant identification number (if they were not interviewed) assigned in the social network strand. Following the transcription, transcripts were further cleaned to remove all verbal fillers, pauses, technical difficulties with Zoom, researcher introductions, and other irrelevant information.

Removing these fillers allows for the researcher to get closer to the data (Creswell & Plano Clark, 2011).

Prior to analysis, each interviewed participant was sent a copy of their transcript and asked to complete a member check. Member checking is an opportunity for participants to approve particular aspects or interpretations of the data they provided (Creswell, 2009). Although some authors argue member checking is better suited for themes or initial interpretations (Creswell, 2009; Doyle, 2007), ethical considerations of social relationships and an individual's role in the network precluded sharing initial analyses. For example, if a participant indicated themself as critical gatekeeper within this group, but no other individual indicated them as critical, member checking would be, at best, counterproductive. No other notations or follow-up questions were provided by the researcher in the member check. Participants were provided one month and asked to verify the transcripts and provide any notations, edits, or redactions. Four of the interviewees responded with no amendments, and two participants did not respond. Following the transcription and member checking, all data were loaded into NVivo for analysis.

Data analysis. Data collected through the semi-structured interviews were analyzed through thematic analysis. Thematic analysis is a flexible tool that helps to make sense of *messy* qualitative data (Boyatzis, 1998; Braun & Clarke, 2006, 2012; Joffe, 2012). I used Braun and Clarke's (2006) six steps of thematic analysis to guide my work; the six steps are 1) familiarizing yourself with the data, 2) generating initial codes, 3) searching for themes, 4) reviewing themes, 5) defining and naming themes, and 6) writing up the report. I began with the first step *familiarizing the data*, through transcription and subsequent reviews. Each of the semi-structured interviews were transcribed verbatim within three days of their completion. No automatic

transcription software was used. Each transcription file and audio recording were read and played simultaneously in totality at least two times before coding began.

Initial coding began with three thematic functions of an emergent network (knowledge diffusion, network learning, and innovation), where evidence of emergent network behaviors was sorted into specific areas. Through the coding process, additional sub-themes were identified. These themes spanned across the initial emergent themes, and provided additional environmental factors impacting the emergent networks functions. Each code was further contextualized and reviewed by the data until the set of themes became "coherent and distinctive" (Braun and Clarke, 2006, p. 88). Once the final codes were established, I returned to original interview transcripts to verify their fit with the holistic experiences described by the participants.

Positionality. Given the heavy capital investment and often contentious nature of undergraduate STEM education, this work necessitates some context and positionality on behalf of the author. As an organizational scholar, I acknowledge the pervasive power of social networks in informing much of an individual's understanding, perspective, and reality. I believe relationships are conduits for information, norms, behaviors, and more tangibly, opportunities. I attribute much of my personal and professional successes to my social connections. Indeed, I met my wife through a mutual friend. As a researcher, I serve as an assistant on a National Science Foundation grant studying the role of formal USER networks. This project seeks to understand the roles, lifecycles, and challenges faced by networks comprised of organizations. My initial introduction to USER initiatives was through this project, and my interactions with those within the space is what spurred the development of this project. My experiences within this space led me to believe those working in USER do so amicably and with the best intentions, but often have

many competing responsibilities that leave formal network organizational responsibilities to secondary tasks.

As a first-generation college student from the rural southern United States, I recognize the need to positively and sustainably reform undergraduate STEM education at all institutional levels. Science education at my secondary institution was underfunded and under-emphasized with few opportunities to engage in advanced scientific study. These experiences led to a confused and often timid reaction to all physical science and mathematics courses at subsequent education institutions. I reject the pervasive culture that substantiates exclusivity in the sciences and firmly believe the continuation of higher education's current role in the United States rests on its institutional ability to reform and advance the needs of students.

Conclusion

The call for more study into the existence and functions of emergent collaborative networks is as contemporary as it is necessary. The use of these networks as both a response to "wicked problems" (Rittel & Weber, 1978) and a lever for systemic change (Bryson, et al, 2006; Huxam & Vangen, 2005; Isett et al., 2011) far exceeds empirical understandings of their functions. Contemporaneous research must push beyond interpreting inter-organizational network reliance on the adage of "the network way of working" to describe the customs, cultures, and functions of emergent networks, and uncover tenets to network success (Popp et al., 2014, p. 28). Indeed, understanding networks successes and functions may very well predict how society overcomes the pervasive concerns of wicked problems.

In serving that end, this study uncovered one emergent network which exists alongside formal networks in the USER space. Through use of a sequential, quant-QUAL mixed methods approach, this study sought to understand the interconnectedness of otherwise assumed disparate

actors before interrogating their relationships (or lack thereof). The social network analysis operates as a critical initial step in establishing connections of leaders and theoretically pointing (through concepts of structural holes, closure, and tie strength) to relationship functions. The semi-structured interviews provide more depth, clarity, and nuance to relationships which cannot be captured from a single cross-sectional survey.

Through probing the emergent networks in USER, studying this phenomenon provides useful information to those operating within USER, and aid faculty, policy-makers, and funders to identify key places for change within the network landscape. It also uncovers potentially *untapped* resources within formal networks. More broadly though, this study adds to the literature by filling several articulated gaps across multiple disciplines. Through use of a requested, yet unique, approach to understanding emergent networks, this study may help practitioners, funders, and scholars truthfully begin to uncover what constitutes *the network way of working*.

Chapter 4: Social Network Findings

The first strand of the mixed-method study focused on gathering socio-metric data on the nominated participants. Concentrating on the first research sub-question (1a), this strand primarily sought to establish the social relationships among the participants and explore the interconnectivity of these relationships. Fifteen of the seventeen participants responded to the invitation and completed the survey. The data gathered captured individual demographic, educational and employment information, and individual formal USER network memberships. Specific social network data were captured through eliciting responses for participants in three separate domains. These social networks were: 1) Spoke about Network Business (*Business*); 2) Discussed STEM Network Problems (*Problems*); and 3) Sought Advice from this person to aid my network (*SoughtAdvice*). As mentioned in Chapter 3, *SoughtAdvice* was transformed to *GaveAdvice* to reflect information flows in the network. The following chapter outlines the initial findings and responses to the social network survey. Although this chapter is primarily organized around three different networks, all three networks pertain to the same individuals in the same contexts of USER. I conclude the chapter with preliminary findings, initial responses to my research questions, and an evidence-based discussion on the existence of an emergent network among these participants.

Results

Although networks were symmetrized in the data cleaning process, reciprocity measures remained moderately high prior to the symmetrization. High dyad reciprocity metrics represent high level of inter-rater reliability (Borgatti, Everett, & Johnson, 2018; Loitz, Stearns, Fraser, Storey, & Spence, 2017). High reciprocity scores similarly reflect a high degree of validity with the data as dyads are providing evidence of an undirected relationship. A table of the

Table 1. *Unsymmeterized Reciprocity Score for all Networks*

	Business Network	Problems Network	Gave Advice Network
Dyad Reciprocity	.6	.57	.29

unsymmeterized reciprocity statistics are found in Table 1. Note *GaveAdvice* was included in Table 1 to for completeness. The reciprocity for *GaveAdvice* is still moderate for a uni-directional network. A summary of participant characteristics is reported in Table 2 and Table 3. These data include information from the non-responsive participants. Twelve participants identified as women (71%), four men (23%), with one abstention (6%). A plurality of participants was in their 50s (47%). Reflecting the lack of racial and ethnic diversity in STEM, sixteen participants indicated they were white (94%), and one participant was biracial (5%). About 40% of participants were employed by a four-year, public research university, and about 30% represented education non-profits or education advocacy groups. On average, respondents indicated at least 23 years working in undergraduate STEM education reform efforts.

Identification of unique formal network memberships were critical to the study, as the researched questions inquired into emergent networks *across* different formal networks. Then different network affiliations reported are located in Table 3. Respondents indicated 19 unique formal USER networks located across the country and funded by both public entities and private foundations. The average number of USER network memberships per individual respondent was 3.41. The Bay View Alliance (BVA) and Accelerating Systemic Change Network (ASCN) had the highest representation in the group, but the majority of networks presented only had one individual involved.

Table 2. *Summary of Respondents' Characteristics (n=17)*

Variable	$\bar{x}$ (range)	Response Category	n	%
Gender Identity		Man	4	23
		Woman	12	71
		Prefer not to respond	1	6
Ethnicity		White	16	94
		Not White	1	6
Age Range		40s	4	23
		50s	8	47
		60s	3	18
		70+	2	12
Position		Faculty	7	41
		University Administrator	4	23
		Non-Profit Administrator	5	28
		Other	1	6
Tenure in STEM	23.4 (8-42)			
Primary Organization		Affiliated Non-Profit	6	35
		Regional Comprehensive College	1	6
		Liberal Arts College	2	12
		Research University	8	47
Number of Network Affiliations	3.4 (1-5)			

Table 3. *Summary of Respondents Network Affiliations (n=15*)*

STEM Network	n	%
Accelerating Systemic Change Network	12	71
Bay View Alliance	8	47
Roundtable on Systemic Change in Undergraduate STEM Education	8	47
Network of STEM Education Centers	6	35
AAU STEM Initiative	5	29
Project Kaleidoscope	3	18
Science Education Resource Center	3	18
Coalition for Reform in Undergraduate STEM Education	2	12
POD Network: Professional and Organizational Development	2	12
Building Leadership Capacity	1	6
Center for the Integration of Research, Teaching and Learning	1	6
Cottrell Scholars	1	6
Mathematics Teacher Education Partnership	1	6
Partnership for Undergraduate Life Sciences	1	6
Student Engagement in Mathematics through Institutional Network for Active Learning	1	6
Science Education for New Civic Engagement and Responsibilities	1	6
Transforming Education: Multidimensional Evaluation of Teaching	1	3
Transforming Education, Supporting Teaching and Learning Excellence	1	3
Venture Well	1	3

*Individuals could list up to 5 networks in which they belong. This increased the networks represented above the number of participants.

Business network. The business network results are presented in Table 4 and depicted in Figure 2. Functioning at one of the most basic levels of interactions, *Business* targeted a general exchange of information across the participants. This network and its cohesion statistics were meant to establish a baseline of how the disparately nominated participants interacted. Participant data in the *Business* provided insight into how this collection of individuals operate**.** The associated centralization statistics demonstrate a high level of interconnectivity across multiple areas. First, overall density for the network was 75% representing a high level of interconnectedness indicating 75% of all possible connections were present in the network. Degree centralization was 28% which indicated the network was not dominated by a single actor within the network. The betweenness centralization (closure) of 3.07% identified few gatekeepers across this network. The statistics for components (1), compactness (88%), and average geodesic distance (1.25) all represented a close, tightly linked group of individuals. Moreover, the absence of any cliques (fragmentation) also indicated there were few places of information bottlenecks with respect to participants speaking about the business items of their networks. Taken together all of these centralization and cohesion measures depict a highly connected network with few central or influential individuals dominating or affecting the flow. From a whole-network perspective, the *Business* network operated as a cohesive grouping of individuals who frequently share or speak about the regular on-goings of their formal USER network business and agendas.

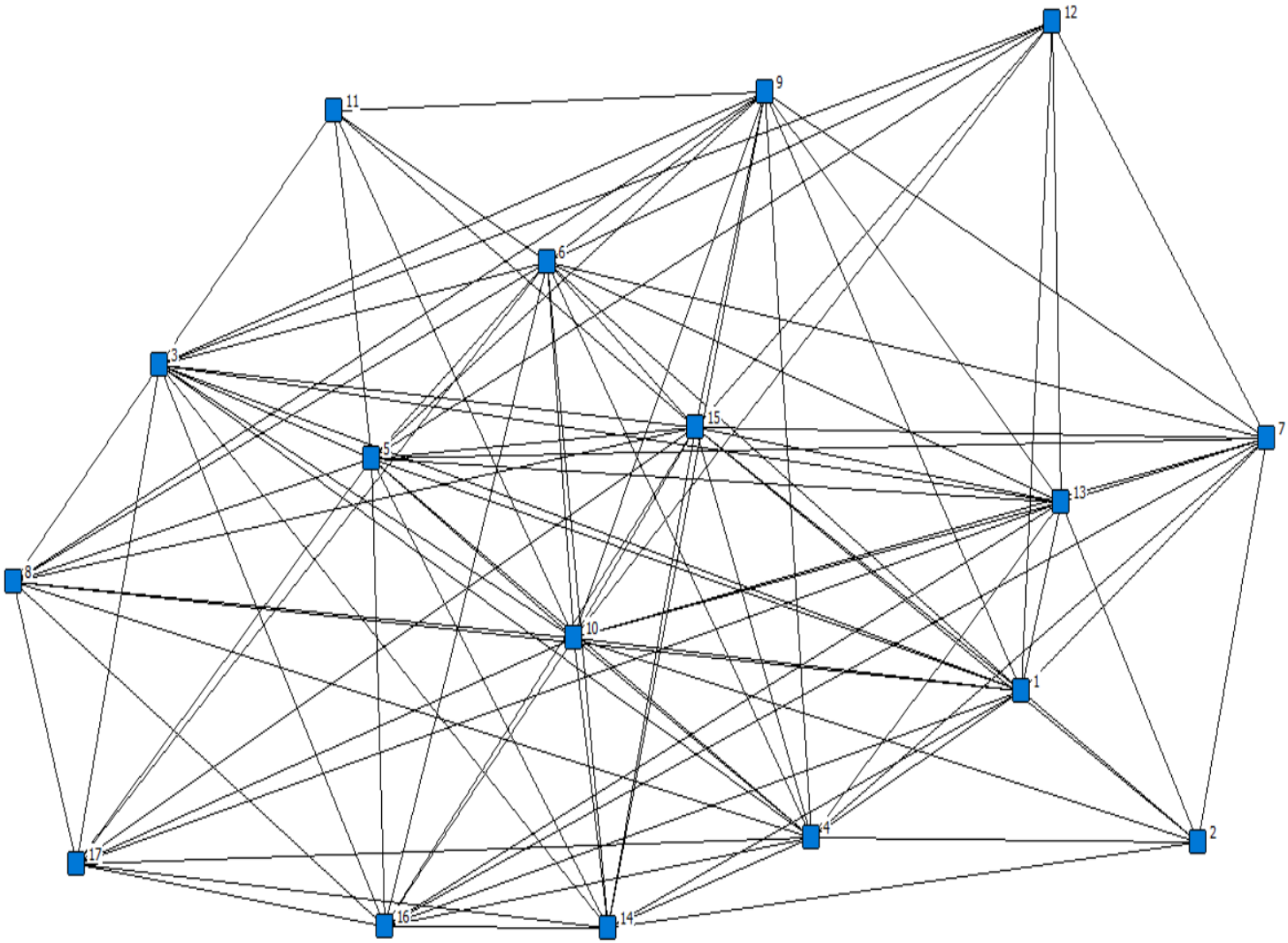
Although density and centralization are important indicators for understanding the whole network, they provide little insight into how the nodes are distributed or affected. In short, more characteristics of the whole network should not be confused with the individual's role(s). For a

better statistical understanding of how the node experiences the network, I measured individual node centrality and power. The average number of ties per individual in *Business* was 12 with a range of ties between 6 and 16 per individual. The modal number of ties was 14. Participant 15 had the highest number of ties (16), while participant 10 had the highest individual betweenness score. Participant 11 and 2 had the two lowest number of ties at 6 and 7, respectively. Individual betweenness scores also mirrored these nodes with individual 15 and 10 representing the highest (5.468) and Individual 2 with the lowest (.202). Betweenness and centrality statistics are depicted in Table 4.

After reviewing the centrality and power scores for each of the individuals in the *Business* network, I used a correspondence analysis to map and reinterpret the distribution of individuals around four factors of centrality (e.g., degree, eigenvector, closeness, and betweenness). Traditionally, the correspondence analysis is used to "help find patterns in a collection of specific measures" (Borgatti, Everett, & Johnson, 2018, p. 109). These types of analyses present a scatterplot of all individuals in the network and primary roles in the network. For my correspondence analysis, I included degree, betweenness, and closeness to represent connectedness, bridging, and proximity respectively. These types of analyses indicate trends in the primary role of individuals in the social network. For example, those who play a bridge in the network will have their node gravitate towards betweenness in the plot. Figure 3 shows the analysis for the *Business* network.

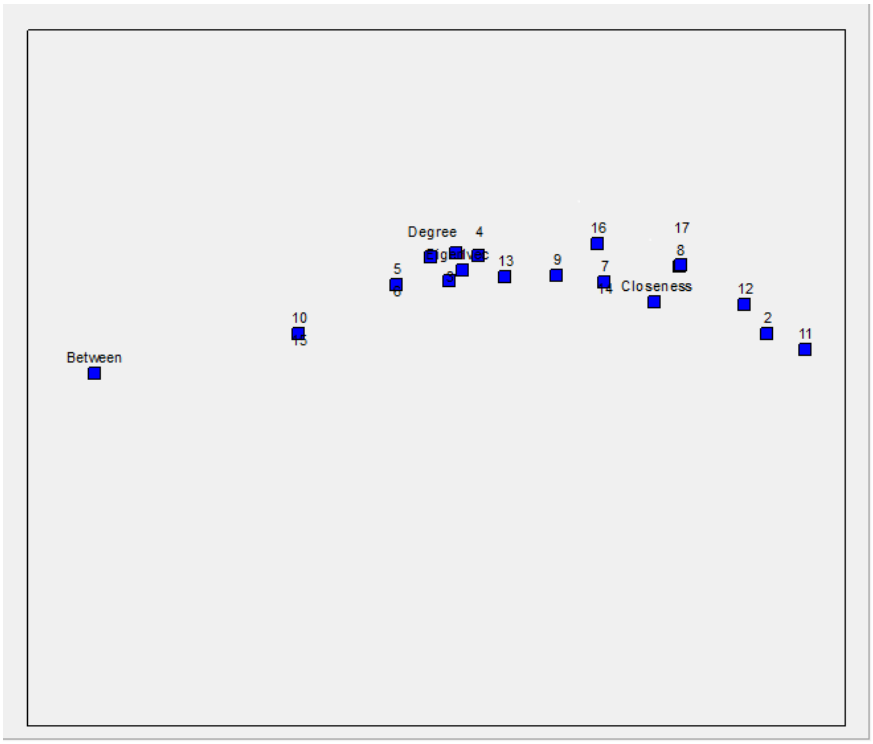
Most of the actors tended to gravitate towards areas signifying connectedness. These are reflective of high degree centrality and eigenvectors. Given the high levels of centralization and cohesion, this is not surprising for this network. As formal USER network items of business are

Figure 2. *Spoke about Network Business Sociogram*



rarely secretive it is logical that information flows relatively freely with few gatekeepers (i.e., low congregation of nodes around betweenness). The two nodes who are nearest to betweenness

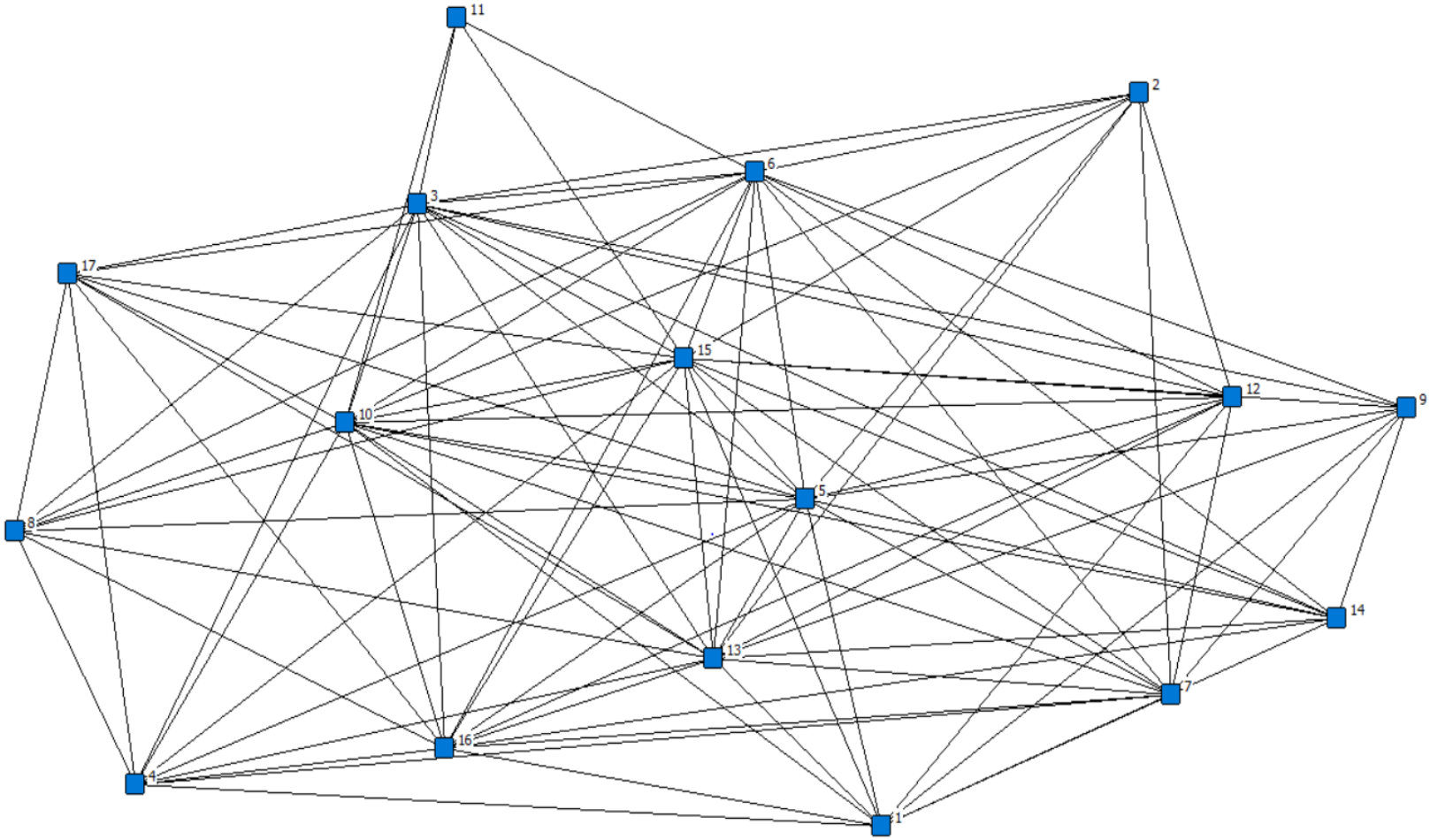
Figure 3. *Correspondence Analysis of Business Network*



are participants 10 and 15, meaning these individuals may serve conduits for information flows. Additionally, persons 2, 12, and 11 are situated on the edges of this representation and the associated sociogram (Figure 3). While not closely linked to many of the members of this network, these individuals may represent structural holes or places unique information enters the business network.

Problems network. Moving to a more specific network than conversing network business, the second network findings pertained specifically to discussing network problems. This prompted participants to think about large-scale problems their formal USER network may be facing (e.g., sustainability, financial resources, membership concerns, etc.). *Problems* aided in understanding how actors within the network may collaborate or cooperate. The results for the

Figure 4. *Discussed Network Problems Sociogram*

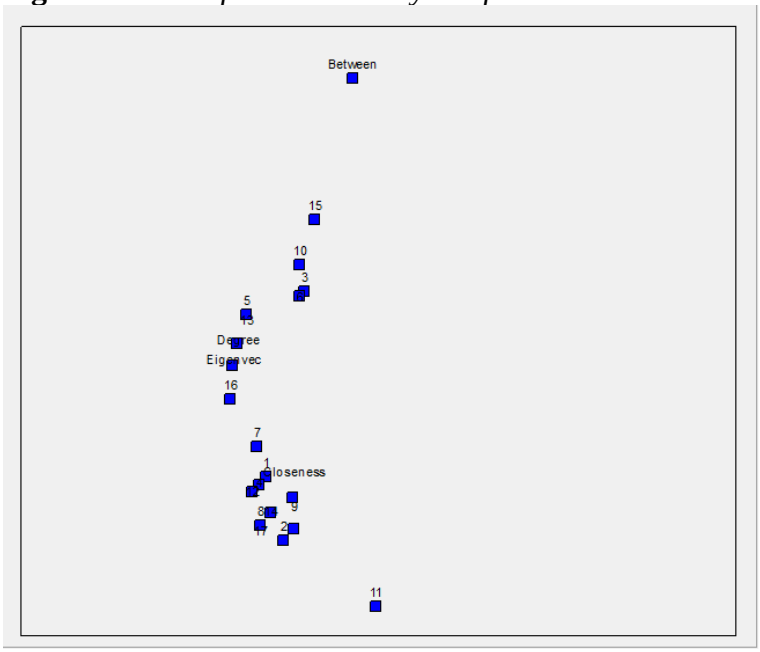


Problems network are in Table 4 and depicted in Figure 4. The measures for the *Problems* network are very similar to those in *Business*. The density for this network is 69.9%, which represented another high level of interconnectivity across the participants. Degree centralization was 34% indicating a moderate level of actor dominance within the network. Betweenness centralization (4.71%) and absence of fragments indicated there were few gatekeepers in the network, as actors who served as bridges were centered within the network. *Problems* did not yield any cliques or subgroup, but one large compact grouping of individuals. The average degree per participant was 11.176 (similar to 12 with the business network) with a range between 4 and 16, and a mode of 10. Findings for components (1), compactness (85%), and average geodesic distance (1.3) all represented a close, tightly linked group of individuals. Moreover, the absence of any fragments also indicated there were few places of information bottlenecks or disparate actors. In sum, the problems network is only slightly less interconnected when compared to the business network, and still highly connected.

With regards to individual node centrality and power in the *Problems* network, Participants 15, 10, and 13 had the highest number of ties and betweenness scores. Participant 11 had the lowest number of ties (4) and was on the periphery of the network in both their betweenness (0) and closeness (28). Figure 5 depicts a correspondence analysis for the problems network. This analysis shows more actors gravitating to factors of closeness. Those who do not center on closeness are being pulled towards both degree and eigenvectors. Again, Participants 15 and 10 tracked closer to betweenness, however their role is not as pronounced as it was in the *Business* network. Given the prompt for the *Problems* network specifically asked about with whom these individuals discuss their network problems, the nodes gathered around closeness centrality were expected; as closeness is often expressed as *a time of arrival* in networks, these

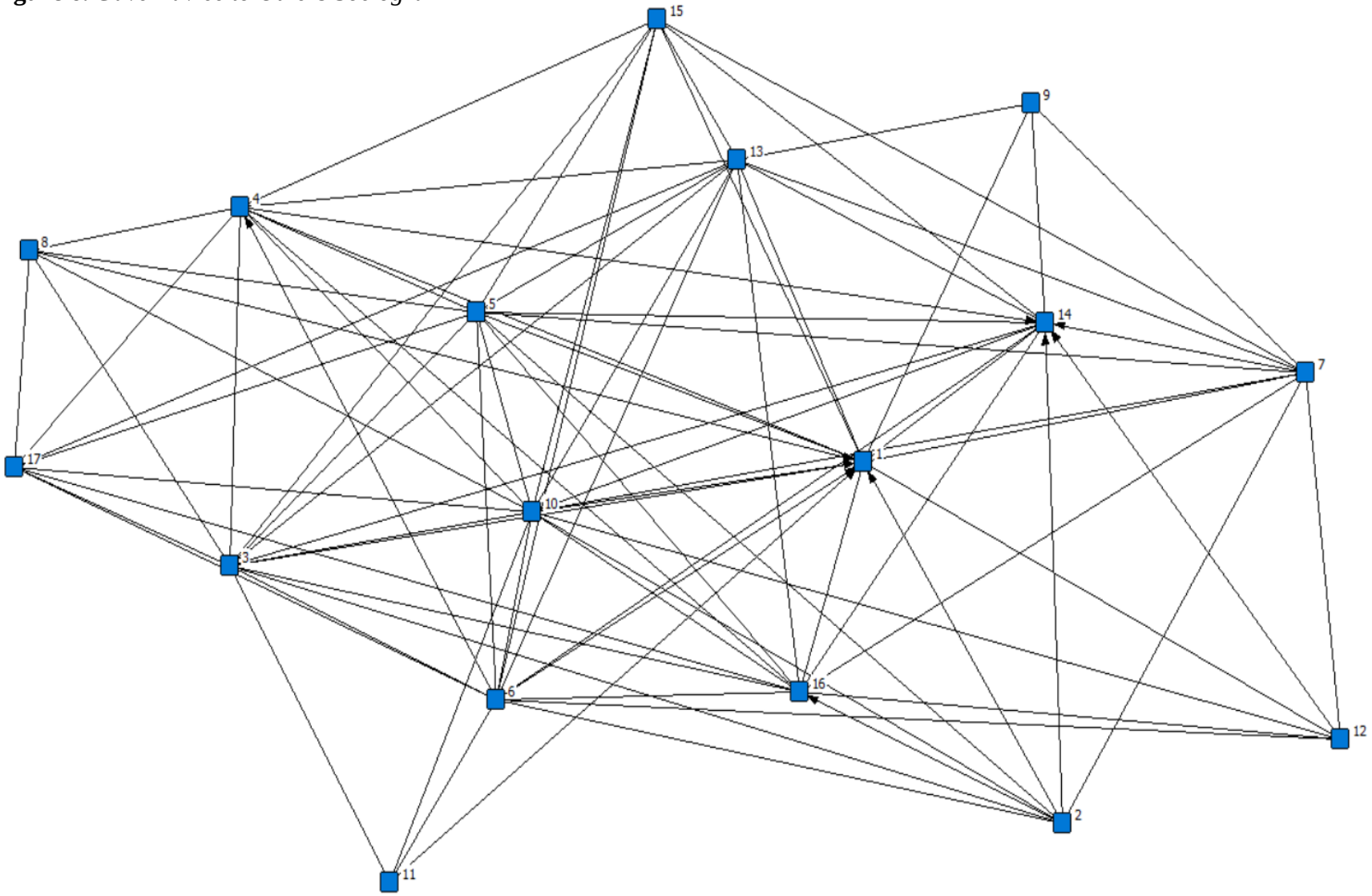
findings suggest participants are closely and quickly sharing information about their USER networks to a close-knit grouping of individuals.

Figure 5. *Correspondence Analysis of Problems Network*



Gave Advice network. The *GaveAdvice* network was the only network considered to be directed. This network was not symmetrized like *Business* and *Problems*. As mentioned, the process of giving advice is typically considered to be one-way, therefore, the network analysis should align with how the information flows (Borgatti, Everett, & Johnson, 2018). Despite not altering the data in the cleaning process, participant-indicated reciprocity remained near 30%. *GaveAdvice* was considerably less centralized and cohesive than the other two. Network density was measured at 40%. Similar to the other network's degree centralization was minimal at 24% and indicated a low degree of individual participants dominating network flows. Network betweenness centralization (4.71%) indicated the network gatekeepers were centered in the

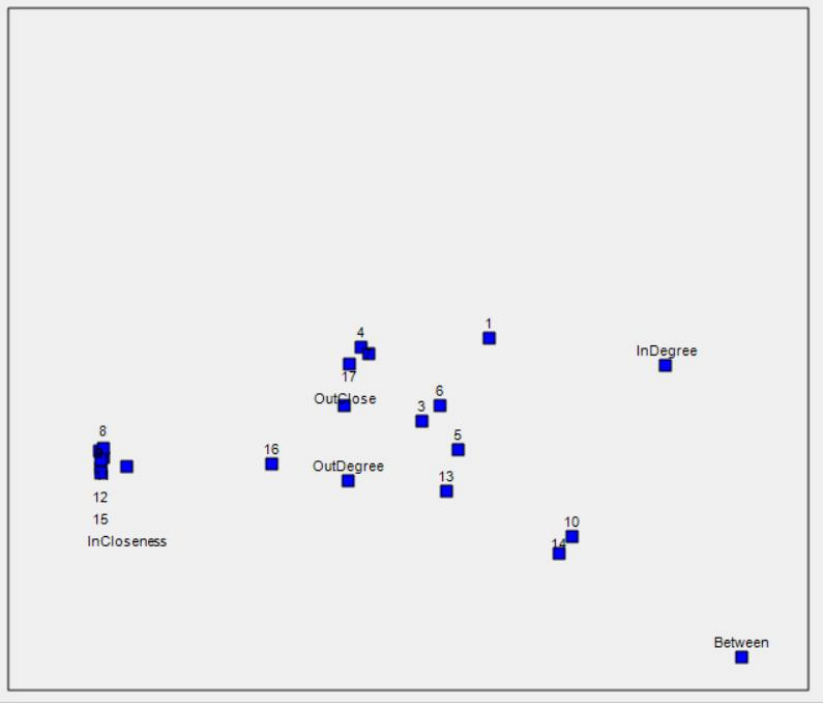
Figure 6. *Gave Advice to Others Sociogram*



network and did not inhibit flows through the network. Interestingly, the average geodesic distance (1.39) is like the same statistic in *Business*. This may indicate a similar rate of flow through the network. The average number of advisees (out-degrees) was 6.5 with a range between 3 and 10; the most common number of advisees was 9. More practically speaking, each of these statistics indicates advice was given throughout the network by many individuals in the network. The lower number of ties and lower betweenness indicate that these individuals may act as a *bottleneck* for advice.

Despite cohesion and centralization measures remaining moderately high, there are demonstrable differences between this network and the other two. Namely, the existence of seven components of the network resulting in semi-isolated groups within the network. Fragmentation in this network (.35) was moderately high indicating the existence of multiple dyads in this network that could be wholly disconnected if one individual is removed. The results for the advice network are represented in Table 4 and depicted in Figure 6. Each of the measured centrality and power scores are considerably more distributed in the *GaveAdvice* network. Participant 15 had the highest number of out-degree ties at 10, while participants 13, 10, and 5 each had 9 ties. More interestingly, participants 2, 8, 9, 11, 12 and 15 did not report seeking advice from anyone in the network (in-degree), indicating these individuals may rely on others outside of the *GaveAdvice* network for advice. Most notably, Participant 15, one of the most central actors in the other networks, is on the periphery of the Gave Advice network. This participant did not indicate seeking advice from any other participant in the study and may indicate a person who is either highly established in USER or an individual who is only partially involved in USER efforts.

Figure 7. *Correspondence Analysis of Advice-Giving Network*



communication and flow. Unlike the other networks, degrees do not play a large role in the network representing smaller groups of advice seekers. The disconnected dyadic tendencies are echoed with the fragmentation findings, meaning there are collections of individuals who seek and give advice relatively regularly, but primarily at the dyadic level. This reflects how advice is often given, through one-on-one conversations among peers. Interestingly, betweenness scores in the correspondence analysis are low. This also explains advice-giving relationships, as participants may not consider themselves to be *thoroughfares* of advice simply *transferring* advice from one end of the network to the other. Additionally, the relative absence of betweenness may indicate that advice seekers may not seek advice from those they do not know.

Centralization and centrality discussion. Centralization and centrality scores primarily aid in the interpretation of whole network structure and individual structural functions within the network. The primary goal of using these metrics was to first understand the existence of

connections across independently nominated leaders working in formal USER networks and interpret the degree to which these individuals interact. The results suggest a high degree of connectivity across several social functions, and individual members take different roles in different contexts. Additionally, this network appears to capture only a fragment of a larger emergent inter-organizational network operating in undergraduate STEM education reform.

Table 4. *Network Density and Centralization Scores*

	Density	Degree Centralization (%)	Node with Highest Degree Centrality		Between Central. (%)	Node with Highest Betweenness Centrality	
			ID	Ties (Normalized)		ID	Ties (Normalized)
Business	0.75	28.3	15, 10 5 6	16 (1) 15 (.938)	3.07	15, 10	15.468 (.046)
Problems	0.699	34.2	15 13, 10, 5	16 (1) 15 (.938)	4.71	15 10 3	7.726 (.064) 6.267 (.052) 5.66 (.047)
Gave Advice	0.408	24.6	16 5, 10, 13, 15	10 (.625) 9 (.563)	5.36	14 10	16.17 (.067) 14.38 (.6)

Emergent inter-organizational network structure. Centralization and cohesion measures were used specifically to assess the emergent network structure. Density, average degree of ties, and degree centralization provided a basic statistic for interpreting the level of interconnectedness. Despite the participants' independent and anonymous nominations, each of the networks presented a high level of connectivity. These connections are especially evident in the *Business* and *Problems* networks. The low-stakes of the *Business* network gave evidence of individuals freely discussing and sharing the on-goings of their individual networks, while the *Problems* network provides a foundation for understanding how the network may operate to tackle large-scale problems in USER. The *GaveAdvice* network takes another step in understanding how this group is internally dependent. The densities of these three networks offer insights into the lived emergent network structure by indicating the participants discuss their

formal USER networks, their associated problems freely, and seek advice from those within this study.

The magnitude to which a network was dominated by a small group of individuals was measured by average degree, degree centralization, and betweenness centralization. Average degree takes the mean number of ties for all members in the network, excluding any outliers who may dominate the network. Degree centralization highlights multiple factors for individuals' centrality in the network, where high degree centralization indicates a network connected by a small group of actors, the inverse is more evenly spread. High degree centralization is often associated with a group's ability to build trust and relationships, while lower degree centrality is associated with generating new information (Borgatti, Everett, & Johnson, 2018). Knoke and Yang (2008) stated inter-organizational groups should strive for moderate centralizations to maximize both benefits, although they grant context always matters in network analysis.

Average degrees fell in the high range, while degree centralization straddled moderate and moderately low. Degree centralization in the *Business* network seems reasonable considering the diffuseness and availability of network agendas, and the number of formal USER networks represented. The low degree centralization in *Business* may indicate a more widespread discussion of network business items and similar agendas across multiple formal USER networks. Similarly, the moderate level of degree centrality within the *Problems* network skews more to relying on trust and relationships to address network problems**.** This suggests a more familiar or trusting relationship across these individuals when trying to address shortcomings or challenges with individual networks. The lowest degree centralization in the *GaveAdvice* is sensible as this network is less dense and built upon directed information acquisition. The betweenness centralization (i.e., the degree to which a few individuals control the relationships

of other in the network) was also extremely low in all of the networks. This indicated that even in the least dense network, information could flow relatively free of gatekeepers.

When taken together, density, degree centralization, and betweenness centralization provide insights into how this group is socially structured. In general, these individuals know each other beyond simple acquaintances, and rely on one another for cooperation, problem-solving, disseminating information and general advice to support their formal USER networks. Although the full contexts of the relationships remain unclear, the prompts in which the participants responded gives some definition to how the relationships function. The absence of gatekeepers within the networks point to a collection of colleagues who operate as peers to generate or (re)interpret knowledge for the benefit of formal networks. This web of emergent networked leaders allows information and knowledge access to formal USER networks even if the individuals are not directly involved in that network's activities.

Dynamism of emergent network actors. Centrality scores were used to statistically describe the varying roles of individuals within each of the networks. Following the theoretical interpretations outlined in Chapter 2, both high and low centrality scores have benefits to the network. Whereas high scores may be associated with trust, relationships, and cooperation, low scores also provide the opportunity for more information or new thinking to enter the network**.** Participants highlighted in this section were selected by calculating the descriptive statistics for each of the centrality measures in each network. Individuals whose scores were consistently near one standard deviation above, below or at mean were selected for more investigation.

Participant 15 is a prime example of a highly connected and potentially influential person in this collection. They have high degrees, eigenvectors, and low closeness scores in all three networks. This participant has the highest betweenness scores of all participants in both *Business*

and *Problems*, pointing to a common person who is likely involved in many conversations across formal user networks. These statistics indicate a critical core member of the network, with one notable exception. Participant 15 does not rely on advice from any particular individual in the sample. Their betweenness score and in-degree for the advice networks are both zero. This is not to posit that Participant 15 does not seek advice, but rather they likely rely on connections in other areas not represented in the study.

The centrality scores and inferences for Participant 15 are supported by the demographic information provided by this participant. Participant 15 reported the second-longest tenure working in STEM undergraduate education reform. Participant 15 also indicated membership in 5 central formal user networks, and actually provided a follow up message including additional networks in which they belonged. Although none of the follow-up networks were included in the dataset, Participant 15 is highly involved in USER and seemingly highly enthusiastic about the work.

Similar to the previous individual, Participant 10 was also a highly connected and influential person in the networks studied. This person had high scores in degrees, eigenvectors, and betweenness with low scores in closeness, which indicated an individual who is likely part of many conversation across multiple networks simultaneously in multiple capacities. They likely discuss network business, problems, and give advice to many members of this sample. The critical difference between participant 10 and 15 is that the former is more central in the advice network. This indicates someone who is embedded more fully across networks who is giving and seeking advice from individuals who work in formal USER networks. The demographic information supports this claim, with this individual working as an administrator for a non-profit who has been working for a considerable time in undergraduate STEM reform. This person

likely is immersed through employment to gather and diffuse information and advice through the network.

Participant 13 averaged close to the mean centrality scores for each of the 9 vectors studied. This person was moderately connected to others and acted as a thoroughfare for information to certain individuals. This is particularly true for the business and advice networks. Interestingly, Participant 13 centrality scores were above the average for the problem network, indicating that while this person was loosely connected in other networks, they were often part of the conversations regarding network problems, or how formal networks can address these problems. These roles are somewhat supported by the demographic data provided by Participant 13. This individual highlighted they were employed by a non-profit as a staff member of a network. This may translate that the individual's employment is to help tackle problems or concerns with one specific network, but not necessarily disseminate those concerns to the network. Additionally, Participant 13 identified they were *relatively* new compared to other members working in undergraduate STEM reform. Their connections to others may still be forming as a result of their newcomer status.

Participant 11 presents an individual who is only loosely connected to the rest of the group. The degrees, eigenvectors scores and betweenness scores for this individual were low for all three of the networks studied. Despite lying in the periphery of the network, this individual was still connected to influential individuals within the network including Participants 10 and 15. This person also provided advice to other influential members of the network. The demographic information further confirms and contextualizes the role of this individual in the network. This person indicated they served in a long-time administrative position for a formal USER network

but has recently retired. They also reported the longest amount of time serving in STEM undergraduate reform of any of the participants in this study.

Finally, Participant 12 is another case of someone situated on the periphery of the networks. This individual scored low on all the centrality measures in the business network. Low scores in this network may indicate they are not necessarily engaged in cross-network discussions and may not have the opportunity to share. Interestingly, participant 12 scored closer to the mean in the other networks, indicating someone who may be referenced or consulted to aid in cross-network meaning-making or planning for problem-solving.

Inter-Organizational Network Properties

Just as critical to the findings of the social network analysis of the individuals nominated for this research was the study of their organizational interconnectedness. While fascinating, a simple study of leaders working in USER only captures their personal networks. In order to investigate the existence of an inter-organizational network among formal USER networks, I compiled the participant-provided data on their network affiliations in a 2-mode adjacency matrix. I used these data to draw centralization and cohesion measures, and centrality scores. This *Network of Networks* consists of formal USER networks as the nodes, and the ties represent shared memberships. Table 5 shows the centralization and cohesion scores for the user networks. Figure 8 depicts a visual representation of the reported formal USER networks in this study with each tie weighted by how many individuals share the affiliation.

The *Network of Networks* demonstrated a moderate degree of interconnectivity with a density of about 37% and an average degree of 6.7 ties. These centralization scores indicated the formal USER networks share a considerable amount of the participants in the study, and on average are connected to almost seven other formal USER networks. The degree

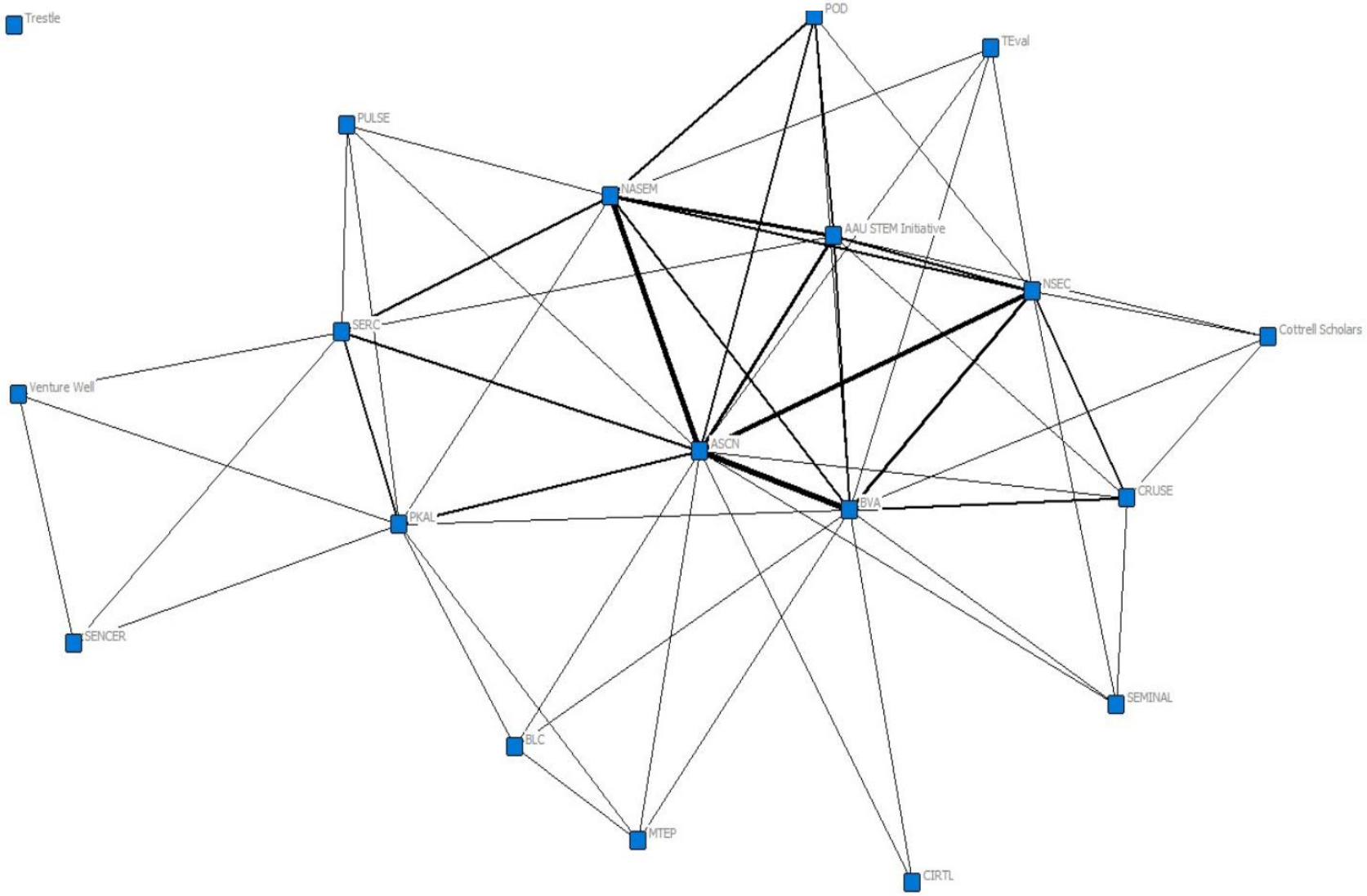
Table 5. *Network of Networks Density and Centralization Scores*

	Density	Degree Central. (%)	Node with Highest Degree Centrality		Between Central. (%)	Node with Highest Betweenness centrality	
			ID	Ties* (Normalized)		ID	Ties* (Normalized)
Network of Networks	0.374	51.3%	ASCN BVA NASEM NSEC	21 (2.11) 29 (1.61) 26 (1.44) 21 (1.16)	21.22%	ASCN BVA PKAL SERC	37.28 (0.24) 29.33 (0.19) 21.03 (0.14) 13.03 (0.09)

*Note individuals were polled to list up to 5 networks in which they belong.

centralization and betweenness centralization measures are high and moderate (respectively) for a network of this size, indicating there are several nodes which dominate the network . The nodes comprising the center of the network are also represented in Table 4 as having the highest degrees and betweenness scores. Contrary to the other networks, the ties in the *Network of Networks* are people (not social relationships), therefore certain networks appear to convene many of the leaders working in undergraduate STEM reform networks. As many of the participants in the study indicated membership in several formal USER networks, they will appear in multiple ties in this network. This core of formal USER networks is easily identified in the sociographic model of the network. Figure 8 displays the *Network of Networks.* Each of the ties in the model are weighted by the number of individuals with shared memberships in both he darker the line the more participants in the tie). The formal USER networks listed in Table 5 are both centrally located in the model and share several weighted lines with each other. This reflects both their high degree and betweenness centrality scores. Both the breadth and cohesiveness of formal USER networks represented in this study establish a suitable foundation of organizational connectedness to assert the potential existence of an emergent inter-organizational network.

Figure 8. *Network of Networks Sociogram*



Dyadic Properties

Moving beyond discussions of network structure and individual function conveyed in centralization and centrality, I explored the individual relationships embedded in the network. Investigating characteristics of the dyads provided insight into why individuals may have sought one another and identified patterns unrecognized by cohesion measures. One method used to analyze these patterns is multiple regression quadratic assignment procedure (QAP) models. This technique uses data permutations to create an expected model using ordinary least squares with a binary dependent variable. In this model, a dependent value of "1" represents the presence of a social network tie and "0" represents the absence of one. Employing permutations provides a basis by comparing each observation by the possibility of it being observed across all participants. These models identify homophilic and heterophilic tendencies within the socio-metric data. Homophiles are defined as the phenomena where individuals tend to gravitate to those with shared identities, and heterophilies are defined as the opposite (Borgatti, Everett, & Johnson, 2018). Given the literature discussion on emergent inter-organizational networks use of homophily in identity and heterophily in ideas as a guide, I used QAP modeling to explore patterns of relationships in the *Business*, *Problems*, and *GaveAdvice* networks. Each of the different computations used all of the categorical, socio-metric, and continuous data provided by the participants to predict the presence of a tie between any two randomly selected participants. Included in each of these computations were covariates for the other two networks. Results for the *Business* QAP regression are displayed in Table 6. Independent variable descriptions are located in Appendix D.

The results from the model show several factors predicting the presence of a tie in *Business*. First, the adjusted R-squared indicates a moderately high model fit, accounting for

almost half of the total variation in the data. Significant covariates in the *Business* network included primary organization affiliation, similar formal USER networks memberships, and presence of a tie in the other networks. Neither an individual's social identities nor their time working in higher education were significant in predicting a relationship. Within the significant variables, primary organization affiliation (e.g., research university, non-profit, etc.) had an inverse correlation coefficient, indicating individuals were likely to have a tie with an individual who did not share a similar primary organization type. A dyad was predicted by sharing a formal USER network membership with another participant. These relationships were

Table 6. *Business Network Multiple QAP Regression Model*

R^2	Adjusted R^2	Obs	Perms
0.50222	**0.48274**	**240**	**2000**

REGRESSION COEFFICIENTS

	Coefficient	p-value	As Large	As Small	Perm Avg	Std Err
Ethnicity	0.02434	0.72414	0.38131	0.61919	0.00034	0.07133
Age Range	0.05264	0.37031	0.18941	0.81109	0.00062	0.06035
Gender	0.05633	0.22589	0.10395	0.89655	-0.00049	0.04857
Primary Organization	-0.13501	0.0484**	0.97401	0.02649	-0.00386	0.07287
Position	-0.05004	0.49325	0.76512	0.23538	0.00149	0.07618
STEM tenure	0.132	0.36132	0.17441	0.82609	-0.00151	0.15748
Same USER Network	0.04391	0.09444*	0.04948	0.95102	-0.00132	0.02956
Gave-Advice Network	0.07157	0.09645*	0.05597	0.94453	-0.00009	0.04542
Problems Network	0.54256	0.0005***	0.0005	1	-0.00253	0.07516

* p≤0.1, ** p≤0.05, *** p≤0.01

certainly, expected in *Business* as members of the same network likely discuss their network's business with one another regularly.

I followed similar procedures for modeling the *Problems* network. This analysis switched the dependent variable (*Business*) with the covariate (*Problems*) and re-ran the model. All other covariates remained the same. This model predicts the presence of a tie between two actors who discuss major network problems (i.e., financial stability, sustainability, memberships, etc.) Results for the *Problems* network model are displayed in Table 7.

Table 7. *Problems Network Multiple QAP Regression Model*

R^2	Adjusted R^2	Obs	Perms
0.50259	**0.48312**	**240**	**2000**

REGRESSION COEFFICIENTS

	Coefficient	p-value	As Large	As Small	Perm Avg	Std Err
Ethnicity	-0.06195	0.32834	0.85657	0.14393	0.00469	0.06737
Age Range	-0.02004	0.72114	0.65717	0.34333	0.00143	0.0611
Gender	-0.02772	0.58621	0.69615	0.30435	-0.00156	0.05302
Primary Organization	0.02518	0.72664	0.37431	0.62619	0.00028	0.0766
Position	0.06733	0.36832	0.18741	0.81309	0.00104	0.07916
STEM tenure	-0.20259	0.0909*	0.89605	0.10445	0.00187	0.17291
Same USER Network	0.07493	0.0045***	0.003	0.9975	0.0013	0.02979
Business Network	0.61191	0.0005***	0.0005	1	0.00148	0.08832
Gave-Advice Network	0.12217	0.01***	0.0055	0.995	-0.00077	0.04972

* p≤0.1, ** p≤0.05, *** p≤0.01

This model demonstrates similar findings to the business network. The adjusted R-squared accounts for a similar amount of variation in the data. Social identities, primary organization affiliation and position within the organization were all found not to be significant. Having a relationship in the other networks was significant and a predictor of a tie. Time spent working in STEM (STEM tenure) was a notable difference in the *Problems* network. The negative correlation again signifies heterophily within this network, predicting ties among dyads with different experience levels. Although this variable is only significant at the 10% interval, it is markedly different than the outputs for the *Business* network. This heterophily indicated the possibility for more cooperation, as formal network problem solving was not resolved for a specific group of individuals. Shared network membership also remained significant in this network, and the correlation coefficient increased indicating a larger prevalence of predicting a tie in *Problems.*

The final QAP regression modeled data was for the *GaveAdvice* network. The same process for calculating the other models was used for this regression. The results for the *GaveAdvice* model are shown in Table 8. These findings predict the presence of an advice-giving relationship within the group of participants and again only track the existence of a directed relationship. As this network is unique to the other two, the regression model is distinct. Accounting for only 15% of the total variation, the adjusted R-square indicated there are many unspecified variables which account for an advice-seeking relationship. These factors are unobserved in this dataset. Social identities, STEM tenure and primary organization affiliation were not significant in predicting an advising relationship. The existence of a relationship in the *Business* and *Problems* network was significant in predicting an advising relationship, which is

Table 8. *Gave Advice Network Multiple QAP Regression Model*

R^2	Adjusted R^2	Obs	Perms
0.18497	**0.15307**	**240**	**2000**

REGRESSION COEFFICIENTS

	Coefficient	p-value	As Large	As Small	Perm Avg	Std Err
Ethnicity	0.06257	0.44978	0.21989	0.78061	-0.00556	0.09875
Age Range	0.09513	0.1949	0.09595	0.90455	-0.00027	0.07911
Gender	-0.02267	0.73513	0.65117	0.34933	0.00148	0.07109
Primary Organization	-0.06195	0.49575	0.75862	0.24188	0.00346	0.09738
Position	0.16441	0.09845*	0.04698	0.95352	-0.0023	0.10462
STEM Tenure	0.34255	0.08346*	0.04348	0.95702	-0.00137	0.20747
Same USER Network	0.03696	0.32734	0.14643	0.85407	-0.00234	0.0406
Business Network	0.1649	0.09895*	0.04448	0.95602	-0.00134	0.10605
Problem Network	0.2496	0.01099***	0.0035	0.997	-0.00391	0.10387

* p≤0.1, ** p≤0.05, *** p≤0.01

logical considering the familiarity needed for an advising relationship. The role of STEM tenure increased, and its coefficient flipped from negative to positive when compared to *Problems*. These statistics point to people seeking advice from peers who have with worked for a similar amount of time in reform. Institutional position also had a significant homophilic role in this network, where individuals often gave advice to those in similar position. This may be impactful in institutional diffusion.

Network Dyadic Properties Discussion

The QAP modeling primarily aided in understanding individual participant preferences within the larger network discussion. Whereas centralization and centrality measures relied on

defining network structure, boundaries, and potential gatekeepers, these models begin a preliminary investigation into how the emergent network is operationalized. While the regressions are limited in their ability to quantify the lived experience of individuals in the network, they do provide insights into group tendencies and, more importantly, what should be further probed at later stages. The following discussion highlights four findings from a cross-models comparison and underscores these findings with both limitations and further questions.

Complexity in relationships. As social interactions drive relationships, the oversized role of the social networks predicting relationships is not surprising. Each social network used as an independent variable in the models was significant in predicting a tie and typically carried the largest correlation coefficients within the networks. Not only do these findings indicate that the presence of a tie in one network predicts a tie another USER social network, but also relationships are one of the best indicators in the dataset. Their significance moves the interpretation of the centralization measures forward by using all three networks simultaneously in a model to predict network structures based on relationships in other domains. Their significance also begins a foundational understanding to the depth of relationships shared by individuals within the networks. As mentioned in earlier discussions, each network pertains to a different domain of formal USER networks. These models indicate the layering of the networks and that individuals rely on their existing relationships across the different domains; specifically, the social interactions are highly correlated between *Business* and *Problems*. This points to similar people discussing network business in tandem with inherent problems with networks may occur more frequently. These relationships (and subsequent conversations) occur both within and between formal USER networks as evidenced by variable *Same Network Affiliation* differences in significance between *Business* and *Problems.*

The lower correlation among *GaveAdvice* and the other two surveyed networks was also expected. As advice-seeking behavior is typically not at random, its correlation is much smaller than those with whom one simply shares USER network business. Lower coefficients point to individuals speaking broadly about business, and problems, but only giving to advice to few within the group. More importantly, these correlations also indicate a hierarchical relationship among the dyads, where 1) individuals speak to many individuals in the business network, 2) speak to a smaller subset of the same individuals within the problems network, and 3) provide advice to an even smaller subset of those individuals. The relative correlations are also supported by the descending density scores of each network outlined in the centralization discussion.

Organizationally focused dissemination. Beyond the discussions of layered relationships within the network, the models demonstrate divergent foci in their respective network domains. In particular, the *Business* network depicted dyadic patterns consistent with organizational affiliations; these patterns were not observed in the other two networks surveyed. Significant variables in *Same STEM Network Affiliations* and *Primary Organizations* indicated a pattern of information sharing across organizational boundaries. The negative coefficient with *Primary Organization* denoted a heterophilic tendency of participants to share formal USER network business with those who belonged to organizations different than their home institution. Given the diversity of organizations represented in this study, this finding shed light on dyads existing despite organizational boundaries and sectors (i.e., research university, liberal arts colleges etc.). These relationship patterns are especially salient considering the role of non-profit organizations in the funding, direction, and operation of formal networks. Note this finding only includes a select number of organization types. No community colleges or for-profit universities

were represented in this study. This finding suggests a low barrier for organizations which have individuals highly involved in USER but sheds little light on the barriers for other institutions.

The variable *Same STEM Network Affiliation* was also significant in *Business* and has implications for how this network influences its organizational affiliations. This variable's significance indicated homophily in participant dyads when they share at least one network in common. This is a logical interpretation, as one expects the participants to discuss their network business with others within the formal USER network. However, no two participants share the exact same formal USER network affiliations. These intra-formal USER network discussions may serve as a base point for information diffusion to other networks as members talk about their business. More investigation is needed in this specific area to fully understand how information flows through dyads within the same network to divergent formal networks. More thorough investigation is needed in this area to fully understand how information is flowing through this network.

The level of organizational involvement is unique to the *Business* network. As the prompt asked individuals to indicate with whom they "spoke about network business," these findings may express a more organizational diffusion purpose to this network. This is accentuated by the near collinearity of *Position* and *Primary Organization* (where one would expect both variables to be either significant or not significant) yet the latter is significant while the former is not. In essence, participants involved in the study may share their formal USER network business with those in similar colleges or universities and not with those who share a similar organizational title. This finding supports literature indicating tribalism among higher education sectors.

Individually focused collaborations. Moving from the organizational themes in *Business*, the other two networks reflect more individual-oriented dyads. This may reflect a more

collaborative focus of both *Problems* and *GaveAdvice.* Whereas *Business* sits in a domain of basic information sharing (e.g., spoke about network business), these networks front a more intentional request for information or general collaboration. Both also require a higher level of involvement from the reciprocating individual. The different characteristics in the latter two networks portray different findings and raise additional questions.

First and foremost, the null findings in the *Problems* network, particularly with *Position,* depict a group of participants who openly interact regardless of institution type or position held. Granted, these models do not fully account for each individual's various human capital. The null finding supports the network learning and innovations functions outlined in the literature on emergent networks. Critical to both of those functions is an open and collaborative grouping of people. Within *Problems* the heterophily in STEM tenure may indicate a collaborative behavior of individuals in the network as they engage with members of different experience levels to address problems within their networks. While this finding reinforces the concepts of collaboration within the group of participants, it contextualized the information sharing as dependent on time within STEM. This may mean individuals newer to STEM may bring fresh ideas into this group for discussion across experience levels. It suggests more experienced individuals sharing strategies or techniques for working with problems with less experienced individuals. The latter of the two explanations may also point to a certain level of socialization within this group. Given these are all nominated leaders in formal USER networks, the socialization may posit an orientation to cross-network work (and not an introduction to formal USER networks themselves).

Not significant social identities. None of the social identities collected demonstrated a capacity to predict homophily or heterophily. There are multiple interpretations to these findings.

The first interpretation is that social identities play no role in connecting individuals working in USER. While the outputs of the model support this interpretation, this is likely not the case. More reasonably, there is a considerable lack of diversity in the participants nominated. Almost all the participants identified as white, and a super majority identified as women. Almost half of the sample indicated they were in the 50s. This lack of variation in the data most certainly limits the interpretation of the role of social identities in dyads. While this lack of diversity does cause disruption in the interpretation of the findings, it does reflect the lack of diversity of those working in USER. For example, countless articles (e.g., Kezar & Holcombe, 2019; Mack, 2019) point to the prevailing whiteness in USER, and Kezar and Gehrke (2015) highlighted the burden of women in undergraduate STEM education reform.

Dyadic modeling limitations. The significant patterns in relationship seeking identified in each of the models are supported by the emergent network literature in both organizational dissemination and interpersonal collaborations. As denoted in Chapter 2, diffusion, network learning, and innovation were the major functions of these networks (Isett et al., 2011; Popp et al, 2014). These findings, nevertheless, fall considerably short in three major areas. First, the patterns unveil nothing of human capital, influence or intentionality within the network of participants. Simply stating the patterns exist is a critical first step, but they do not confer causality, an individual's level of influence, or why two individuals work with one another. Second, the models do not account for information flows. Despite the directness of the social network survey prompts, their responses were open to the participant's interpretations. Questions about *what is shared, why is it shared,* and *how is it shared* all remain unresolved by the models. Third, multiple independent co-variates remain unexplored in the error. This is particularly salient in the *GaveAdvice* network, where only 16% of the total variation was explained.

Conclusion

With regards to the research questions, the social network analysis provides some answers, and aids in the focusing of others. In consideration of research question 1a) how interconnected are leaders across formal network, the data demonstrate a high degree of interconnectedness across multiple domains. These disparately nominated individuals know almost every other nominated individual and communicate regularly. Moreover, the density of these networks also provides insights into the emergent network structure. Based on the social network data, few gatekeepers to information exist within the network. In consideration of research questions 1b), 1c) and 2, the social network analysis demonstrates the opportunity for knowledge diffusion, network learning, and innovations to occur, but delivers little in fully realizing these processes. Although one may assume these emergent networks are occurring, these data lack depth and clarity to many of the nuances and subtleties of emergent network activities. The following chapter discusses the findings from the qualitative inquiry into the lived roles of the participants in this study and uncovers more information on how the emergent network is operationalized in formal USER network efforts.

Chapter 5: Interview Findings

The second strand of the study gathered and analyzed more contextualized data on the roles of the relationship web established in the social network survey. Conducted as a separate strand of the study, the interview data provide insights on how relationships were actualized among the participants and how their collective actions contributed to this group serving as an emergent interorganizational network. Although the data from the social network strand were available at the time of qualitative analysis, this chapter only speaks to qualitative findings which emerged from interviews. The integration of both strands' findings is located in Chapter 6.

In designing a mixed-methods study Creswell and Plano-Clark (2011) stated one of the strands may carry greater "emphasis" (p. 194). Referring to either qualitative or quantitative techniques, *emphasis* is defined as a study's strand which is better suited to address the research questions. Granting a strand emphasis in a study also acknowledges the findings as being more substantial in explaining the phenomena. In Chapter 3, the interviews strand of the research design was highlighted as the more dominant (i.e., emphasized) aspect of the study. As the interactions and impacts of emergent networks are at the core of my research questions, the qualitative data collected in this strand were better suited to understand these phenomena. While social network design (the first strand of the study) was helpful in illustrating the connectivity of individuals in the network, it did not carry emphasis in the study as it is not methodologically suited to answer the majority of the research questions. As highlighted in the conclusion of Chapter 4, social network techniques were greatly limited in their ability to interrogate experiences, knowledge exchanges, and depth of relationships.

Participants were selected for interviews by their standardized composite centrality measures collected in the social network strand. Two participants from those with the lowest,

average, and highest standardized composite centrality scores were interviewed, resulting in a total of six interviews. The following chapter outlines the findings and responses from the individual interviews and does not include many direct quotes from participants. The interview protocol asked participants to discuss their actions within a network, their network membership(s), employment, and social circles related to USER. Given the questions' high degree of specificity and relatively small number of individuals working as leaders of networks, direct quotes were not an ideal method for sharing findings and presented unforeseen challenges. If quotes were inserted as spoken, they would often belie confidentiality through the participants' network membership, employment, or social connections. If pseudonyms were used however, the quotes would lose their intended effect and muddle the point. In the end, quotes were only used when redaction was not necessary or the quote was imperative to the discussion. The contents of this chapter include: (1) an overview of each interviewee; (2) larger cross-interviewee trends that support how the participants work collectively; and (3) a discussion of how their collaboration serves as an emergent USER network.

Participant Profiles

In working with qualitative data in mixed-methods designs, Creswell and Plano-Clark (2011) stressed using participant profiles to preserve the human aspects of the study. Arguing data-mixing often muddles or dehumanizes qualitative data, participant profiles provide audiences with a window through which to see participants (Creswell & Plano-Clark, 2011). In the spirit of *preserving the human aspects of the study*, I provide thematic profiles of each participant's experience prior to the integrated analysis. Each participant profile uses an assigned pseudonym and randomly generated gender pronouns. These steps were taken to further protect participant confidentiality.

Each of the profiles presents participant experiences as related to three functions of an emergent interorganizational network. Outlined in the literature review, the functions of an emergent network are centered on major actions members take in serving their convening purpose; these functions are knowledge diffusion, network learning, and innovation (Popp, et al., 2014). Knowledge diffusion referred to the ability of an emergent network to share information both within and outside the emergent network. Network learning was defined as a meaning-making process where emergent network members take lessons from their respective organizations to draw larger field-based perspectives. Innovations referred to outputs or contingencies the emergent network created to address shortcomings in members' home organizations. Specific to undergraduate STEM education reform (USER) efforts, each profile outlines the participant's definition of knowledge in USER and how knowledge is exchanged throughout the network. The profiles highlight participants' responses on network learning and other collaborative actions and conclude with a discussion of their role in creating new strategies or initiatives in USER. Each profile is presented alphabetically (by pseudonym with a randomly assigned gender), and the ordering is unimportant to the findings.

Allie. Allie is the longest serving USER-related professional in the study. Despite not having a STEM-related degree, Allie founded an influential formal USER network. Over several decades Allie has received high profile grants and other funding. Other participants described her as an avid consumer of formal network reports and scholarly articles in STEM education. One participant mentioned, "I was at a conference and saw Allie carrying around one of my papers. She even cited it in a presentation! As a young professional that blew my mind!" (Andrew). Although Allie has remained in close connection with those working in USER, she does not actively participate in formal USER networks.

Knowledge definition. As Allie has left the USER network space, most of her discussions on knowledge and transfer were either framed in the distant past or in the context of a few current interactions with professionals in USER with which she spoke. Regarding the concepts of knowledge, Allie primarily discussed organizational outputs like grant reports, research, official national association or foundation publications, and other literature pertaining to USER. The documents contained findings she believed useful in the context of USER. This knowledge originated from large, established organizations like colleges and universities, and the National Science Foundation. She stated these documents contained valuable findings on the state of USER, formal USER network successes, funding organization priorities, and new potential funding opportunities. They also "kept [her] current" with influential individuals working in the space (Allie). During her interview she referenced seventeen separate reports pertaining to USER dating from 1988 to 2018. Most of the documents she referenced were annual National Science Foundation (NSF) grant reports of formal networks operating in USER. Similarly, Allie spoke of formal USER network operations and outputs (e.g., research, publications, press releases, grant reports) as a knowledge base. She believed her work in USER helped to shape conversations and decisions in national associations. "Within 4 years of [our network] starting, reviewers and funders were reporting back to me and saying how often others were citing our efforts and events as transformative" (Allie).

Aside from tangible network products, Allie also indicated knowledge generated from operating and leading a formal USER network. She described this as the "know-how" of running a nationally-funded network and included logistical knowledge on how to file grant reports, recruit members, budget plan, or plan an event. "You see many of the people in STEM are trained in their disciplines and usually don't get training on how to work with people" (Allie).

Allie indicated her experience in running a network was highly sought after by those in USER. According to Allie, the knowledge of how to run a formal network provided her the opportunity to interact with people across STEM disciplines. She was often approached by leaders in USER (primarily in physics, mathematics, and chemistry) for advice on how to form a network. She attributed her work with those USER leaders as critical to her success, as she learned discipline-based language, norms, and behaviors, which provided the necessary buy-in from others imbedded in the disciplines. She mentioned her work with a physicist in Wisconsin "[he] said, oh Allie, you can't say that, everyone will immediately stop listening to you…" (Allie). Knowing different STEM discipline norms and behaviors aided her to cross discipline boundaries and speak to a broader field of leaders in USER. She felt ill-equipped without the knowledge on how to speak to others and said reform work was pointless until you could communicate. "It's the due diligence part of change, knowing what others are doing so you don't repeat their successes or worst of all, their failures".

Network learning. Allie spoke directly to how she believed other participants in the study enhanced learning. Likening her experience with network learning to J.R.R. Tolkien's *The Hobbit,* "I really like the metaphor of there and back again. That is what we do. We have people develop a plan to take out to their group then report back." This metaphor fits with the network learning definition of sharing organizational information with the network for greater understanding of field-level problems. Filtering information out of the network to the organization, then back to the network is a critical aspect of network learning as it provides content for the meaning-making processes of learning.

Allie highlighted consensus building and coalition building as two critical aspects of network learning. For consensus building Allie lamented the lack of agreement across STEM

academic disciplines and indicated the work of networks was to build consensus on new norms, behaviors, and language to enact change. “[Our meetings] were not just people coming to a conference and smiling for two days then going home with nothing and changing nothing” (Allie). In short, consensus building was necessary for the different people in USER to speak to one another. Second, Allie argued coalition building was also important to network learning, stating that learning needed passionate people with different approaches. She was adamant she attended conferences to “cherry picking the provocateurs, outliers, and change agents” to build a group for network learning (Allie). She felt working with the “outliers” was the best way to initiate change.

Innovation. Allie spoke of several different products derived from her work with other leaders in the study. Given her desire to seek out “outliers and provocateurs,” much of the innovations she discussed were directly linked to the formal USER network she helped to found. These innovations included additional grant proposals both related and unrelated to her USER network, various whitepapers associated with the state of USER, and collaborative workshops. Each of these different products were in association with, or inspired by, another individual within the study. The proposals written in conjunction with others in the study were typically directed to funding organizations while whitepapers were directed to be more of a “press release” or “state of the field” in USER networks. Interestingly, Allie stated she considered herself to be a consumer, not producer of scholarship. She did not attempt to produce any original research in USER.

Andrew. Andrew is a STEM faculty member working at a research institution. He received a STEM-related terminal degree and cited two other non-interviewed participants as “old friends” and “grad school drinking buddies” from his time as a doctoral student (Andrew).

Andrew is also a founder of a formal USER network and serves as a primary investigator on multiple USER grants. This participant considers himself to be heavily involved in USER. In addition to his work as a tenured faculty and researcher, he also assists with operating a Center for STEM Education improvement on his home campus. Andrew indicated a significant amount of his time is dedicated to "leading and advising" two formal USER networks.

Knowledge definition. Similar to Allie, Andrew primarily centered his definition of USER-related knowledge to his work with a formal network in USER. For him, *knowledge* was represented in three ways. First, Andrew described knowledge as STEM education expertise existing in other "scholars" working in STEM education. He clarified by indicating expertise was related to evidence-based curricula and pedagogy, and the point of USER was to share that expertise for systemic change in STEM education. Indeed "that is the whole point of networks, to share expertise. We need some mechanism for sharing, because the disparate approach does not work fast enough" (Andrew). Andrew was adamant the pedagogical knowledge was not enough to leverage change, and that expertise on how pedagogical change could occur was more difficult and precious as there was no single universal strategy.

Second, Andrew described a body of knowledge related to formal networks. Again, described as expertise, this area focused on the establishing, funding, governing, and sustaining formal networks in USER. As a trained STEM scientist, Andrew articulated a lack of confidence in his ability to run a formal network without consulting others with experience in networks. Andrew also discussed seeking out "credible" knowledge from people affiliated with multiple organizations. He mentioned he often sought knowledge from these "well-connected individuals" as a means to contextualize ideas or initiatives within his formal USER network.

> Well I mean [there are several people] who are on just about everything in STEM reform. They have a lot of experience doing a lot of different things in

> this space and have, you know, a lot of credibility with others out there…they understand the possibilities, how you would frame things, and that kind of stuff. (Andrew)

For these particular contextual knowledge holders, Andrew stressed the importance of their multiple USER-related affiliations as a driver for his formal USER network consultations or even inclusion in his USER network. He indicated those with the contextual knowledge in USER drastically help improve the network. He identified four individuals with whom he sought advice regarding formal networks. Andrew further clarified by indicating the relationships he had with those individuals provided a window into the operation of different formal networks and helped him to shape his own networks. "We really tried to look at other organizations that had been successful and use some of the tools they were using" (Andrew). Nevertheless, the relationships Andrew had with the four individuals he cited pre-existed any formal network affiliation. Andrew knew these people prior to formal networks, which he stated, drove him to contact them for advice.

Third, Andrew indicated personal information was a knowledge form across some but not all individuals. This included knowing others personally, their backgrounds, hobbies, interests, families, and politics. Andrew said knowing personal information about others working in USER was not a necessity, but "it was nice". He indicated sharing personal relevant information helped him trust others within the space aiding in him sharing potential pitfalls or challenges within his formal USER network. Andrew also indicated several of the other participants as long-time friends and even "conference drinking buddies" with whom he could regularly share information.

Knowledge exchange. Andrew cited multiple venues and mediums where he believed people shared their knowledge with others. Not surprisingly, Andrew indicated that personal

relationships were the single greatest asset in formal USER networks. If he was friends with someone, he would simply call them and ask his question. He quickly identified three people within the study whom he would call to ask a question. Outside of personal relationships, Andrew underscored the role of small conferences as a place to share knowledge. He was adamant that small science education conferences played the largest role in providing a venue for people to connect and share information pertaining to USER. The small size of the conference was very important as its purpose often felt more targeted to Andrew. He specifically spoke of a conference that he helped organize which directly led to one of the first convenings of the formal USER network he founded. "We pulled together a small conference of change strategists in higher education here in town, we had something like 40 people come with some great speakers. Ah, we were so young and naïve then..." (Andrew). Formal network leadership roles (e.g., president, chair, or director) were also highlighted as a venue where formal network knowledge and expertise was shared with others. These *leadership roles* often took the form of primary investigator, network elected official, hired network consultant, or membership on steering committees or advisory boards. According to Andrew, sharing knowledge was the point of these leadership positions. "Look we are all science faculty with other things to do too. We have to rely on one another for ideas because we cannot tackle this alone" (Andrew).

Coalition building. When prompted about network learning, Andrew spoke more about how he worked to involve critical stakeholders in developing or growing formal networks. For Andrew, building relationships with others predated their work in formal networks, but was the cornerstone to their work now. Andrew outlined how and where he met many of the other study participants at various USER-related events; he called them, "conference pals". Their shared passion for STEM education formed a strong relationship in opposition to the complex problem

of institutional reforms. Andrew said over time, the budding conference pals became partnerships, co-PIs, and advisors with whom he could consult for initiatives or problems. If he needed advice for a network, he could consult some of his old conference pals for approaches to the problems Interestingly, many of the *conference pals* shared similar network memberships.

Conference pals also could also be a benefit when applying for funding from USER grantors. As a trained disciplinary scientist, Andrew explained he did not get much exposure to other USER-minded professionals in other disciplines. Working with his conference pals, he was able to build a case for funding an inter-disciplinary team which helped his chances of receiving funding. When discussing the content of his proposals he stated he "tried to think of portfolios, and what built off the work of other organizations…we really tried to think about the national level, and what is the national academies saying?" (Andrew). If he needed experts in specific disciplinary areas (e.g., chemistry, biology, etc.) to increase his chances of funding he would check-in with his colleagues and invite some to join his initiative.

Innovation. Andrew spoke primarily about using innovation as a way to monetize and support existing formal networks. Focusing on network longevity (especially post-grant-funding) he spoke about ways to monetize formal network by selling services to colleges, universities, or other postsecondary affiliated organizations. Included in this discussion was the possibility of selling some network products to other formal USER networks. This could be research on network effectiveness or even network organizational consulting. Each of these areas "seems like a good opportunity to get funding in a place where no work was being done" (Andrew). The strategies discussed were presented as way to maintain existing formal networks and continue their work as non-profits advocating for USER. Andrew's largest questions on monetizing network services primarily came from how to enter a traditional market: "If we started selling

things, what would we sell and how much would we need to sell them for in order for it to make sense" (Andrew). He indicated these were the questions he would ask members of his steering committee and other peers he sought for advice.

Hilarie. Hilarie currently works for a national higher education organization and works with multiple organizations and postsecondary institutions in USER. She described her current role in USER as a connector and sounding board for "excellence in STEM education". She interfaces with many faculties, administrators, policy-makers, and higher education advocates and believes her position in the USER landscape uniquely situates her to serve many communities advocating for change. Hilarie serves as a permanent or proxy member on several formal USER network steering committees, and often attends various formal network meetings to better understand current practices in network functions.

Knowledge definition. Hilarie directly linked knowledge to specific formal network practices, organizational structures, and bylaws. Pragmatically, she discussed knowledge as a resource which could be used by networks to increase their chances of getting funding or avoid certain organizational pitfalls. In an example, Hilarie cited her work in drafting a formal network proposal. In creating the proposal, she borrowed bylaws, theories of change, or network governance structures from several other network proposals to build a case for why the network should be funded. Citing an established funding history, Hilarie argued borrowing these practices was intentional as she needed to build a persuasive case for NSF funding. Using the precedent of previously funded projects allowed her to focus on other substantive aspects of forming a formal network. Hilarie specifically identified three other formal USER network leaders whom she contacted in the construction of her network. These three individuals were also participants in the study.

Hilaire also highlighted her position at a national higher education association gave her perspective on the status and situations of formal networks. She serves on many network leadership teams and has access to many *closed-door* conversations about contemporary network concerns. She felt she was aware of the successes and current shortcomings of many formal networks. She believed this form of knowledge was critical to her role in USER in two ways. First, she thought it made her a better network leader because she could draw on many different experiences to address network concerns. Second, she credited her knowledge of other networks to her placement among other leaders in USER. Downplaying her credentials, she said "Who am I? You have people like Shirley Malcom, or [other prominent researchers]. I don't have their expertise and backgrounds, and yet here I am in this study. Why is that? It's because of where I work" (Hilarie).

Knowledge exchange. Hilarie's affiliation at a national higher education association also played a role in how she thought about sharing her expertise. Although the mission of her employer was to work with institutions of higher education, Hilarie felt she could interface with many individuals in USER. This sentiment carried over to her work with formal USER networks too, as many institutions she visited were also affiliated with USER network projects or initiatives. She felt her role in USER was to "highlight and amplify" the work occurring in USER, and to share widely across all those working in USER (Hilarie). Serving as part ambassador and cheerleader, Hilarie saw herself as a conduit for sharing information about networks as she completed site visits for member organizations of her employer.

Consensus building. Hilarie specifically mentioned consensus building as a necessary task for people working in USER. As a collection of cross-discipline faculty at different institution types across the country, she explained the diversity within USER led to a multitude

of definitions, processes, and ideas. In order for progress to be made in STEM reform, Hilarie indicated leaders needed to be able to understand one another. The ability of people working in USER to come to mutual agreements on those definitions was critical to USER success, otherwise "people just end up talking past each other" (Hilarie). Hilarie said consensus was a foundation part of all collaborative work in USER, and she believed it was the best strategy for moving beyond the different organizing silos (e.g., discipline, institutional, geographic region, etc.).

Although she indicated the consensus building process permeated all aspects of USER, Hilarie emphasized the importance of consensus in formal network operations. Formal networks specifically bring a diverse group of people together to work towards a problem, thus she contended consensus building was crucial to network successes. She bifurcated the consensus building in her discussion to intra- and inter-network consensus building. Intra-network consensus building referred to meaning-making processes taken by individuals within a single network. This could be discussions and agreements made by network leaders about the state of their network efforts, critical network-organizational decisions, or future planning for the network. Intra-network consensus building was more of a dynamic "brass tacks" form of consensus building where individuals negotiated personal experiences (Hilarie). She attributed it simply to being part of a network.

Inter-network consensus building referred to a similar process of finding mutual agreement *across* different formal networks. Hilarie discussed how networks *try on* organizational processes or language from other networks. These could be specific forms of formal network governance or bylaws, grant proposal structures, written or spoken language, or strategies for network longevity. Hilarie contended formal network sharing of processes was a

separate form of consensus building. She believed the constant sharing of organizational processes had a winnowing effect on new ideas. She admitted networks were often grant-funded and unwilling to take risks on unproven organizational contingencies. It was easier for networks to adopt previously-proven processes so they could focus on their mission of USER. She lamented there were only a "handful" of practices established to address organizational concerns, and as a result "all the networks are dealing with the same problems" (Hilarie). Interestingly, Hilarie pointed to formal network leaders as the conduit for sharing information and building-consensus. The leaders of formal networks often had more experiences with organizational processes and took those experiences from network to network.

Innovation. Hilarie spoke about other participants' capacity to create new formal networks. Hilarie cited study participants who served as primary investigators on multiple networks and stated one of her formal USER network affiliations was a product of conversations with others in this study. She described the beginnings of a formal USER network as a simple conversation:

> [Participant 17] had an idea for a network, so [Participant 8] and I met up with him. He was thinking he wanted to use a network structure similar to the ones we were using. So yeah, we helped him process though that; we were there when [Participant 17] started [the network]. We helped him through the model he was trying, and I think we were on the initial grant. (Hilarie).

Hilarie also mentioned two other proposals recently submitted to funding organizations which sought to create new formal USER networks. These proposals included various combinations of study participants and non-participant USER leaders.

Hilarie spoke a lot about monetizing formal network products as a way to help financially stabilize the organization post-grant funding. She identified several other networks whose leaders were contemplating similar organizational moves and indicated the general sense that networks

have traditionally not ended. “In that regard, we have no other option but to think about how we can gather enough resources to not fold.” Hilarie stated many individuals in the study were at a critical point in network innovations, as funders were starting to withdraw opportunities from networks unless they could demonstrate their effectiveness. Citing a shifting resource landscape and the retirement of a specific individual at the NSF, Hilarie argued USER networks will likely need to innovate their way to solvency with a more for-profit mindset.

Jennifer. Jennifer currently serves as an academic administrator at a four-year college. She has a terminal degree in a STEM-related field, and served as a faculty member, researcher, STEM center director, network leader, and funder. This participant also is currently a co-primary investigator on a grant studying formal networks. Jennifer reported that she only belongs to one formal network, but mentioned she assisted in the formation of several other formal networks. Despite her lack of network memberships, she is often invited to attend meetings for her insights.

Knowledge exchange. Despite Jennifer not belonging to many formal networks, she indicated her various roles in USER allowed her to work on the formation and further building of several networks throughout her career. The experiential aspects of working in USER for an extended period of time, Jennifer argued, was the best form of knowledge because “they don’t train you on this type of work at [graduate school].” When speaking about forming networks, Jennifer named two distinct formal networks from which she borrowed practices, bylaws, or initiatives. “One of the things I did for [network 1] was served as a [representative to colleges]. I actually wrote that early on into the forming of [network 2] years later. The program was not some great original idea that I had; it was a [network 1] idea I borrowed.”

Drawing from experience, Jennifer stated her role was not necessarily to identify knowledge within the space, but to serve as a connector of as many people as possible to increase

the chances of information flows. She specifically stated, “I want to see people’s synergies align. I think that is really how I try to operate in [this] world” (Jennifer). She indicated this mindset came from years working as a faculty member in close proximity to other universities and especially in her role as a formal USER funding administrator. Jennifer also indicated the role of shared formal network leadership as a catalyst for both knowledge generation and exchange. Advisory boards, grant meetings, formal USER network steering committees were all mentioned in her interview; however, Jennifer indicated her role was less about *being* present in the room and more about recommending the appropriate others to be present to help the network. When pressed further Jennifer acknowledged that she was often on various committees, but different roles throughout her career kept her from fully participating (for either conflicts of interests or simply time restraints).

Consensus building. Jennifer lamented the disparate nature of USER and called for more alignment from USER leaders. Similar to Allie and Hilaire, Jennifer argued the diversity of STEM education and complexities of USER generated competing ideas on how systemic change could occur. These differing ideas led to an overabundance of formal networks all focused on some different aspect of change. Although she acknowledged the variety of different networks was not necessarily a negative, the “cacophony” was difficult to manage without critical connectors attempting to build consensus. Jennifer said that was part of her role as a connector. She wanted to be the “happy puppy dog” who ran from formal network to formal network helping to share information across networks, create alignment across leaders and build consensus on the state of USER. Her previous positions at different organizations helped her to achieve these goals, as USER leaders were interested in her perspective on many issues facing formal USER networks.

Innovation. Jennifer framed most of her innovation responses by referencing her aforementioned "connector role". She identified four formal USER networks which she had either served as a founding member or advised colleagues in its formation. This list did not include any formal networks she had funded in her administrator capacity. She also gave an in-depth story about how another study participant approached her in the founding of a formal USER network. "[Participant 9] was very involved and interested in leveraging [STEM] funding. We both realized that both being scientists, the conversations began to look too *science-y*" (Jennifer). Jennifer argued she and another participant created a formal USER network to re-center students in the conversation of USER to make it more accessible.

Similar to Allie, Jennifer also mentioned site visits, consulting trips, or other workshops in which she presented. Many of these interactions were driven through connections she had made within the network. Although Jennifer downplayed her role as a major funder in USER, she acknowledged some of her invitations may have come from that role. Some of these invitations were from people within this group wanting to share information about the work happening in other parts of USER.

Lindsey. Lindsey is a professional working at a national higher education organization. Although not directly involved in the leadership of networks, she serves on multiple steering committees, advisory boards, or consulting groups for many formal USER networks. She has worked collaboratively with faculty and administrators at colleges and universities to publish scholarship on the state and roles of formal USER networks, and as a result she is often invited to attend various USER-related meetings across the country as a function of her employer.

Knowledge exchanges. Lindsey's role at a national higher education organization heavily influenced her perspective on knowledge exchange. Lindsey stated she was on countless steering

committees and at least four USER-affiliated advisory boards, attributing her membership primarily to a function of her employment with the national association. With regards to the nature of knowledge in formal USER networks, Lindsey argued her definition of knowledge was irrelevant, deferring to others especially faculty members. Instead, Lindsey viewed her role similar to what Jennifer articulated. She thought herself to be a social resource or a people-connecter. When asked how information flows through leaders in USER, Lindsey stated it likely occurred in both formal and informal settings surrounding steering committee meetings. "Questions of [mandated] network governance, financing, leadership, trajectory, expansion of networks all happens in these meetings, and people don't just forget it when they walk out the door" (Lindsey). Lindsey also mentioned that this form of socialized knowledge in this space lent itself to credibility. By being in the room, conversations among leaders spurred specialized knowledge which leads to being asked to participate in other specialized conversations.

Lindsey also discussed the importance of sharing personal information to build trust and multidimensional relationships which were much more durable in times of formal network turmoil. She spoke of every single participant in the studying saying,

> Most of these individuals I know quite well. It's not just superficial. I know about them, I know their families, I know about their lives in pretty significant details. I mean this applies to some more than others, but I could tell you the ages of their kids, I can tell you where their kids go to school. Who is recently divorced or back in a relationship. I can tell you about their personal lives outside of work, who has had a death recently, who are feeling pressures or regret at their jobs and why they moved jobs… (Lindsey)

This level of personal knowledge aided, in what Lindsey called, the emotional support of networks, and increased the flows of information especially in times of crisis. Having the contextual relationship knowledge increased the likelihood that Lindsey would share knowledge more quickly as she felt as though she was helping a friend in need.

Network learning. Speaking directly about network learning, Lindsey highlighted multiple steering committee meetings she believed underscored how decisions were made in USER. Although she mentioned the steering committees typically had highly structured agendas and schedules, the discussions pertaining to formal networks drew primarily from individuals' experiences in other formal USER networks. During discussions, members of the committee would discuss different approaches their formal USER network took to address the agenda topic, and members would add amendments or reject the items discussed entirely. The topics of the steering committee agendas served as a prompt for members to begin to draw their collective experience and share what strategies worked. As an example, Lindsey spoke about her experience working with an unspecified network in charging membership dues. In this discussion, she emphasized how different individuals talked about their formal USER network rates, and most notably, how one individual's network charged a smaller membership fee for members from resource-scarce universities.

Innovation. Lindsey did not identify specific outcomes, outputs, innovations, or products coming from the group of participants. Although she stated additional networks were a product of conversations among some participants, she related most of the *innovating* to activities within formal networks. Lindsey contended new formal networks were the product of gaps in USER. Lindsey also referenced individuals who were not participants in the study as strong contributors to USER. All of these individuals were STEM faculty conducting STEM education-based research at large public research universities around the United States. After listing work each of these individuals were conducting Lindsey said, "I put them down as people who are not known nationally, but are doing very strong, solid work in the space...I think they may be more known in the next few years" (Lindsey). This may reflect the connector role in which Lindsey views

herself. As she connects individuals to others, she may not participate in additional conversations or products from the social networks.

Luke. Luke is a STEM faculty member at a research institution. He worked on several funded grants in USER and is an active participant in several formal USER networks. He explained that most of his work in STEM reform occurred at the institutional level or within his geographic region. Only recently had Luke entered USER at the national level and become involved in nation-wide formal networks. Luke felt close with many people working in the USER but contended he did not know many of the study's participants. He has several pending grant proposals to begin new formal USER networks at the time of data collection, Luke had not been given a response on the status of his proposals.

Knowledge exchange. Most of Luke's discussions on knowledge transfer included people working in USER outside of the study. To him, *knowledge* was defined as simply knowing whom to ask what. This spoke to a certain level of understanding of key players and language in USER. Luke also cited the role of steering committees and advisory boards as a mechanism for becoming acquainted with others in USER and providing contexts for whom he could consult. Luke primarily talked about social connections established at these meetings as a feedback loop for his goals and thoughts for transformation in USER.

Beyond the personal connections provided by the formal USER network steering committees or advisory boards, Luke openly shared disdain for their function stating there was "far too much discussion and sharing" and individuals were too busy "think-tanking it" (Luke). When asked about his relationship to others in the study he stated, "These are people who usually just sit around and spitball discussions on how we can improve networks, never mind undergraduate education. I don't really talk to them outside of those meetings." Despite Luke's

open disconnect with others in the study, he did state the origin of a new formal USER network currently in the proposal stage. He attributed the forming of this network to conversations between him and others at a formal grant meeting for a different network several years prior to his interview.

Coalition building. When prompted on his thoughts of coalition building among the participants in USER, Luke primarily discussed how participants organically built partnerships in reform efforts. He spoke about how people in USER would identify "gaps" in current reform efforts and create theoretical strategies to address those gaps. Those individuals would then "go on the hunt" for other reformers to build partnerships in USER (Luke). Although the reasons for coalition building varied, Luke speculated funding was the primary driver of coalition building. He argued most reform strategies created needed funding to get started. Thus, reformers would seek coalitions with others who could increase their chances of receiving funding. This could take the form of someone who is socially connected to funders, had received funding in the past, or could appeal to the funding priorities of grantors (e.g., interdisciplinarity, diversity, equity, and inclusion, etc.).

Innovation. Along with several interviewed participants, Luke highlighted how many individuals in the study collaborated together to form different formal USER networks. He indicated many study participants entered USER from various organizations and backgrounds, and the diversity of experience led to the proliferation of new networks to fit different niches. "There are the Scholarship on Teaching and Learning (SOTL) folks and Discipline Based Educational Researchers (DBER) all pulling different directions and coming up with new networks to tailor fit their worldview" (Luke). Luke also recognized his role in the proliferation

both outlining his progression through multiple NSF grants, and his exasperation with systemic change in USER.

Cross-Case Analysis: Knowledge

A cross case analysis of emergent network findings provide several insights in how knowledge is defined within the space. Understanding how the group of participants defined and exchanged knowledge provides evidence to the existence of emergent network functions, and more importantly it provides greater context to the role of connections among the participants beyond them simply knowing one another. First and foremost, knowledge took many forms, and was dependent on the context in which it was needed. Whereas one may seek knowledge on how to structure or build a USER network, they may value knowledge on forming a network more than someone who has led a network for several years. Similarly, one who views themselves as a *connector of people* in USER may value and define personal friendships in that space differently than one who is required to be in the space because of their employment. This value-context is a driver for what constitutes knowledge, how valuable it is at that time, and helps to account for the varying definitions of knowledge within the study. *Knowledge*, as defined by the participants in the interview, primarily falls into five overlapping themes: (1) formal network expertise; (2) formal network outputs; (3) disciplinary background; (4) USER domain; and (5) personal information. Table 9 contains each of the sub-themes, definitions, and examples for knowledge.

Fundamentally, the most common recognition of knowledge within the group of participants was formal network expertise. Participants widely valued any information that could aid their formal USER network affiliations. This knowledge concerned many of the functional and organizational needs of beginning and sustaining a formal USER network and included steps on how to get initial funding, how to grow a formal network, questions of financial

sustainability, leadership concerns, and formal USER network partnerships. Knowledge in this form was critically valued by those who helped to begin a formal USER network, as many networks were founded at the same time and were experiencing similar problems (Lindsey). This definition of knowledge was the most commonly cited by participants.

Relatedly, formal network outputs were another highly valued form of knowledge. This form differentiated from formal network expertise as it related to the specific purpose and function of formal networks. Knowledge in this theme was more about formal network products and services and not directly associated with *how to run a network.* Defined as initiatives, projects, reports, conferences, forums, or other activities held by a formal network, this form of knowledge was critical to leaders working in USER as it gave actualized definition to the purpose of each network. Knowledge about the on-goings of other networks *kept leaders current* on the state of USER and provided potential activities for them to use within their own networks. For example, if [formal network A] convened a successful forum [formal network B] may host a forum to replicate A's success and further B's goals.

Disciplinary background represented another area of valued knowledge with participants. Defined as knowledge of specific discipline-based cultural and social norms, this form speaks to the interdisciplinarity of USER. USER exists at the intersections of many different fields and disciplines. Aside from each faculty in STEM-related fields, USER includes education faculty, university staff and administrators, higher education associations, and funders. Each of these groups carry specific and unique languages, backgrounds and cultural norms associated with their domains. Importantly, this theme does not necessarily include discipline content (i.e., ecologists knowing civil engineering). Seeking out discipline background knowledge was crucial for many leaders seeking to build networks or other initiatives, as it allowed them to speak to

wider audiences and gave them the necessary cultural capital to mobilize leaders across discipline silos (Allie, Hilarie, Jennifer). This knowledge was crucial for participants who did not hold STEM-related degrees and allowed for participants to engage with a wider variety of individuals within the space. Background knowledge also was a critical component in operating formal networks.

Related to discipline backgrounds, USER domain knowledge refers to knowledge gained from learning language and a set of behaviors associated with those working in USER. Primarily expressed from those who had not been working in USER for an extended period, several participants articulated the value of using appropriate language or formatting on grant proposals, or awareness of individual and organizational actors in USER. With regards to USER-specific language, participants highlighted the "alphabet soup" of acronyms (e.g., NSF, INCLUDES, APLU, NIC, RAC, etc.). As a learning process, several participants articulated a "coming of age" story in USER work. This process included learning how to act at various USER meetings or conferences, and some jokingly referenced perceived missteps in their few years working in USER (Hilaire, Lindsey, & Luke).

The fifth theme for knowledge was personal information. This constituted any information about individuals in the study that was not directly linked to formal networks or USER more broadly. Personal information included knowledge most commonly found with social friendships. People described knowing other hobbies, families, work-life, dietary preferences, and other personal information. This information appeared to modify existing relationships beyond simply discussing USER business. Individuals in this study who knew personal information about the others may have been more likely to share information about the other *knowledge themes* than with people they did not know as well.

Table 9. *Knowledge Thematic Breakdown*

Knowledge: Information or other expertise as defined by participants and valued by its scarcity

Categories	Definition	Examples
Formal Network Expertise	Knowledge and experience working with formal USER networks.	Knowledge on how to: 1. Get network funding 2. Grow a network. 3. Manage a network.
Formal Network Outputs	Knowledge and information derived from the actions of networks.	Knowledge related to: 1. Network grant reports. 2. Network press releases. 3. Network conferences and forums.
Disciplinary Background	Language, knowledge, credentials, and cultural understandings associated with working in a specific academic discipline.	
USER Domain Knowledge	Process by which new entrants into USER learn the language, norms, stakeholders, and behaviors associated with working in USER.	Knowledge of: 1. STEM Acronyms 2. Formal network names. 3. Influential funders in USER.
Personal Information	Knowledge of other participants personal lives.	Knowledge of other participants 1. Family members. 2. Recent personal occurrence. 3. Dietary needs.

Cross-Case Analysis: Knowledge Exchanges

Although defining knowledge in the formal USER space provides some insights about this group of participants, it does little to address questions of why and how USER knowledge moves through the social networks. Given that information diffusion and knowledge exchanges are foundational aspects of an emergent network (Isett, et al., 2011; Popp, et al., 2014), the motivations moving information around the social network must be explored further. Defined as the movement of knowledge bases throughout a network, information diffusion and knowledge exchanges refer to the actions taken to share or seek information in a network, albeit differently. Diffusion of information is an organizational term used to refer to network-wide or organizational saturation of knowledge (Rogers, 2003). Typically paired with a time-component information diffusion is more closely related to network analysis. Knowledge exchanges on the other hand, refer to individual interactions where two people share knowledge or information (Hartlet & Bennington, 2006). These exchanges include the time, place, and manner or the exchanges, and also the motivations for exchange (Huang, 2015). As the social network chapter discussed aspects of information diffusion, this section will more focus on aspects of the knowledge exchanges. At the conclusion of this section, Table 10 depicts a brief summary of the knowledge exchange discussion.

The first question in approaching knowledge exchanges may be: *what knowledge is exchanged?* In this study, I drew upon the bodies of knowledge defined by the participants in the previous section. Those groups were (1) formal network expertise, (2) formal network outputs, (3) disciplinary background, (4) USER socialization, and (5) personal information. With regards to the exchange of the knowledge previously outlined, the participants identified four knowledge exchange themes. These themes were to: (1) aid internal formal networks; (2) seek input from

peers; (3) contribute network successes to USER; and (4) USER socialization. Interestingly, the participants did not indicate knowledge about others' personal lives (i.e., personal information in the knowledge section) as an area of knowledge exchange. Whereas people may have sought knowledge to aid a formal network, *getting to know someone* did not appear to be a primary reason for people exchanging information. This is likely attributed to the participants knowing one another quite well at the time of the interviews.

Knowledge exchanges to aid internal formal network processes related directly to the operation, sustainability, and overall stability of USER networks. In general, many participants cited their lack of expertise in network management, advice from peers, or the need for precedence as other motivating factors in knowledge exchanges. Most participants described needing to access knowledge within their social network directly following a successful grant. Hilarie and Andrew described a sense of overwhelming aimlessness when starting a USER network and feeling like they were "drinking from a fire hydrant" with the number of tasks required to establish a network. "People put <u>*so*</u> much effort into getting a proposal funded…they often feel slammed when it actually goes through" (Jennifer). This sentiment of feeling anxious or overwhelmed ebbed and flowed throughout the course of the formal network. Several participants discussed similar feelings when their grant cycles neared completion. At this point, leaders described consulting with others in USER about how their formal networks could exist without grant-funding. Participants discussed seeking out other leaders who had been associated with older networks which made similar transitions. Allie, who made a network-funding transition, specifically commented on how many consulting visits she had tended to in her "retirement." In sum, participants sought knowledge exchanges related to formal network operations in times of uncertainty from individuals within the USER.

Participants also indicated a strong desire to seek the input from others in this study. Although the relationships did not necessarily have to be "an advisor-advisee sort of thing" (Lindsey), these knowledge exchanges were more about validating or refuting reflections on observations made in USER. This knowledge exchange was particularly prevalent when the leaders identified "gaps" in current reform efforts. Andrew, Hilarie, and Luke all mentioned consulting others in their social networks in the seminal phases of beginning a formal network. In these conversations they acknowledged the gaps in current USER efforts, then sought input on how their proposed networks could fulfill the needs. Conversation on USER-related observation also included other forms of participant-defined knowledge (i.e., internal formal network operations, etc.) the fundamental purposes differed for sharing the information. Although most participants contended seeking input was positive for those working in USER, Jennifer argued the seeking input from others was more of a "window dressing." Lamenting the piecemeal group of network and initiatives working in USER, Jennifer felt many of the conversations were opportunities to appear to be seeking input. In actuality she said these interactions were more to spread new ideas in USER and gain support from the community for upcoming initiatives or proposals. Overall participants all indicated leaders in USER engaged in knowledge exchanges for the purposes of seeking input or consensus from others, and they all acknowledged how relationally-connected many leaders were in these exchanges.

Showcasing formal network successes was a third area of knowledge exchanges. This form of exchanges is defined by USER leaders using multiple mediums to update or share information about the work their formal network is successfully doing. This knowledge exchange could be in a formal setting like conferences, forums, or meeting, and could also include personal conversations or interactions. Allie called it "the due diligence of change work,"

and contended it was morally objectionable not to "show your work" or know what other networks were doing. These sentiments were echoed by Jennifer and Lindsey, who visualized themselves as "connecters" within USER. Indeed, Jennifer articulated she thought sharing information across networks and leaders were her primary function in USER. Other participants explained many formal network events were designed for the purposes of network knowledge exchanges. Andrew and Luke stated they hosted (and often attended) network forums or conferences to showcase their network's work and successes in implementing systemic change.

In addition to sharing network successes, most participants expressed a desire to share formal network shortcomings. Speaking to Allie's "due diligence of change work," all participants discussed the necessity of seeking this knowledge to avoid similar mistakes or pitfalls. In contrast to network successes though, network failures were typically shared in personal *offline* conversations. "[Network shortcomings] are a bit harder to get at. You don't see the NSF hosting big failure parties, or people interested in hanging a 'we almost did it' banner" (Allie). Knowledge exchanges related to sharing network shortcomings relied strongly on the personal relationships and interactions of USER leaders.

Outside of knowledge exchanges on formal networks, individuals sought knowledge to acclimate to USER. As mentioned in the knowledge section, USER is a space with domain specific language, norms, and behaviors. The desire to seek USER domain-specific knowledge mirrors many aspects of a USER-centered socialization. Described as a process of learning values, skills, attitude, norms, knowledge, and language, Merton (1957) argued proper socialization was necessary for admission, acceptance, and social mobility in a given group. Participants recounted multiple instances of trying to learn USER language and norms. Hilaire and Lindsey both recalled taking actions to learn specific language as a function of their

employment. “When I go on an institutional member visit, I need to talk-the-talk, or no one will listen to me” (Lindsey). For others the process of USER socialization was more latent. Participants discussed seeking others at the beginning of their careers to learn the “correct phrasing” for grant proposals (Andrew). In his example, Andrew identified the correct phrasing as a language which had proven to be funded by grantors in years past. Multiple participants joked about the “alphabet soup” of networks, university divisions, funders, and programs (Andrew, Lindsey, & Luke). In addition to these aspects of socialization, these individuals also highlighted other aspects of “learning the field” as it helped them navigate conversations with others in USER.

Mediums of knowledge exchanges. The place where knowledge exchanges occurred varied for each of the participants. Although participants cited many communication mediums (i.e., telephone calls, e-mails, in-person conversations, etc.), in-person meetings were mentioned by all. Occurring at conferences, workshops, or other collective USER functions, these physical spaces provided a forum for casual conversations on contemporaneous events with formal USER networks. Andrew, Lindsey, and Luke all highlighted conferences where they sought other participants for their input on USER-related topics. More in-depth conversations among the participants occurred in formal network steering committees, grant advisory boards, national association meetings, or other small-group gatherings. Lindsey and Jennifer both cited the importance of these meetings and the conversations among those groups even when not “in session”. These groups typically had a structured agenda, and several hours dedicated to discussing them. These meetings allowed multiple participants to regularly interface with one another and discuss topics in more depth when compared to other mediums.

Table 10. *Knowledge Exchanges Thematic Breakdown*

Knowledge Exchange: Motivations and settings for diffusing USER knowledge across the emergent network.

Categories	Definition	Examples
Aid Internal Formal Network Functions	Seeking knowledge to build processes in a current or future formal network with the intention of addressing network problems.	Seeking knowledge on: 1. Network processes and structure. 2. How networks were funded. 3. How networks grew.
Seek Input from Peers	Individuals consulting with peers about observations they made regarding formal network actions or other USER-related efforts.	Consulting others about: 1. Shortcomings in USER efforts. 2. Shortcomings in their formal networks. 3. Effective strategies from other domains
Contribute to USER Success	Sharing positive and negative network outputs for leaders in the community to replicate or avoid.	Looking for knowledge in: 1. Personal communication 2. Network grant reports. 3. Network press releases. 4. Network conferences and forums.
USER Socialization	Seeking information related specifically to the USER domain for the purposes of learning to operate more effectively in the space.	Seeking knowledge related to: 1. Current USER efforts. 2. Existing formal Networks 3. USER-specific language

Cross-Case Analysis: Network Learning

While the discussion of knowledge and knowledge exchanges highlight how an emergent network in USER values and shares information, it does little to unveil how the group of participants collaborates with one another. Simply highlighting a collection of individuals which shares knowledge does not indicate an emergent network; in fact, it makes it indistinguishable from any other network (Isett, et al., 2011). In order to *distinguish* an emergent network from a simple collection of leaders in USER, network learning (the second emergent network function) showcases how an emergent network operates organizationally (Popp et al., 2014). Defined as a "tertiary level of organizational learning" in networks (Knight & Pye, 2002), network learning is a process of reflection and meaning-making involving individuals who represent organizations. The process involves individuals bringing information from their respective organizations for "system-level discussion and meaning-making process" (Popp et al., 2014, p. 35). Indeed, network learning is one of the primary drivers' organizational actors engage in networks (Provan & Huang, 2012). As highlighted in the literature review, network learning is also a process built on a foundation of relationships. Without the interpersonal cornerstone of trust and fairness, network learning cannot occur (Leach, Weibe, Vince, Siddili, & Calanni, 2014). In reviewing the cases participants discussed three themes related to trust-building, fairness and learning. The themes were (1) consensus building, (2) coalition building, and (3) network learning. Table 11 displays the thematic breakdown for network learning and interpersonal dynamics.

Consensus building. Drawing on tenets of Weick's (1969) sensemaking, consensus building requires a group to reflect on prior experiences and observations for the purposes of establishing agreement (Bezdeck, Spillman, & Spillman, 1978). These agreements provide mutual definitions for individuals to ground conversations and actions and shape future work and

have the potential to become ubiquitous within a domain. While consensus does not necessarily imply unanimity, it does establish a generalized set of understanding for a group to base their interactions. With regards to consensus building in USER, participants generally sought to build consensus in several areas related in USER. In many cases participants discussed observations on USER landscape or sought input from others on problems within their formal networks. Participants also discussed reaching out to others for input and meaning-making for building a novel funding proposal. In these conversations, participants' shared experiences or USER observations and were often looking for clarity or a thought-partner.

Several participants discussed the necessity of seeking consensus and acting as a sense-making partner. The most prominent example of consensus building occurred in formal network steering committee meetings. In these meetings, participants discussed agenda items and built consensus based on how they made sense of the concerning issue. "The nature of these meetings is to discuss problems coming from [mandated] networks. The agendas are, more or less, set up for us to figure out what is going on and help problem solve" (Lindsey). For example, Hilarie indicated funding was an agenda item at a recent steering committee meeting. In that meeting, leaders in USER convened to discuss how other networks in which they were involved confronted funding concerns. They combined their previous approaches with the current context of Hilarie's network to build a path forward. Jennifer spoke directly about instances where she served as a consult for USER-specific knowledge. Drawing from her long career, she indicated people often came to her in need of historical context required to make sense of current network phenomena.

The role of consensus with the participants demonstrated another level of complexity and interdependence within this group. The capacity and motivations to consult with one another

depict a sense of collectiveness as the participants seek to make meaning from others in similar situations. As mentioned, steering committees or advisory boards played a large role in the participant's ability to build consensus. Indeed, the meetings associated with steering committees or advisory boards allowed the involved individuals to aid a particular network, but more than the aid, the meetings also served as a space for USER leaders to build approaches to USER problems more generally. The consensus or shared meaning taken by the leaders from these meetings were used to both frame conversations for their networks but also used in subsequent meetings as established foundational understandings. Thus, each of these meetings built on one another, offering opportunities for these leaders scaffolding to continue to filter new information and build consensus.

Coalitions. The second theme regarded how participants sought partnerships in network-related actions. Coalitions are defined as a collection of individuals who share a common interest who agree to work together to achieve a common goal (Wolff & Berkowitz, 2000). The process of negotiating the *agreement* to work together is commonly cited as coalition building and often includes aspects of consensus building as the parties involved define their intentions, aims, and goals (Kaye & Wolff, 2002). Different forms of coalitions were cited by all participants in different capacities.

First, Andrew and Jennifer discussed building coalitions as a step in forming a formal network. In their discussions they highlighted the importance of getting critical stakeholders *on-board* with the new initiative or network. Andrew and Jennifer, nevertheless, differed on *who* should be recruited to build a coalition. Jennifer explained building partnerships with organizational actors such as funders or universities and contended that funders sought partners to move USER efforts forward. These coalitions could drive convergence in a disparate field of

actors. She cited the term "theory of change" as an example of a funder pushing for common language in USER. "We need to get individuals in [USER] to speak in more systemic language, to think about levers of change…For many of them it's just nonsense." In Jennifer's description, funders set parameters for individuals to present opportunities for coalitions. Andrew, on the other hand, insisted on building coalitions within formal networks. He wanted individuals who were reform-interested but otherwise unengaged in USER efforts. Underscoring the importance of persuading stakeholders who were not currently involved in the USER, he cited this group as a source of more knowledge and expertise. Building coalitions was a strategy for Andrew in the facilitation of formal network management and survival.

In addition to Jennifer and Andrew's definitions of coalition, Allie discussed the importance of leaders building coalitions across her self-described silos in USER. These silos were informal divisional boundaries that segregated reformers in veins of USER work such as research silos, discipline-based silos, and formal network silos. "There are just so many groups working in STEM reform now….everyone has their own groups; you have to be able to talk across them to be successful. But to talk across the groups, you have to have a buy-in"

Table 11. *Network Learning Dynamics Breakdown*

Network Learning: Interpersonal processes for achieving system level learning.

Sub-theme	Definition	Examples
Consensus	Sharing knowledge or observations within USER with others for the purposes of reaching agreement. Employed to create a foundational understanding and operate as a collective.	Conversations among leaders to: 1. Understand USER environment 2. Aid formal network 3. Align formal networks.
Coalitions	Shared interest partnerships created across USER to increase the success of an individually articulated USER goals.	1. Receiving a grant from a funder. 2. Seeking others for a project of initiative. 3. Building relationships across the different disciplines in USER.
Network learning	Sharing USER-related organizational knowledge (e.g., formal networks) within emergent network to gain perspective on system-level occurrences.	

(Allie). This "buy-in," Allie explained, was through coalitions, or having an insider vouch for you.

Network learning. Although a few participants mentioned situations of shared organizational experience and meaning-making, there were little data to suggest the system-wide learning. One participant suggested systemic change in higher education was the goal in USER, but further mentioned that aim is too ambiguous for operationalization and measurement (Luke). Popp et al. (2014) stated emergent network learning must have an emergent organizational objective with which to channel the shared knowledge and measure growth. Despite sharing experiences, building consensus and coalitions, much of these efforts were for short-term and specific ends (i.e., how to get funding) without further organizational implications or feedback loops. There was no consensus expressed on how to achieve systemic change in higher education. There was little evidence of a formalized togetherness expressed by those interviewed.

Cross-Case Analysis: Innovations

The final cross-case analysis concerns outputs of the emergent network. While knowledge exchanges and network learning are critical functions of an emergent network, they tell us little about how the network interacts with the environment. The final emergent network function (innovations) highlights how an emergent network affects the domain in which it is situated. Innovation refers to the collaborative capacity for a network to operationalize its knowledge and learning to change its organization or system (Provan & Huang, 2012). Keast et al. (2004) called this the "*so what*" factor (p. 368). The innovations identified by the participants in their interviews were: (1) new formal networks; (2) proposals; (3) formal network governance

structures; and (4) formal network sustainability strategies. Table 12 depicts the thematic breakdown for innovations at the conclusion of this section.

By far, the most cited innovation referenced by participants was their collective capacity to generate new formal networks. Participants cited changes in undergraduate STEM education on college and university campuses, faculty concerns, and changes in the funding environment as drivers for creating new formal USER networks. Several individuals stated the sprawl of new networks was necessary as systemic change was difficult. Creating new networks allowed people in USER to engage new individuals in reform efforts and evolve with the universities (Jennifer & Lindsey). The new formal networks spawned by participants typically targeted unengaged actors (university faculty and administrators, education policy-makers, etc.) in USER, and in some cases were in direct response to new funding opportunities. In particular, two interviewed participants and another un-interviewed participant had recently submitted two proposals to begin a new formal network. One of those proposals aimed to directly engage faculty on educational research and came from conversation among these individuals at various conferences or workshops.

In connection to new formal network generation, most of the participants indicated their collective capacity to create funding proposals for various initiatives. Different from new formal USER network proposals, these proposals were broader and included funding for specific projects, workshops, conferences, information depots, or toolkits. Proposals generated by participants were almost entirely directed to the NSF or FIPSE and sought funding for formal network business initiatives. For example, one formal network was looking to incorporate more initiatives in diversity, equity, and inclusion, so some participants discussed applying for an ADVANCE grant to be managed or attached to their formal network. Most participants indicated

their submissions were in response to open calls for proposals from major funders and were in conjunction with formal network needs. Some participants stated their networks needed financial sustainability and grants provided the necessary funding to support their efforts. Others argued these proposals allowed their formal networks to align with changing priorities in USER. Multiple participants cited different proposals for diversity, equity, and inclusion initiatives offered by funders.

Third, participants indicated various governance strategies for formal USER networks. Most often this took the form of participants "borrowing" organizational procedures from other participants' formal networks. Jennifer discussed "borrowing" the consulting model from one network to be used in another because of her experience with its success in a different area. Hilarie cited the *research action cluster* (RAC) model as an organizational form she used in developing her network. In her example, she specifically talked about consulting with members in [a formal network] and their experience with a RAC. Similarly, Luke indicated using a *networked improvement community* (NIC) in his proposal borrowing the thought from two other participants' formal networks. There were divergent motivations for borrowing and adapting these processes. Some articulated experience and proven success with structures imported to other networks. Others argued it lightened the cognitive load in addressing the network's development. For these individuals, they wanted to focus on other aspects of the proposal or network and argued that using a previously funded network model increased their chances of funding through precedence. Others also granted that they were not experts in organizational design and simply needed a starting point for their formal networks to debate. This borrowing of governance structures was not a simple copying of the governance from one network to another, but dynamic conversations among this study's participants. Along with sharing

Table 12. *Innovations Thematic Breakdown*

Innovations: The capacity for a network to operationalize the knowledge and learning to change their organization or system.

Sub-theme	Definition
New Formal Networks	The creation of new formal networks in USER as a result of emergent network interactions.
Other Proposals	The creation of other, non-formal network, initiatives, programs, toolkits or workshops as a result of emergent network interactions.
Formal Network Governance Structures	The creation or adaptation of new formal network governance or leadership structures to assist with formal network development.
Formal Network Sustainability Strategies	The creation or adaptation of organizational stability strategies to assist with the long-term viability of formal networks.

knowledge related to the governance structure; these conversations included an adaptation process for how one network's bylaws could be used in a different network with different contexts. Through these conversations, adapted governance structures were customized and created to fit a new formal network's needs.

Fourth, formal network sustainability strategies were cited as a strategy-in-development for many participants. Almost all of the participants interviewed expressed anxiety over the sustainability of their formal network. This sustainability was mostly linked to the financial health of a formal network and its connection to a grant-funding cycle. Most of these strategies sought to decouple the formal network from the funding cycle and assumed major organizational changes for the formal user networks. These strategies were to: (1) transition formal networks to independent non-profits; (2) link the formal network to an existing college or university; or (3) link the formal network to an existing higher education association. Although these strategies were highlighted by participants, they were viewed as *in development* as most of the participants were wrestling with issues of sustainability.

USER Emergent Network Function Discussion

Independently each of the emergent network functions discussed by participants provide unique insights into how this collection of individuals operate in USER. They seek USER-specific information about formal network operation or other phenomena in USER, and transfer knowledge in steering committees or advisory board meetings. These meetings also allow for consensus and coalition building to occur and often generate some initiative or output for networks or USER strategies as a whole. An emergent network, however, is more than a group of individuals working in tandem. Emergent networks are organizations (Isett et al., 2011; Popp et al., 2014), complete with governance, power, and processes. Although recognizing the

emergent network-like functions (i.e., knowledge diffusions, consensus and coalition building, innovation) are important in understanding some process-oriented aspects of the emergent network, they do not address aspects of power or governance. The following discussion builds on the emergent network functions established in the previous sections comparing the data to existing literature on human capital and organizational theory.

Emergent network as an open system. Interpreting the emergent network functions as a cycle presents an opportunity to view this network as a structured organization using systems theory. A collection of organizational theories on structuration of processes, termed systems theory, posit organization as amalgamations of social structures that provide a schema for those within the organization to act (Scott & Davis, 2003; Bertalanffy, 1956). A subset of systems theory, known as open systems theory, contend an organization socio-behavioral structure are built through the consensus of loosely affiliated parts (Ashby, 1968; Glassman, 1973). In this theory, traditional organization boundaries are porous and ill-defined. Instead an organization is bounded by those who partake in institutionalized processes and behaviors, with individuals entering and exiting the organization fluidly (Scott & Davis, 2003). The processes and behaviors which constitute the organizational body rely on reciprocal social ties built upon interdependence and information flows (Burton & Obel, 2004). Boulding (1956) likened open system organizations to a "multi-cephalous" organism (p. 201), where consensually agreed upon norms govern the body but many different heads could encounter information and act. These semi-autonomous decisions were informed through consensus and coalitions built across the many-heads of the organism, whose mission was to "create, but also appropriate knowledge, know-how, and meaning from its environment" (Scott & Davis, 2003, p. 106).

As the theory suggests, participants in the emergent network are not constrained by any formal organizational boundary. Instead, they are all loosely affiliated through mutual social relationships and shared memberships on committees or boards scattered throughout USER. Using the organism analogy, this organization of individuals is often activated by observations in the USER environment, and responds to "create, but also appropriate knowledge, know-how and meaning" (Scott & Davis, 2003, p. 105). This may be new funding opportunities or perceived shortcomings in USER efforts. The emergent network functions (i.e., knowledge exchanges, network learning, and innovation) occur within the emergent network, but do not need to incorporate all members simultaneously. The leaders do not serve as a single monolith within the network, but rather act on new information or in the face of shortcomings in USER with consulting only a few other leaders. This mirrors the multi-cephalous metaphor presented by Boulding (1956) by anchoring individuals in social processes but allowing them to act semi-independently.

Using an open systems approach to the emergent network in USER presents several opportunities to frame the functions. First and foremost is the importance of the environment. In open systems, "the environment is perceived to be the ultimate source of material energy and information" (Scott & Davis, 2003, p. 106). Assuredly, this emergent network would not exist without undergraduate STEM education reform or the resources created by the funders of USER. Moreover, without environmental problems in USER, there would be little need to convene and strategize remedies to the environment. In short, without the critical role of the environment, the network (and its functions) would simply not be relevant.

Setting aside the role of the environment, the necessity of interdependence is critical to an open system organization. Exploring each function of this network demonstrated the need for

interdependence. Indeed, knowledge exchanges, consensus and coalition building cannot be accomplished in a vacuum. They require others with which to exchange or cooperate. Even innovation (which does not assume interdependence) was assumed to be a cooperative process by participants. The interdependence exhibited by the participants in serving these functions demonstrate an organizational bond which links them together in contrast to the environment.

Finally, interpreting the emergent network as an open system provides perspective on ill-defined notions of network learning. Many of the participants struggled to define or highlight instances of network learning occurring in the emergent network, instead underscoring moments of coalition or consensus building as a means of sense-making. With only loose affiliations tying the participants together, there are no centralized systems in which to channel any systematic organizational learning, much less network learning. Instead, feedback loops are disaggregated and spread across the organizations. While these loops still provide sense-making opportunities, they do not rise to the degree of system-level learning commonly associated with network learning.

While the open systems theory provides much needed context for understanding how this emergent network operates in USER, it does fall short in several critical areas. First, the theory unveils little about the origination of the function cycle. Although some scholars may point to the processes originating in the environment (Scott & Davis, 2007), more exploration is needed. Additionally, while the open system theory recognizes a porous organizational border, it does not detail conditions for open inclusion or exclusion in the network (i.e., who is in or out and why). The following section begins an exploration in human capital and explains how manifestations of capital affect interactions among participants in this network.

Emergent Network Governance and Capital Manifestations

Although there is not much research on the how networks operate, the existing scholarship articulates the importance of formalized networked governance (Kezar, Gehrke, and Bernstein-Sierra, 2017; Milward & Provan, 2006; Popp et al., 2014). Defined as "the use of institutions, structures of authority, and collaboration to allocate resources to coordinate the joint action across the network" (Provan & Kenis, 2008), formal networks use written charters, constitutions, or bylaws as binding documents which support formal network stability and effectiveness (Milward & Provan, 2006). Unlike the formal networks however, emergent networks do not have formalized bylaws, governance, or leadership hierarchy with which to govern how members interact with each other and the network. Indeed, the lack of organizing documents are, in part, what make emergent networks difficult to study (Isett, et al., 2011). In emergent networks, items typically outlined in formal network charters are amorphous and undefined. Whereas a formal network may simply list the member organizations of the network, an emergent network *membership* is embedded in individual relationships, with no outright reason for a single individual's involvement in the network.

Although emergent networks do not have written structures governing how individuals operate, they do still adhere to more latent principles which "govern" how people interact in social settings (Provan & LeMaire, 2012, p. 45). In lieu of written bylaws, different forms of human capital influence how people interact in emergent networks. Human capital refers to an individual's set of assets, which are capable of continually generating benefit for the individual (Becker, 1962). Human capital generally confers influence, power, trustworthiness, or some other socially desirable quality. Without written bylaws aspects of human capital guide how interactions occur. Although not unique to emergent networks, finding commonality in how

capital in USER is valued and used provides insights to how a more latent governance structure manifests in emergent networks. Interviewed participants discussed several forms of human capital as they existed in USER: namely, cultural, organizational, and intellectual capital. Each form of capital bestowed some form of trust, influence, or credibility to those who possessed desirable forms of capital by those within the space. As a note, the impacts and manifestations of social capital were outlined primarily in the social network analysis and findings chapter.

Cultural capital. Cultural capital refers to the social assets of a person that promote their social mobility and desirability (Bourdieu, 1977). Originally outlined with multiple sub-forms, cultural capital generally represents power through symbols and affiliations. These affiliations and symbols link an individual's credibility to some other entity (often an organization) and bestows influence or trust if the organization is viewed favorably by a social group. Ostrom (2019) used the example of celebrities entering politics by leveraging influence granted to them from television, professional athletic organizations, or military affiliations. More specific to USER, participants referenced the influences of cultural capital in negotiating social interactions among leaders. Using Bourdieu's (1977) sub-forms of cultural capital as a framework, I present findings on how cultural capital manifests in the emergent network.

First, the *institutionalized state* (Bourdieu, 1977) was easily identified by participants. During the interviews, individuals referred to other participants by their affiliations with colleges and universities, higher education associations, government entities, or funders. These affiliations appeared to help participants remember and contextualize the relationship they had with others. When discussing an individual, participants most often referenced the individual's name, their role and college or university, and then any funding organizations with which they were affiliated. For example, "oh, of course, [Participant 03] is a physics faculty at the [College]

working on some really interesting stuff in [the teaching and learning center]. He started [formal network] with [non-participant]… I think their NSF funding cycle end this year" (Lindsey). In her introductory comment, Lindsey listed 5 organizations with which the participant was tied and served to credential the person in question.

Although simply listing organizational affiliations does not necessarily bestow cultural capital or inherently indicate power in a social setting, two types of organizations were consistently referenced as desirable: funders and higher education associations. Although there is some overlap across the two categories, the most commonly cited funding organizations were the National Science Foundation, Howard Hughes Medical Institute (HHMI), and the Alfred P. Sloan Foundation. Jennifer explained the role of funders in USER gave "credibility" to those perusing projects stating, "If you want to have impact [in USER] it is credibility, and credibility comes from institutional affiliation and dollars." Beyond the "dollars" though, the symbolic-cultural gave credibility to those working in USER by tying their work to the organization's reputation. Their grant funding and affiliation provided a *shortcut* for individuals to vet a person's credibility.

The second grouping of organizations were higher education associations (Associations). Unlike the relatively few funders cited, participants identified numerous different Associations. The groupings were typically non-profit organizations with either a mission to address USER or some organizational imitative to address STEM education. Some Associations served as political advocates or centralized confederated organizing bodies. The most commonly cited groups were the Association of American Universities (AAU), Association of Public Land-Grant Universities (APLU), the National Academies on Sciences, Engineering, and Medicine (and its corollary the Board on Science Education), and the American Association for the Advancement of Science

(AAAS). Different than the symbolic power associated with grants, affiliations and power linked to the associations provided a more collective or representative power linked with college and university legitimacy. Jennifer discussed the symbolic power of those affiliated with the AAU, "the value of the AAU STEM Initiative isn't whether or not it is actually successful; the reason I think it is so valuable is if AAU says that teaching is important, everybody else is going to get on-board." Lindsey, Hilarie, and Andrew all echoed these sentiments citing individuals who worked with AAU or the National Academies as major actors in the field. " [Leader at Association] gives the marching orders, and we just follow" (Allie). In sum, the power of the *institutionalized state* sub-form of cultural capital is prevalent in USER, as funders and associations bestow influence on those affiliated with their work.

A second form of cultural capital, termed *the objectified state*, refers to power or influence an individual receives for their domain-defined desirable qualities (Bourdieu, 1977). Ostrom (2019) indicated there were clear in-groups and out-groups when considering the objectified state, and these qualities could be earned or unearned (e.g., education or physical appearance). Within the group of participants, an individual with a STEM-related terminal degree held more influence than those without a STEM-related degree. Clear distinctions were made when participants discussed others with terminal STEM degrees and those without STEM degrees working in USER. Giving more power to those who had a STEM degree, the shared experience of being *in the sciences* carried the symbolic weight of *being in the know* or having a similar educational background. This distinction was made clear by a participant (Person A) who dismissed another participant (Person B) by stating Person B was "not a scientist…she works in a center." Although Person A later indicated they meant "social scientist," the distinction

contextualized their contributions as someone who does not carry as much credibility in the USER.

Knowing the USER landscape, language, critical players, and organizational actors represents a third form of cultural capital. Bourdieu (1977) defined linguistic capital as distinct assets associated with proper socialization and refers to a person's mastery of language in a given domain. This form of capital is the knowledge about *how* to talk about the landscape, critical players, and organizational actors within the domain. For example, Ostrom (2019) talked reflected on his first time on a park basketball court where he referenced the National Basketball Association by its full name. Although he knew of the organization, he did not know the colloquial term NBA and was ridiculed for it. Turning back to the study, several participants discussed similar phenomena occurring (with less ridicule). Luke highlighted his socialization process by arguing how USER is full of acronyms, a random assortment of funders, and influential people. He mentioned how any misstep in understanding the players in USER could marginalize an individual as an outsider.

> You have to know of Carmon [pseudonym], she gives the marching orders, but you also need to know AAAS and that is different than BOSE inside of National Academies, which have pieces dedicated to STEM reform, but also your institution may be affiliated with AAC&U, or APLU or AAU, or both, and they all have separate initiatives funded by the NSF, or do they? I don't even know. That doesn't even include Gates or Sloan who sometimes dabble in one-off STEM affairs. (Luke)

In discussing USER socialization, none of the participants cited particular education strategies (i.e., evidence-based instruction, multi-cultural pedagogy, etc.) pushed by many of the formal networks. The socialization focused almost entirely on learning the language to use in reference to organizations, and individual actors within the space.

Organizational capital. Opposed to the symbolic significance of organization affiliation with cultural capital, this organizational capital speaks more to pragmatic aspects of controlling resources (i.e., financial, physical, geographical, etc.). The ability to access and use resources to pursue a goal falls within this category as they can exhibit power and influence (Morgan, 1998; Scott, & Davis, 2007). Participants discussed organizational capital primarily through affiliations with USER funders, formal USER networks, and higher education associations. In addition to the cultural capital provided through a successful grant, the grantor-grantee relationships provided the avenue for individuals within USER to complete their work. Most commonly, funding relationships provided large sums of money to individuals working in USER and physical space to either host meetings, conferences, or events. Many participants discussed how this capital helped them establish a formal network or initiating a study of USER. Allie recalled working with the Fund for the Improvement of Post-Secondary Education (FIPSE) at the start of her career, stating "they were the only game in town…without them [my work] was going nowhere." Although Allie saw her relationship with funders as an avenue for *doing the work of reform,* Luke viewed funding relationships as a cycle for social mobility beset with exclusionary barriers. Linking organizational capital to cultural capital Luke said, "getting funding is half [of] the equation; once you do something with it, then you start getting invited to all kinds of events." In his mind, Luke viewed the resources affiliated with organizational capital as a vehicle to increase one's cultural capital in the USER. The symbiotic relationship between organizational and cultural capital was also echoed by Hilarie whose recently funded proposals were occupying more of her time than she intended. In her example, she felt ethically and professionally compelled to complete her work lest her "professional reputation" takes a hit. A

funding relationship, nevertheless, provided the power and resources for an individual to create other forms of human capital in undergraduate STEM education reform.

Affiliation with a national higher education association demonstrated another form of organizational capital. As mentioned, national higher education associations (Associations) are a diverse group of non-profit organizations, primarily located in Washington, D.C. Associations may be funded through government agencies (e.g., National Academies, AAAS) or through college and university membership dues (e.g., AAU, APLU, AAC&U), and act as a convening or advocacy space for institutions or individuals. These associations typically carry significance in USER due to their proximity to funding or policy-making. Every participant in the study held some formal affiliation with an Association. Some individuals were employed by an Association, while others were on committees, task-forces, or other association initiatives. While affiliation with Associations provided cultural capital (as discussed in the cultural capital sections), they also lent meeting spaces, convening power, and financial resources to their affiliates.

Intellectual capital. Participants also discussed knowledge as a form of capital. Often referred to as intellectual capital, this form concerns the asset of possessing unique and pertinent knowledge, experience, or other scarce information. Stewart (1998) described intellectual capital as domain-specific knowledge could be leveraged to generate other forms of capital (i.e., social capital). Individuals with domain-specific knowledge hold capital in their ability to use and apply it. Intellectual capital aligns with much of the discussion on knowledge, knowledge exchanges, and may be a driver of knowledge transfer and coalition building.

The participants discussed intellectual knowledge primarily as those who were sought to aid formal networks. Allie spoke about seeking outliers and provocateurs in USER for connections arguing that those on the “fringe” of USER were most inclined to question

assumptions. To her, the provocateurs were able to see STEM differently than those already engrained in the cultural norms of their disciplines. Andrew echoed Allie's points indicating he often sought individuals with different perspectives to work with in formal networks. Jennifer also acknowledged intellectual capital in USER, saying her "connector" role meant she was to find and connect "smart people" together. In this regard, individuals who held intellectual capital were considered others, or non-participants, by those interviewed. Intellectual capital then, was sought by participants seeking novel information for formal networks or Associations. Incidentally, intellectual capital was leveraged by individuals to gain access to the emergent network. Indeed, Lindsey stated, "we want 'smart people' working at [an Association]." In this regard, intellectual capital was used by those external to the emergent network to generate social capital and gain access to conversations occurring in the emergent network. As an example, provided independently by two participants, Lindsey discussed a closed-door committee at an Association, where committee-member selection was "very structured" with blind application review, interviews, and approvals. In a separate interview, Luke stated he was invited to join the same committee through a "cold call" from a USER leader on the committee. Although the rationale for his "cold call" was not clear to him, Luke attributed the impetus of the invitation to his participation in a regional USER conference a few weeks before the call. He mentioned in his sessions he asked interrogative questions, and "struck up conversations" with other USER leaders during the conference.

Capital, Governance, and the Emergent Network

In sum, four forms of human capital impact how individuals within the emergent network interact. The previous sections outlined how cultural, organizational, and intellectual capital all bestow power and influence on individuals who hold capital in those areas. Social capital creates

a fourth form of human capital. Although not highlighted in this section, social capital was explored heavily in the 4th chapter. Within social capital theories, individual power and influence is derived from structural holes (Burt, 2000), boundary spanning (Katz & Tushman,1980), and weak ties (Granovetter, 1977). Essentially, individuals gain influence by connecting individuals who do not know one another. To revisit the findings from Chapter 4, individuals within the study were closely linked to one another and exhibited many aspects associated with network closure (i.e., high degrees of trust, free flow of information, etc.) (Burt, 2000). While a highly connected network does have many network-wide benefits, it does not provide much leverage for an individual to wield connecting power. As most of the individuals know one another, social capital does not appear to necessarily serve as a form of power or influence. In short, everyone knows one another in the network, therefore no one can serve as a gatekeeper of information within the network. Instead, power and influence primarily comes from (as Jennifer stated) organizational affiliation and funding.

Returning to the discussion of how human capital serves as an informal set of governing bylaws, several findings emerge. Inclusion in the emergent network is connected to cultural capital. Being connected to higher education associations or funding organizations (institutionalized state), having appropriate STEM-related credentials (objectified state), and speaking the appropriate language (linguistic) applied to all of the participants interviewed. More than simple inclusion or exclusion, organizational affiliations were how individuals gained access to the most highlighted knowledge exchanges: steering committees and advisory boards. Without participation within these groups, individuals in the emergent network would not be able to engage in the primary functions outlined in the previous sections.

Similarly, cultural and organizational capital provided the basis for aspects of emergent network leadership. Discussing networks in healthcare, Metzger, Alexander, and Weiner (2005) defined network leadership as an ability to create a vision for the objectives of a network, yet still provide flexibility and consensus for those working within the network. In their discussion, the authors stressed the importance of multiple-stakeholder input in determining how the vision was achieved, but the overarching goals were determined by leaders. As Luke discussed, a formal position within a funder or higher education association provides power to shape STEM reform efforts or "give the marching orders" (Luke). This may be directly through providing resources to shape how reform work is conducted or setting initiatives in reform. Indeed, three of the individuals interviewed had recently held executive positions within a funding organization or higher education association.

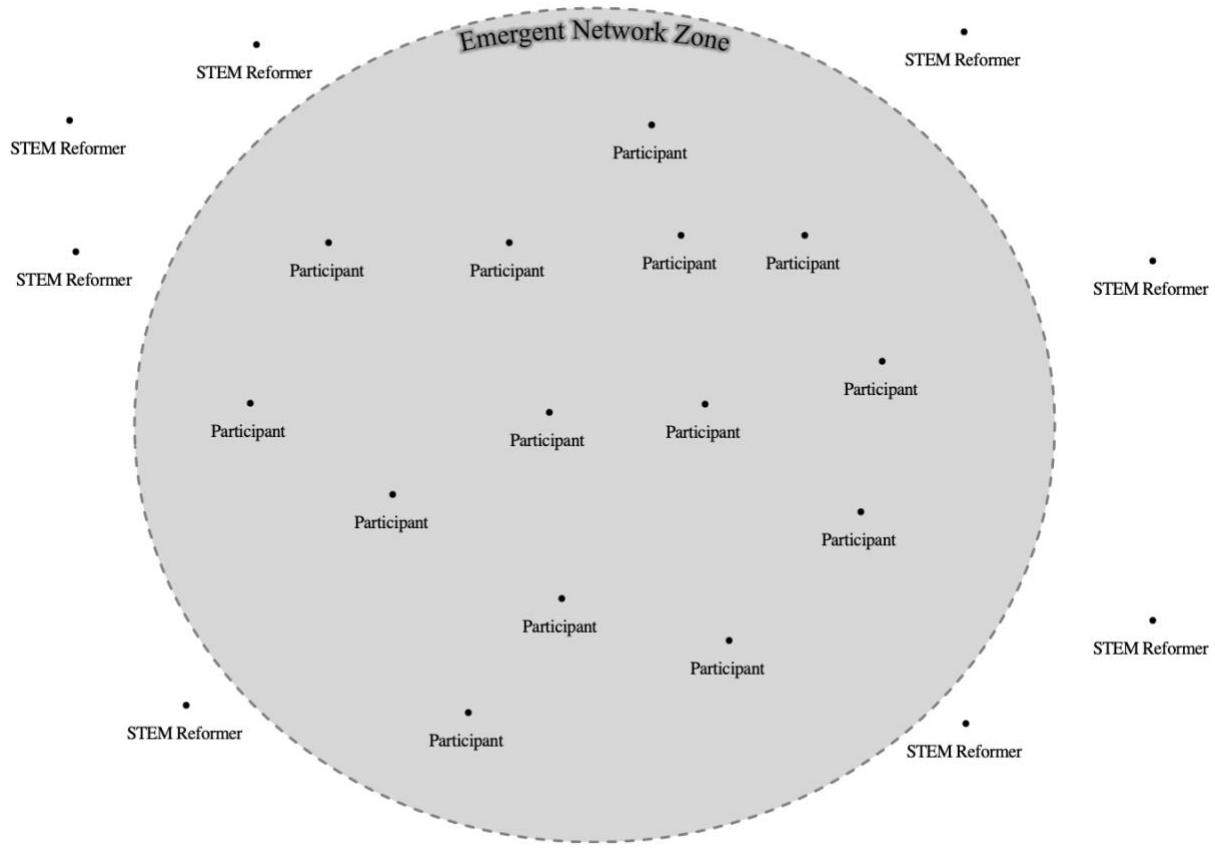
As in the discussion of the multi-cephalous, open system emergent network, aspects of human capital inform how the many heads of the emergent network interact with one another and explains some of the semi-autonomous behaviors. Other than providing the aforementioned knowledge exchanging spaces, organizational affiliations lent prestige to influence how consensus could be built and leveraged funding to shape innovations of the emergent network. Allie and Hilarie both discussed how they constructed proposals to align with higher education association and funder priorities. While these actions had a pragmatic grounding (i.e., get funding to continue USER work), they also allowed them to gain greater influence (through affiliations) in USER. With regards to coalition building, individuals appeared within the network partnered with one another to offset any perceived deficiencies their own human capital. Many of the examples encircled know-how (intellectual capital) in USER. Luke referenced his inclusion in a formal network began when someone noticed his novel ideas at a conference and

wanted to include him. Andrew discussed how he started a formal network but had no idea on how to operate the group. In his example, he sought others in the emergent network to draw on their experience and help with his project. In this regard, the multi-cephalous emergent network put some of their proverbial heads together to achieve a goal of an organizational affiliation.

Discussion

Considering the findings outlined in this chapter, several emergent network functions among participants and informal governance structures arise from the analyses. Whereas functions describe the collaborative actions of those within the group, the different forms of capital construct an informal governance structure underpinning and informing how individuals interact with one another, and most importantly, establish an in and out group. In this section, I present a model of the emergent network function cycle using the findings gleaned in the earlier sections of this chapter. I construct the function cycle by outlining different aspects of the emergent network before presenting the model in its entirety. First, *the emergent network zone* (ENZ) is an open area which includes all individuals operating as leaders in USER. Those within the ENZ are individuals who are highly involved in USER-work and possess the necessary funder or association organizational affiliation (cultural capital), language (cultural capital), resources (organizational capital), and relationships (social capital) to participate. Depicted in Figure 9, the ENZ creates a fluid boundary for leaders who operate in an emergent network capacity (i.e., exchanging knowledge, network learning, innovation). Within the ENZ, interactions are influenced by operationalized human capital, and individuals interact at various USER functions. On the periphery of the ENZ boundary are others working in USER who either

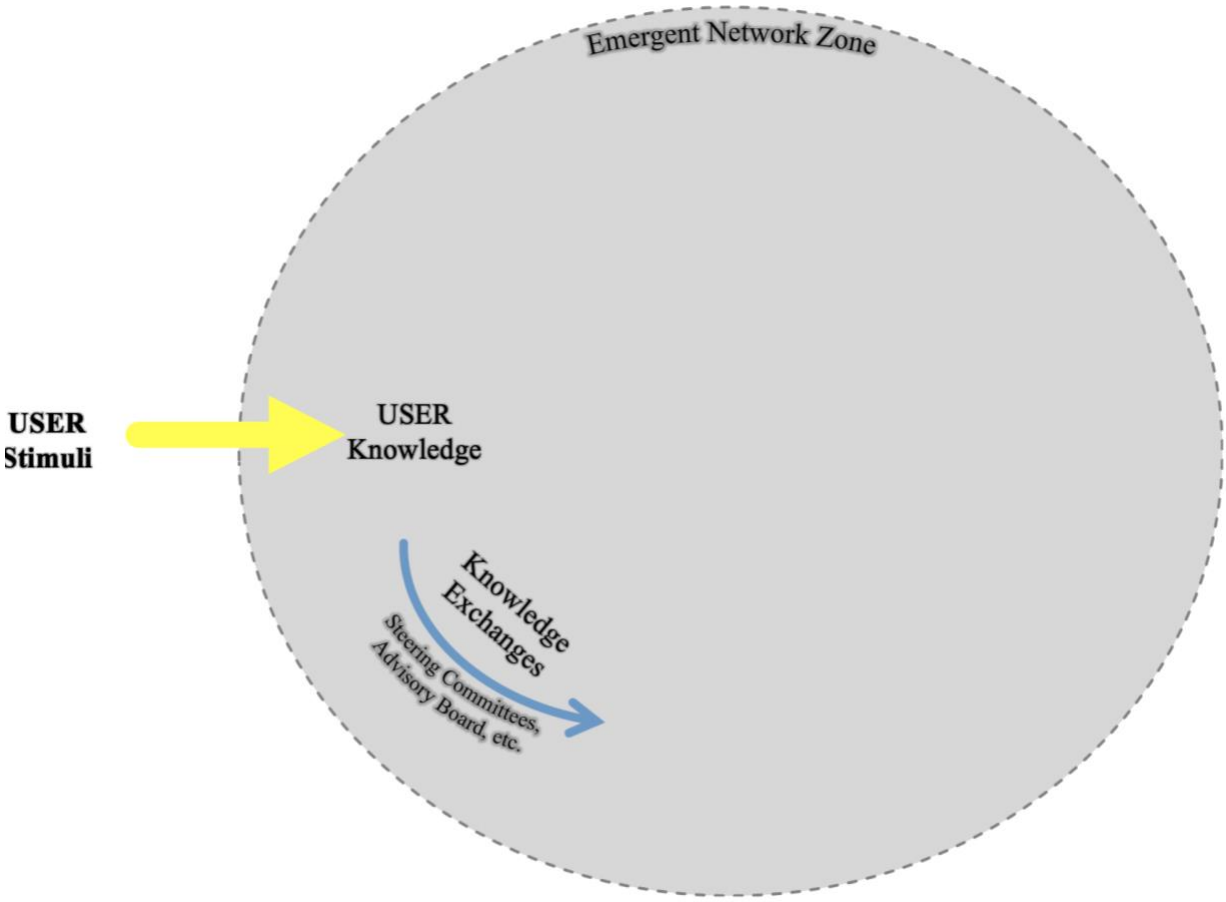
Figure 9. *Emergent Network Zone*



are interested or disinterested in participating in emergent network activities. The area external to the ENZ also represents the organizational environment in which the ENZ interacts.

Individuals within the ENZ interact with one another at various points throughout the year but are activated when a stimulus arises from the USER environment. As outlined by participants, this could be an issue with formal network operation, shortcoming in existing USER strategies, or an opportunity to access more funding. As the stimulus enters and spreads across individuals in the emergent network various processes begin simultaneously. When individuals encounter the stimulus, they compare it with their domain-specific knowledge and

Figure 10. *Emergent Network Activation*

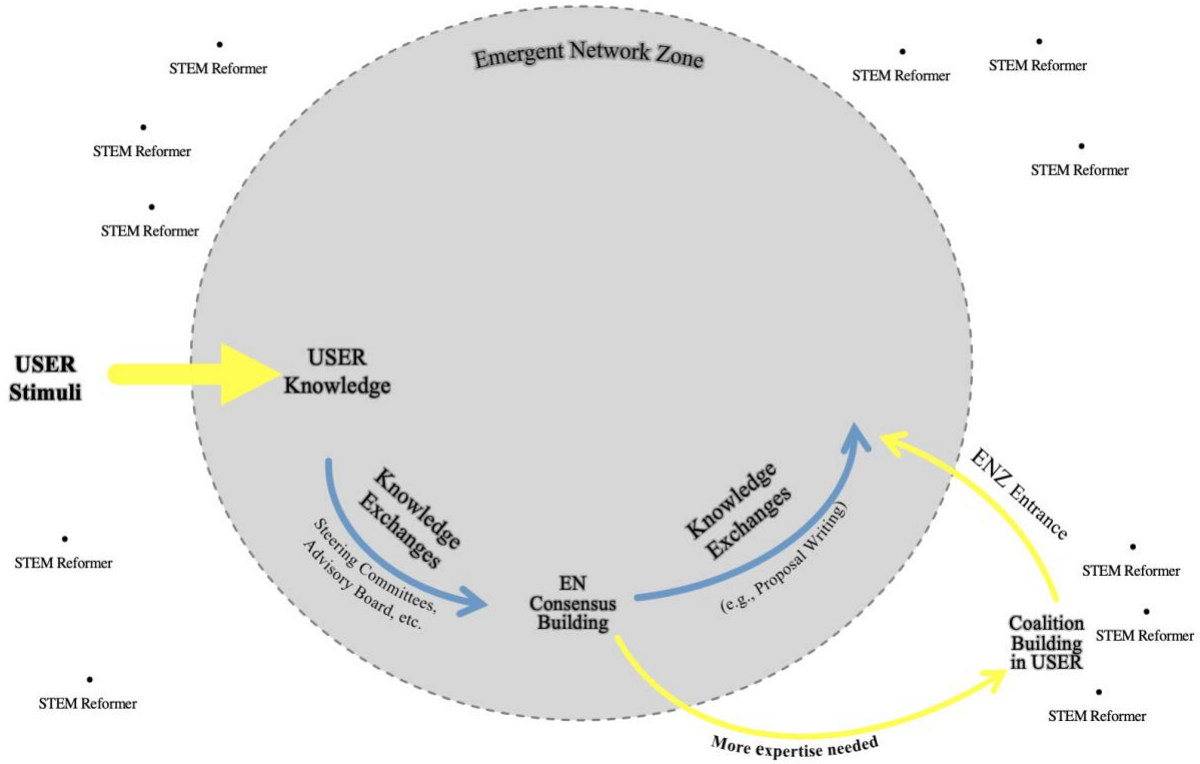


experiences and confer with others in the ENZ. This may include some or all of the participants but does not necessarily implicate every individual within the ENZ. Those implicated individuals contextualize the stimulus through conversations and compare it with established domain-specific knowledge. This knowledge may target amorphous concerns arising from the need for systemic change in higher education or specific needs of formal USER networks. The value of the domain specific knowledge is dependent on its scarcity and the credibility of the knowledge-holder. This knowledge ranges from domain specific language (e.g., theory of change) and the alphabet soup of acronyms within the field, to the intricacies of transitioning a formal network from grant-funding to a more stable financial structure. These processes of knowledge exchanges among these leaders occur across USER at various meetings, steering committees, advisory

boards, or other small conferences that host high profile individuals in USER, which are only accessible to people affiliated with high cultural and organizational capital. Namely, a person's organizational affiliations and funding dollars.

Simultaneous to knowledge exchanges, those individuals engage in consensus building. During this process, similar definitions, approaches, language, and understandings are negotiated (Figure 11). Conferring and sharing with each other illuminate either new opportunities for grants, proposals or potential holes in the emergent network zone. If those engaged in the emergent network zone believe they have enough credibility and content-knowledge, they may move forward with a proposed strategy to address a shortcoming in USER. This may be a funding proposal for a new formal network, additional funding or processes for an existing formal network, or other initiatives. If additional insights, knowledge, or credibility is needed by those engaged in the consensus building they locate someone with the necessary credibility to

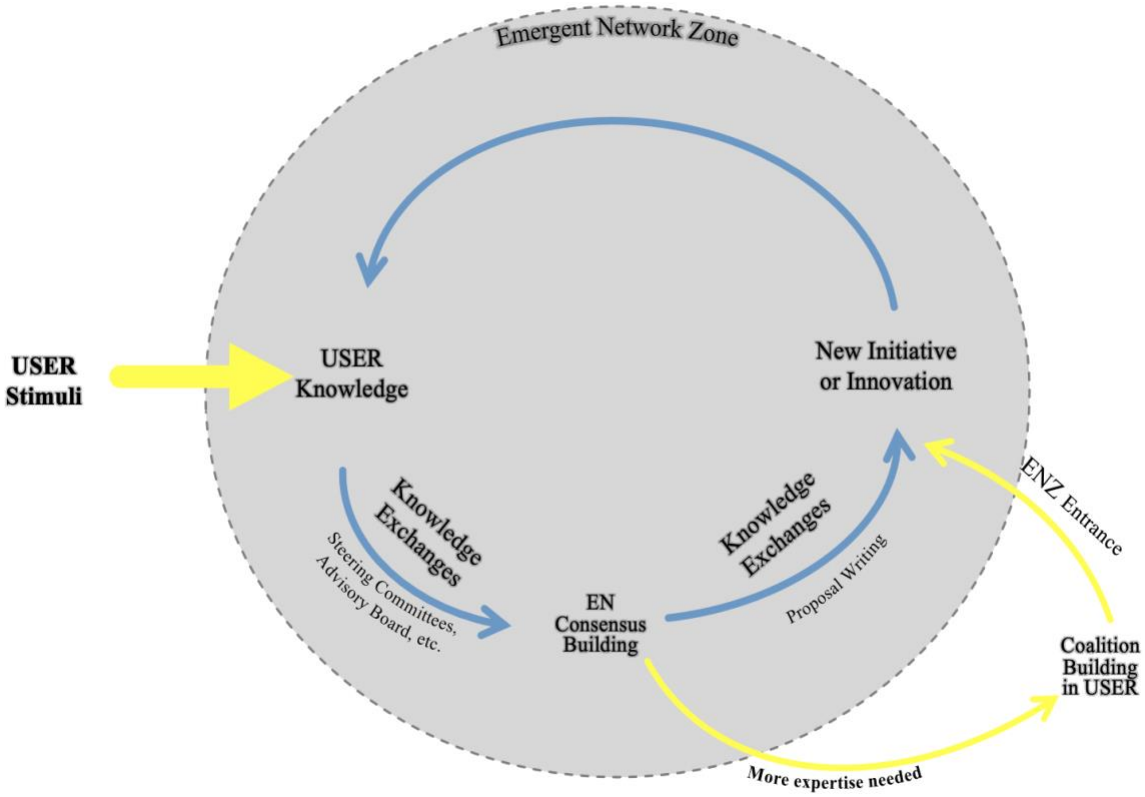
Figure 11. *Consensus Building and ENZ Strategizing*



add to the project. This person may be within the emergent network zone but may also be outside the group. Individuals outside of the emergent network zone who are recruited to join a project often undergo a socialization process, where they are *brought up to speed* with prior consensus established in previous conversations. Although these newly recruited individuals may be asked to partake in certain aspects of innovating, they generally lack the capital to renegotiate any of the previously agreed upon definitions or processes within the network.

Following the consensus and coalition building in the emergent network, individuals within the ENZ create projects, initiatives, or other strategies. In many cases these new creations are new formal networks, strategies to improve formal networks, or publications from formal networks. In all instances, the innovations drew upon perceived shortcomings in USER and sought to share new approaches or innovations to address those shortcomings. The innovation aspect of the cycle is also the point in the emergent network cycle where grant funding may be

Figure 12. *Emergent Network Function Cycle*



requested and awarded. If the innovation receives a grant, the cycle continues with the innovation diffusing within and out of the ENZ to other STEM reformers. If the innovation requires a grant and is not funded, the cycle begins anew. Individuals in the ENZ share their unfunded projects with others and build consensus and coalitions to increase their chances of receiving funding. After innovations are implemented in USER, all the information associated with the innovations creation and impact are diffused through social connections to the rest of the emergent network zone (Figure 12).

In total, the emergent network within USER is a collection of individuals who are affiliated with higher education associations and funding organizations and collaborate to generate strategies to help reform undergraduate STEM education. Their processes follow a cyclical pattern which originates from observed concerns in the USER environment and follows USER grant funding cycles. Notice, network learning is not included in this model. Despite it serving as a research-based function of emergent networks, few participants indicated any collective or organizational meaning making from the function cycle. Indeed, several participants (Hilarie, Lindsey, and Luke) all indicated their efforts were typically future-focused and considered what progress should be made with future endeavors. Based on the nature of organization networked-learning, its likely placement in the cycle is between "new initiative or innovation" and "USER Knowledge," but more research will be needed to explore this aspect of the emergent network.

Conclusion

The analyses presented here offer compelling evidence to the individual relationships and the functional capacities of the web of relationships. Overall, the nominated USER leaders acted as a collaborative interorganizational emergent network through actualizing many of the

processes associated with interorganizational network activities. First, various manifestations of human capital create an informal barrier among this group of leaders creating an in-group and out-group dynamic. Those in the in-group share information, build consensus, and engage the out-group through coalition building activities, before creating products, interventions or other networks to address challenges in USER efforts.

Regarding the proposed research questions, the qualitative strand of this study targeted the following questions:

1b). How do leaders engage in knowledge diffusion regarding their networks?
1c). How do leaders engage in network learning?

2. How does this emergent network affect USER formal networks?

The findings in this chapter argued for the knowledge within the emergent network zone to be composed of: (1) formal network expertise; (2) formal network outputs; (3) disciplinary background and expertise; (4) USER socialization; and (5) personal-relational information. Knowledge was activated and moved throughout the social network at different formal events related to formal networks (e.g., advisory boards, steering committees, etc.) to address a targeted need within undergraduate STEM education reform. This chapter also discussed the absence of emergent network learning by any scalable metric. Although some individuals cited network learning as an aspect of their work in USER, their examples either directly pertained to their work in formal networks or lacked the specificity to constitute inter-organizational network learning. Nevertheless, many of the examples provided by participants did provide insights into how this group negotiated consensus and rationale for coalition building in USER.

The effects of the emergent networks on formal USER networks is also layered. Many of the participants are founders, leaders, or advisors of formal networks. The emergent network

serves as a knowledge base and support structure for those in the leadership of formal networks and provides a group to strategize solutions for problems in formal networks and, at times, offer emotional support for those dealing with the problem. Additionally, the emergent network serves as a potential birthplace for new formal USER networks. In the concluding chapter, I integrate the findings from both strands of the study to present a holistic view of the emergent network structure, functions, and bylaws. I summarize the study before discussing its resonance with the literature base on emergent networks and conclude with future research into the roles of collaborative interorganizational emergent networks in higher education.

Chapter 6: Data Integration

The intention of this study was to further clarify the existence and role of an emergent network within undergraduate STEM education reform. Given the ambiguous and latent nature of emergent networks, this study's mixed-methods design adopted a pragmatic methodological grounding to use "the full complement of [research] tools" in its investigation (Creswell & Plano Clark, 2011, p. 2). Employing a sequential quan-qual research design provided multiple vantage points to begin decoding the actions of those within the network, and how the network operates as an organizational unit. Following a multi-round nomination process, 17 participants completed a social network survey, and six individuals from the sample were subsequently interviewed. In accordance with mixed-method design, each method was selected to address a proposed research question.

1. How do formal and informal leaders across formal networks in USER serve as an emergent network?
    1a). How interconnected are leaders across formal networks?
    1b). How do leaders engage in knowledge diffusion regarding their networks?
    1c). How do leaders engage in network learning?
2. How does this emergent network affect USER formal networks?

While the previous two chapters explored each of the study's data strands independently, this final data chapter completes the intended research design by blending and reinterpreting the findings to better understand this emergent network. Following a brief review of each strand's findings, the data integration discussion focuses on the confluences of individuals' structural placement in the social network (established in the social network analysis) and adds to the role of the undergraduate STEM education reform (USER) environment highlighted in interview strand. The study concludes by tying the study's integrated findings directly to the intended research questions, before highlighting future research opportunities.

Strand One: Social Network Findings

The first strand of this study employed quantitatively-focused social network analysis to map social structures embedded in the emergent network. Data collection included gathering participants' demographic information, USER organization affiliations, and socio-metric data on participant relationships (i.e., who knew whom). This strand used centralization and cohesion measurements to explore network-wide properties, centrality metrics to measure individual participant characteristics, and Quadratic Assignment Procedure (QAP) regression modeling to identify potential patterns in network relationships. Individuals within the network were also highly interconnected with no structural holes and few information bottlenecks. Cohesion metrics showed one dense, reciprocal, unfragmented network, with three structural layers: a center, middle, and periphery. Also, a composed sociogram network-of-networks displayed these individuals represented nearly 20 different formal networks or other committees operating in USER. This eliminated the possibility of all the participants coming from a single formal network, university, or other organization.

Analysis of an individual's centrality revealed complexity to each relationship as individuals generally interacted with the same people across different USER network concerns. QAP modeling yielded similar findings. Finding heterophily in organizational sectors and homophily in prior relationships indicated individuals interacted across organizational boundaries and used existing social relationships to problem solve issues in USER.

All findings in the first strand of the study indicated an open, densely connected social network of highly connected leaders in USER. More than simply connected, the findings from the social network strand quantitatively indicated complexity and depth to many relationships, meaning these relationships were more than simple acquaintances.

Strand Two: Interview Findings

The second strand drew participants from the social network survey to conduct semi-structured interviews. Interviewed participants were selected based on their placement in the network. Two participants from the center, middle, and periphery of the network were individually interviewed in one-hour video conferences. Findings from the interviews presented more in-depth explorations on how the emergent network operates, the functions it serves in USER, and its relationship with the environment.

After analyzing participants responses, definitions emerged for USER knowledge, knowledge exchanges, network learning, and innovation, and the emergent network was identified as an open systems organization operating as a *multi-headed*, semi-autonomous organism. Much like a hydra, individuals in the emergent network operated independently or in coalitions to generate innovations or other USER outcomes. Despite some autonomy, each of the metaphorical *heads* participated in a similar cycle of exchanging USER-related knowledge, building consensus and coalitions before proposing innovations.

Following the assertion of the emergent network as an open system, environmental factors were explored as a means to give shape to aspects of power, influence, and informal emergent network governance. These findings yielded affiliations to funding organizations or higher education associations and financial resources provided power and influence within the network, with one participant equating “credibility” in USER to “organizations and dollars” (Jennifer). The strand concluded with a conceptual model of an emergent network operating in USER. This model incorporated a porous border which interplayed with the environment and included the open system function cycle for those within the emergent network.

Data Integration

In following the intended mixed methods research design, the final analysis of the study combined data and reinterpreted findings from both prior strands. Integrating the findings is critical in mixed methods designs as the process adds robustness to otherwise disconnected findings and creates a more comprehensive analysis of the phenomena in question (Creswell & Plano Clark, 2011). While integrating data from different forms of inquiry may take many different forms (Creswell & Plano Clark, 2011), mixed methods designs have two ways of integrating. The first way, termed "sequential integration," refers to a process of using findings from the second strand to reinterpret the first (Creswell & Plano Clark, 2011, p. 71). This process typically allows for greater refinement and nuance in the first strand's results. Another form of data integration regards a strand's emphasis. As mentioned in Chapter 5, emphasis in mixed methods deigns refers to a study's strand that is better suited to answering the research questions. The second form of data integration, therefore, uses the un-emphasized strand's findings to complement, complete, or nuance the emphasized strand's findings (Creswell & Plano Clark, 2011, p. 86).

Considering this study, I present findings from both forms of data integration. Sequential data integration findings are presented first. This integration and discussion concern the findings from the social network analysis strand. Given new findings from the interviews, more context and understanding were added to the original evidence presented at the conclusion of the social network analysis. An emphasis-driven data integration follows the sequential data integration and highlights how the social network strand aids in the understanding of the open system, emergent network function cycle.

Sequential Data Integration

As this integration form takes findings from the interview strand of study and folds them into findings from the social network study, this section primarily focuses on network structure and interconnectedness. Using centralization and cohesion metrics, reinterpreted findings are presented first at the network-wide structural level. This provides a more nuanced understanding of the network structure and individuals placement within the network. After concluding the network discussion, reinterpreted QAP findings aid in understanding dyadic level interactions.

At the network structural level, participants were arranged by their average centrality scores into three categories based on their location in the network. Their locations were determined by averaging nine statistics spread across three networks, which yielded three structural zones. Although traditional network analysis bifurcates network structure by central and peripheral actors, a substantive break in actor betweenness measures necessitated a third

Table 13. *Structural Location of Participants in Networks*

Structural Location	ID		Average Degree	Average Closeness	Average Betweenness
Peripheral	11	(Allie)	4.67	31.00	0.00
	2		5.67	29.67	0.10
	8		8.33	27.33	0.14
	12	(Luke)	8.00	27.33	0.24
	9		8.00	27.33	0.70
Meso	17		8.67	28.00	1.67
	6	(Andrew)	8.67	27.33	1.59
	1		9.00	27.33	2.61
	13	(Hilarie)	8.33	27.67	5.96
	4		12.00	26.33	1.47
	16		11.67	24.33	2.12
Central	15	(Jennifer)	13.67	21.67	4.40
	7		11.67	24.33	4.77
	5		9.67	23.00	4.91
	3		12.00	24.00	4.54
	14		12.33	23.67	5.07
	10	(Lindsey)	13.33	22.67	8.71

structural location. This third, *middle* group, was termed the *meso-level* as the actors fell between the central and peripheral actors. Table 10 displays the structural location of participants and their structural location in the social network (derived from their average degree, closeness, and betweenness measurements across *Business, Problems,* and *GaveAdvice*), and the interviewed participants are marked by their pseudonym. Each subsequent section discusses the properties of their structural location.

Peripheral actors. Individuals on the peripheral of the emergent network were those who held the lowest average betweenness scores among participants. The term *peripheral* comes from the visual plotting in a sociogram where these actors are visually on the outside edges of a given network (Borgatti, Everett, & Johnson, 2018). This placement is always relative to others in a study. Peripheral actors are not viewed as internal network information brokers or internal information gatekeepers, and typically have less influence in social networks as they simply *know less people within the network.* Interestingly, Granovetter (1977) and Burt (2000) argued individuals on the periphery (or with weak ties) are uniquely situated to bring new information into a network. This placement gives peripheral actors more power to connect others in the network to information and people outside of the network, yet few individuals within the network with which to communicate.

Considering this study's participants, the periphery encompassed five people including interviewed participants Allie and Luke (Table 10). These participants had the lowest average centrality metrics across *Business, Problems,* and *GaveAdvice*. Most notably, were their averages in betweenness. Network betweenness is a statistic which describes how connected or *between* an individual is relative to others (Borgatti, Everett, & Johnson, 2018). All of the individuals in the periphery had the lowest betweenness and generally low degree and high closeness metrics.

Given insights provided by Allie and Luke interviews, several interpretations emerge regarding the structural role of the periphery of this network. First, both interviewed participants indicated a time component of their work in USER. Allie continually asked if she was the "oldest person" in the study and referenced her long career working in STEM reform. Indeed, Allie was the longest serving member, and had recently retired from "almost all of her work." Luke, on the other hand, described himself as recently entering national USER efforts, having been "cold-called" by several leaders to join formal network efforts. The large variation in time spent working in STEM was reflected by all participants in the periphery. Those five participants indicated working in STEM between 45 years (the longest) and the 8 years (shortest).

The temporal component of the periphery adds complexity to the working understanding of its role and begins to describe an entry point to the emergent network. In his example of a cold-call (outlined in the interview chapter), Luke discussed his rationale for the call as "[the primary investigators] needed a [science] guy" for their work on a grant-funded project affiliated with a national association. By joining the grant, Luke became affiliated with two influential organizations in USER. This example provides two findings for the emergent network. First, the process reflects an avenue for individuals to enter the emergent network. Leveraging intellectual capital and knowledge related to the chemistry field, Luke was able to affiliate with influential organizations and enter the emergent network. Second, his inclusion demonstrated a capacity of the emergent network to build a coalition to fill gaps in network's knowledge. This reflects aspects of the emergent network function cycle and the hydra reaching into the environment so that its internal processes may be sustained.

Actors who were retired or nearing retirement also occupied this space. Two of the participants in the periphery reported over 35 years of working in USER. Although they had

limited connections to the larger group, these older participants were tied to the most central actors, and not connected to those in other network locations. The two participants with the longest time in USER were in the periphery and were not connected to one another. The retired actors generally held an *emeritus* title affiliated with a formal network and generally did not participate in many of the knowledge exchanges. Instead, these individuals used personal communication (e.g., telephone and email) to stay connected with their friends. These relationships served as an information conduit for both individuals involved. The retired actors provided advice on formal USER networks, context to historical outputs of networks, and were generally *friends* with the people with whom they were connected. Those with whom the peripheral actors were connected provided updates to the state of USER, and in one instance gave advice on formal network financial sustainability (i.e., formal knowledge expertise).

Each of these findings presents a greater understanding of the network's periphery. The timespan of individuals working in USER combined with the entrance and exiting dynamic presented by Luke and Allie point to a transient space of coming-and-going. Members within the periphery may be ramping-up their work in USER having recently entered the emergent network zone, or scaling-back because they are retiring from their USER-work or fulltime employment.

Central actors. In contrast to the peripheral, central individuals in the emergent network were those who held the highest averages of centrality scores among participants. Given their high connection to other individuals, the term *central* refers to both the visual representation within a social network (i.e., in the center), and the critical role these actors play in facilitating network operations (i.e., communication flows, connecter) (Borgatti, Everett, & Johnson, 2018; Wasserman & Faust, 1994). Central actors in social networks are typically associated with high trust, influence, power, or popularity relative to others structural zones. In contrast to those in the

periphery, central actors are viewed to be efficient in communication, knowledge exchanges, and diffusion of information (as they are connected to many others), but these actors are often viewed as insular or otherwise unable to reach beyond the boundaries of the existing network(s) (Burt, 2000; Hawe, Webster, & Shiell, 2004).

In this study, there were six central actors including interviewed participants Jennifer and Lindsey (Table 10). These participants all held the highest averages in their centrality measurements. Table 10 displays a clear break in betweenness metrics between central actors and other locations. With the exception of Participant 5, central actors also had more connections (degrees) to others, which indicated they simply *knew many more people* across *Business, Problems,* and *GaveAdvice.* All individuals in this location were administrators of high-profile higher education organizations, and most served in some capacity of formal USER network leadership (i.e., executive director, founder, president, etc.). Over the last 10 years these actors received 39 different grants from the NSF for over $ 2.75 million. This figure does not include 2 central actors because they were ineligible to receive funding due to employment conflicts of interest. Five of the central actors either work or previously worked in Washington, D.C.

This group represents the core of the emergent network and epitomizes the emergent network function cycle. Their affiliations as administrators in high-profile organizations combined with their demonstrated ability to get funding provides the organizational and cultural capital for them to serve as connectors in building consensus across the emergent network zone. This group is also split into two groups: funders and high-profile individuals. The funders' interconnectedness demonstrates their power in the network and their ability to participate in all functions of the emergent network. The funders also participate in a different function of the emergent network - funding innovations. This adds complexity to the innovation's aspect of the

emergent network function as it represents a cross-over between knowledge sharing, innovation proposals, and funding. Importantly, their roles as funders provide an official avenue for them to continually review new ideas in the form of funding proposals. These roles ideally situate them for identifying potentially new people and ideas for USER and potential inclusion in the emergent network. High profile individuals share many similar qualities to the funders, with one notable exception: they are not funders. They have similar forms of influential organizational and cultural capital, which may come from their employer, numerous and sizable grants from the National Science Foundation, or both. These individuals participate in many functions of USER and are present on many steering committees, advisory boards, or other small gatherings outlined in Chapter 5. They are in the leadership or founders of at least one formal USER network. High profile individuals participate in similar capacities in the emergent network but have different access to new knowledge and participants. Their primary organization roles (i.e., higher education associations or expansive, high profile networks) provide this the center of the emergent network with access to new information that may help formal USER networks or the larger USER efforts.

Each of these findings presents a new understanding of the emergent network's core. Many of the central actors are (or have been) employed by high-profile organizations and funders. Aside from providing cultural and organization capital through association, their positions inherently connect them with many others working in USER. In fact, Lindsey stated it was inherently a condition of her employment. These connections allow the core to more actively interact with the environment than the formal definition of central actors indicate. This also presents a new interpretation for the role of social capital. Whereas the discussion on capital manifestation in the interview strand dismissed social capital as a grantor of influence, the

central actors' ability to reach into the USER environment through grant proposals provides power by *knowing the USER landscape* and potentially perpetuating their placement in the center of the emergent network. Central actors and their organizational affiliations aid in explaining the composition of the emergent network function cycle outlined in the interview chapter. The cycle of knowledge exchange, consensus building, and innovation mirrors actions individuals take in preparing a grant proposal. This cycle also keeps those who connect individuals and funders in the center of the emergent network as they often are those deciding who may get funding. Finally, central actor analyses also provide geographic hub of emergent network. As many of the central actors (and network-connectors) work in Washington, D.C., most of the remaining network members are tied to the city. This may translate to many knowledge exchanges occurring in Washington, D.C. at meetings, conferences or other forums. In sum, the integration of two strands demonstrates the critical role higher education associations and funders play in the functioning of the emergent network. They are central.

Meso-actors. As the name implies, the meso-structural location lies between the peripheral and central actor network regions. Individuals in this group had their average centrality scores fall within one standard deviation of the overall centrality mean. Traits in this area are less defined by literature on networks as there can be myriad reasons on why people are located there (Wasserman & Faust, 1994). Indeed, most bodies of research tend to dichotomize network structure into central and peripheral as it makes for easy comparisons (Borgatti, Everett, & Johnson, 2018). The distinction between meso- and other actors in this study is attributed to a major break in the middle group's betweenness scores (Table 10). The betweenness disparity between the peripheral and meso actors indicate a potential different role among these individuals in the network.

The meso-region was comprised of six individuals and included interviewed participants Andrew and Hilarie. With the exception of one actor, the meso-region was comprised entirely of faculty members. All faculty members in this space are on active NSF grants affiliated with formal USER networks. The non-faculty member in this location (Hilaire or Participant 13) works as an administrator at a higher education association. The distinction in the meso-region's betweenness scores indicate greater communication and interconnectedness among these leaders and the central actors and less communication with those in the peripheral.

Folding in findings from Andrew and Hilaire's interviews, this communication appears to be driven by a need for more formal USER knowledge. Both participants discussed the desire to access and implement new information to build or otherwise aid formal networks in which they were affiliated. Hilarie highlighted the importance of reaching out to peers to borrow ideas for the sake of precedent in funding proposals, and Andrew stressed his reliance on peers in negotiating the future of a formal network he led. For more in-depth discussion of their experience, please reference the interview chapter.

The combination of mostly faculty formal network leaders in the meso-region presents an interesting case. In some respects, this region may include many established leaders in USER actively working and sharing information throughout their social networks to improve their USER efforts. When compared to the peripheral, those in the meso may be those with more capital (i.e., more funding and organizational affiliations). These individuals are likely *doing the formal network work* in running reform efforts within their formal networks. Compared to the central actors, those in the meso are those not employed or otherwise directly tied to higher education associations or funders. Meso-actors' comparatively lower human capital provides less

influence in the space, but still allows them to connect to one another on issues concerning formal network operations.

Sequential data integration summary. Blending and analyzing the findings from the interview strand provide greater insights into the different structural locations established by the social network analysis. In sum, participants in the network's periphery have a temporal component related to their membership. Some individuals are relatively new to the emergent network, while others are long established and seeking to take a step back from their time in USER. Central actors, on the other hand, are individuals with a lot of cultural and organization capital. These individuals typically have employment or consulting experience with large national higher education funders or associations and serve in a self-described "connector" capacity (Jennifer, Lindsey). Finally, the meso location appears to primarily be comprised of faculty members who are active on funded-grants and delivering institutional reform or services directly to institutions of higher education.

Applying these refined findings also aids in understanding how the emergent network operates from a process standpoint and gives insights into where specific knowledge exists in the network, and in part, the content of dyadic knowledge exchanges. For example, knowledge exchanges between two central actors may pertain to how to better connect with others (e.g., individuals or institutions), while a knowledge exchange between a central actor and a meso-actor may pertain more to operationalizing a grant. This area needs more exploration, but these initial findings demonstrate a second level to the processes established in the emergent network cycle (as discussed in the interview chapter).

Emphasis-Driven Data Integration

While the previous sections on sequential data integration add greater context to the social network analysis, the findings are limited by the integration process. Inherently, the sequential data integration process folds the interview findings into the quantitative social network data. This foregrounds the first set of findings and uses the second to complement and complicate the first. When using a quantitative method as the first strand, this has the effect of constraining qualitative data by limiting the stories participants tell (Creswell & Plano-Clark, 2011). In this study, the findings from the qualitative analyses were limited to explaining aspects of the social network structure presented in the first strand. While integrating in this way presented a fruitful analysis of the social network structure, it did little to explain other aspects of the emergent network studied.

In contrast to sequential integration, emphasis-based integration completes a similar process but instead applies the un-emphasized strand's findings to the emphasized. This process effectively *flips* the data integration by allowing the research to integrate the findings in a way that most fits the intended research design (Creswell & Plano-Clark, 2011). As mentioned, the interview (second) strand of inquiry was the strand that carried emphasis as it was better suited to address many of the intended research questions. This discussion, therefore, is structured thematically by findings in the interview strand and uses social network findings to complement and complicate meaning derived from the data.

The emphasis-driven integration and subsequent analysis relied heavily on findings gleaned in the QAP regression modeling discussion outlined in the social network strand. This predictive modeling is a non-traditional regression method used to identify relational patterns embedded in a social network. In general, this process identifies when homophily (dyads share a

particular trait) or heterophily (do not share a trait) is common throughout the network. With respect to the social network of the participants in this study, four specific findings were discussed in the social networks strand: a) complexity in relationships; b) organizationally focused dissemination; c) individually focused collaboration; and, d) not statistically significant social identities. A more thorough explanation of these findings may be found in Chapter 4.

Emergent network function cycle. The emergent network cycle outlined in the interview chapter is a continuous process beginning with an observed problem or shortcoming originating in USER efforts. Following the observation some leaders within USER begin a process of applying their knowledge, seeking new knowledge, finding consensus, and building coalitions. Once a proposed solution is agreed upon, the individuals act. Depictions of the emergent network function cycle are located in the interview strand findings.

The QAP findings both reinforce and provide more context to how the emergent network function cycle occurs. The understanding that dyads exist across employment organizational boundaries as highlighted in the *organization focused dissemination* complement the notions of knowledge exchanges in USER. This is particularly salient when considering the heterophily in an individual's employed organization sector. Allie, Andrew, Lindsey, and Jennifer all mentioned they participate in many different USER related meetings which bring together diverse individuals from disparate post-secondary institutions, disciplinary fields, and sectors (e.g., colleges, associations, funders, formal networks, etc.). The inter-organizational nature and boundary spanning aspects are furthered again by the structural density of the network. Each of the supporting findings gleaned from the social network analysis point to a multitude of organizational identities represented within the emergent network. These findings better capture

knowledge exchanges within the emergent network as the exchanges come from multiple cross-sector organizations.

Secondly, the QAP findings identified *individually focused collaborations* as a behavior of the network. The collaborations identified by the analysis support both concepts of consensus building and coalition-building in the emergent network function cycle. Briefly, the QAP finding indicated homophilic tendencies based on time working in USER and employment position, and homophilic tendencies when discussing formal network problems. The distinction in these two behaviors point to participants building relationships differently dependent on the knowledge needed. In cases of discussing network problems, participants looked for those with different experiences. Hilarie and Andrew both highlighted this behavior when discussing their work with formal networks, underscoring the need to bring in new ideas or expertise to help their network achieve goals of receiving funding or financial sustainability. When it came to advice seeking though, the behavior appeared to be limited to those with similar experience. The act of seeking someone with similar experience for advice reflects some aspects of the consensus building processes outlined in the function cycle. As individuals encountered different problems in the USER landscape, they consulted others with similar experiences to clarify or make sense of the phenomena. Andrew spoke of this when he highlighted how his network was looking for financial sustainability opportunities. In general, *individually focused collaborations* provides a bit more context to the traits of individuals engaging in coalition and consensus building activities, but more exploration is certainly needed in this area.

Open system organization. Moving beyond the discussion on the function cycle, the second strand posited the collection of participants operated as an open system organization. Arguing the participants were bound to the emergent network cycle and vested human capital,

each person acted semi-autonomously with the environment in their USER efforts. The goal of this emergent network-organization is to improve undergraduate STEM education. This organization was likened to a multi-cephalous organism, able to work on multiple and unrelated projects at one time. When placed in this context, three of the social network findings add more perspective to how this organization operates. First, the finding outlining complexity in relationships demonstrates the familiarity and interdependency of its members in serving the goals of reform. The interconnectedness and dependency are also supported by the network centralization and fragmentation metrics. As mentioned in the social network strand, complexity in relationship extends beyond simple acquaintances and indicates the participants rely on one another for problem-solving and advice. These relationships bounded by the goal operationalized by the emergent network cycle all indicate a group of individuals working as a unit.

Individually focused collaborations also provide perspective on how the network may operationalize the emergent network cycle. Aside from indicating that individuals may work collaboratively, it showed small groups were the preferred method of working in USER. Indeed, no participant indicated a single instance where all participants were working together or jointly. Jennifer bemoaned this in her interview arguing the need for a centralized coordinating system for the efforts. Allie likewise agreed complaining that there were too many silos in USER efforts, and people were talking past one another. Although the silos may exist in other parts of USER, the social network findings indicate that collaborations and knowledge exchanges were central to the functioning of the emergent network. These behaviors point again to the STEM hydra. Individual choose to exchange knowledge, ideas, and occasionally work together, but are semi-autonomous in how they operationalize the knowledge gained. The heads of the hydra though, are bound to the processes established by central actors and high-profile USER organizations.

Despite many of the social network findings supporting the open system organization, some questions still remain. Namely, other than the significant co-variates listed in the QAP, what characteristics or conditions are necessary to drive collaboration among participants? Does the emergent network ever act in unison toward a specific goal more nuanced than USER? Similar questions exist regarding the how the emergent network cycle formed.

Conclusion

This chapter completed the research design by integrating the findings from the two previous strands of inquiry. Although the social network analysis demonstrated the interconnectedness and social structures of the network, it alone could not unveil the valued aspect of human capital or how power was distributed throughout the network. The social network analysis, furthermore, could not elucidate the contexts of the relationships beyond the survey prompts.

Through the sequential data integration, findings from the interviews provided data to further explain these relationships, and their contact frequencies. Indeed, many of the participants are more than simple acquaintances, and the structure of the emergent network indicates power is centered with funders in Washington, D.C. The emphasis-driven integration similarly combined data by using the interview data as a lens to re-interpret the QAP findings in the social network strand. Findings in *knowledge* and *knowledge exchanges* gave greater depth to concepts of knowledge transfer outlined in the regression models by providing both 1) what knowledge was exchanged, and 2) where and when the knowledge was exchanged.

Following the data integrations, I concluded with a discussion on how the behavior of the emergent network aligns with aspects of open systems organizational theory. I contended each of the participants acted semi-autonomously to serve their network and USER goals but were bound

to one another through social structures. These social structures mirrored the emergent network behaviors and capital outlined in the interview strand. In the final chapter, I revisit each of my research questions, provide evidence to address them and offer both theoretical and practical implications for scholars and practitioners alike.

Chapter 7: Implications and Conclusion

Returning to the research questions established at the onset of the study, the questions sought to establish the existence and role of an emergent inter-organizational network in USER. The first question identified individual behaviors indicative of an emergent network, and each of the sub-questions investigated different literature-supported functions of an emergent network. The second research question targeted impacts of this group on other USER efforts. Specifically, the research questions asked:

1. How do formal and informal leaders across formal networks in USER serve as an emergent network?
    - 1a). How interconnected are leaders across formal networks?
    - 1b). How do leaders engage in knowledge diffusion regarding their networks?
    - 1c). How do leaders engage in network learning?
2. How does this emergent network affect USER formal networks?

Following multiple rounds of data collection, analysis, and integration, the findings for this dissertation are a bit overwhelming. Indeed, Creswell and Plano-Clark (2011) argued mixed-methods design often complicate and obscure findings. In order to better clarify the evidence elicited by the research, I provide data to address each question directly. The following sections consider a specific question (or sub-question) and couple the question with evidence. I begin by outlining the sub-questions.

How Interconnected are Leaders across Formal Networks?

In attending to the first sub-research question, data in the social network analysis provided ample evidence to address questions regarding leader interconnectedness. The results from a social network survey revealed a high degree of interconnectivity across all participants. These findings included high network density statistics, no fragmentation, and low betweenness centralization measures. The centralization measures were consistent across all three of the social

networks investigated (i.e., *Business, Problems, and GaveAdvice*). On average, the participants were directly linked to 70% of the others in the study. Each of these statistics point to a highly connected group of individuals.

Translating the statistics beyond the numbers and percentages, the social network survey indicated the participants knew most of the other participants reasonably well. Most participants communicated with one another regularly, and often saw one another semi-regularly in various meetings in Washington, D.C. These relationships ranged from acquaintances to trusting friendships, and in many cases, participants knew details about others personal lives. With regards to USER-related work, there were few structural bottlenecks for USER-related information to get trapped. The lack of network fragments in the denoted USER knowledge freely flowing throughout the network. In short, almost everyone was *in-the-know* with regards to USER work and operating from a similar understanding on the current state of USER.

A potential explanation for the high degree of connectedness among the participants would be that all of them belong to the same formal network. If true, this formal network would explain why all participants knew one another and calls into question the existence of an emergent network across USER. In fact, the findings outlined in the dissertation could all be dismissed as circumstances associated with all the participants' membership in one formal network. To address the potential pitfall of dismissing the findings, all participants were surveyed on their network memberships. Although some USER formal networks were more prevalent than others, no single network could be linked to all participants. Instead the 17 participants provided almost 20 different formal networks, which were populated into a social network. This Network-of-Networks (discussed in Chapter 4) was less densely connected than the other social networks highlighted (i.e., *Business*, *Problems*, *GaveAdvice*). The high degree of

interconnectedness across participants combined with the low degree of interconnectedness in the Network-of-Networks pointed to a collection of leaders who represented their organization.

How do Leaders Engage in Knowledge Diffusion?

Concerning the second sub-question, findings gleaned from the semi-structured interviews provided insights into what the participants considered to be knowledge, why knowledge is moved across the network, and when it is shared. Participants generally defined knowledge as the possession of critical and scarce information that may aid USER efforts. Knowledge fell into five different domains: (1) formal network expertise; (2) formal network outputs; (3) disciplinary background; (4) USER socialization; and (5) personal information. These different knowledge domains were valued by all participants regardless of their structural location in the network, time spent working in USER, or other discernable variables. The first two knowledge domains (i.e., formal network expertise and formal network outputs) focused on the work of the formal networks and relied on individual participants sharing knowledge through their experience working with formal networks. This may have been using previous governance structures or network programs. The latter three domains were more individually focused. Participants discussed seeking individuals who held knowledge about a discipline or highlighting information they encountered through working in USER for an extended period of time.

Drawing again from the interview data, knowledge diffusion occurred through personal exchanges among participants in various mediums. These actions were termed *knowledge exchanges* and were signified by participants discussing any of the knowledge domains. Knowledge exchanges occurred primarily in three venues. Featured most prominently in this study were conversations held in formal, closed-door meetings pertaining to USER grant-work, most often cited as either steering committee or advisory board meetings. In these meetings,

various leaders from across USER came together to discuss concerns with networks and at-large USER issues and were often comprised of different combinations of participants. The second venue identified were small grant-funded USER conferences. These venues provided an opportunity for the leaders to update one another on their network affiliations and loosely discuss strategies for aiding formal networks. Third, participants discussed personal communications like email and telephone calls. This was mentioned less frequently than the other methods and presupposed a level of familiarity.

Findings from the social network strand also support a high degree of knowledge exchange and a general ease of information diffusion. As mentioned, the participants produced an interconnected social network. Burt (2000) associated high degrees of interconnectivity with network closure stating, "there is no one who can escape the notice of others" (Burt 2000, p. 37). Essentially, everyone knows one another and has the ability to stay updated on what others in the network are doing. Coleman (1990) also argued closure facilitates greater information diffusion across social networks because individuals trust one another and view knowledge sharing as "less risky" (p. 306). Knowledge diffusion across a network is also further increased when individuals know personal information about others as it may signify a social relationship beyond the formal ties of organizational membership.

In summary, the social network findings provide a conceptual understanding of the social structures in which knowledge flows through the network. This indicates the mechanisms of *how* knowledge is diffused. The network of participants is dense, and information flows freely across the members through their social connections. Findings from the interviews provide more dimension to *what* knowledge is moved, and *when* or *where* the information is operationalized.

In that discussion, the five knowledge domains are moved through the network and during various meetings of different USER leaders throughout the year.

How do Leaders Engage in Network Learning?

With regards to emergent network learning, the findings were more nuanced than for the other sub-questions. On the surface, few interviewees articulated aspects of network learning beyond simply wanting to improve undergraduate STEM education. Indeed, the organized aspects of network learning may be more inherent in formal networks, which may have a more explicit mission focused on network learning and improvement (Popp, et al., 2014). The social network findings also provided little evidence of network learning. Although the findings indicate a social structure for network learning to occur, there was no socio-metric statistic to indicate active feedback loops. In response to these findings, the role of emergent network learning in USER remains unclear; however, the lack of formal organizing structures and amorphous nature of the open system organization point to the actions occurring dyadically, not systemically.

In lieu of network learning, participants indicated other social organizing activities which occurred within the network. Interviewees frequently discussed their roles in building coalitions and consensus with others operating in USER. Members of the emergent network sought input from others to make-sense of the phenomena occurring in USER efforts and formal networks. This often took place through conversation with others at conferences, steering committees, or other emergent network knowledge exchanges. Participants also discussed building coalitions as an aspect of their work. Coalitions were primarily sought by participants in the innovations the emergent network put forth. Most prominently, this was featured when emergent network

members were co-authoring a grant proposal or initiative to address some problem perceived in the undergraduate STEM education landscape.

How do Leaders across Formal Networks in USER serve as an Emergent Network?

Recalling the opening sections of this dissertation, the study sought to identify and explore the existence of a collaborative emergent inter-organizational network operating in undergraduate STEM education reform. The first research question speaks directly to the study's intention. In serving this question, I define each component of the collaborative emergent inter-organizational network and provide evidence which support or negate its existence among the participants.

First, the term "collaborative" reflects a type of network where independent actors work together to provide a public good, service, or value when a single institution is unable to create the good on its own" (Isett, et al., 2011, p. 157). The collaborative nature of those working in USER fit within the collaborative network definition, as they often enter networks as willing independent actors trying to help their institutions address the systemic problem of USER. Indeed, many participants discussed the collaborative work completed in the service of formal network missions and in the greater USER landscape. Lindsey emphasized her "connector" role as an administrator, and Hilarie talked about her work with higher education associations stating, "Lindsey, Henry (pseudonym) and I really try to push as much information to our university partners as possible." Jennifer too underscored the togetherness stating, "part of this, Levi, is we all plays different roles in this, and we all need to work together to push for further change." In their views the collaborative work was two-fold. First, they worked as a group of reformers assisting colleges and universities to implement better undergraduate STEM education practices. Second, they worked as a group of leaders in formal USER networks assisting in better practices

within the networks. While these collaborations targeted different audiences with different messages, they still fit with the collaborative network definition as these independent individuals worked together to help different organizations.

Second, *inter-organizational* simply refers to an entity comprised of actors representing different organizations. Literature indicated inter-organizational networks were a preferred strategy by organizations with limited resources who face a similar complex or systemic "wicked problem" (Rittel & Weber, 1973, p. 8). With regards to this study, ample evidence indicates the participants represent multiple organizations. First, no two participants were employed by the same institution. In fact, no sector of higher education (i.e., research university, liberal arts college, etc.) comprised the majority of participants. Table 2 in the social network analysis chapter highlights the employing organization breakdown. Secondly, each participant indicated they represented multiple formal inter-organizational networks. Participants identified 19 different formal networks in which they belonged, thus adding a second level of inter-organizational boundaries to the study. Table 3, Table 5, and Figure 8 in the Social Network Chapter display the relevant formal network inter-organizational statistics.

The third term, *emergent network*, is more difficult to define and identify. The ambiguous and amorphous nature of social relationships often muddle or complicate individuals acting as friends, colleagues, confidants, or in a networked-capacity. Although available research on emergent networks is relatively limited, several authors provide different frameworks to identify their existence in social networks. Isett et al. (2011) described emergent networks as loose collections of "organically derived" relationships whose existence stemmed from organizational needs (p. 162). Popp et al. (2014) indicted emergent networks were informal collections of individuals who respond to large systemic problems and address organizational needs. Several

authors provided approaches to identify emergent networks, but many lamented the difficulty of "labeling" emergent network organizational behavior (Rodriguez, Langley, Beland, & Denis, 2007, p. 325). Popp et al. (2014) pushed a strategy of identifying emergent networks by how the social network behaves. They argued recognizing emergent network functions (i.e., knowledge diffusion, network learning, and innovations) within an inter-organizational social network would indicate that an emergent networks existence. These functions underpinned the sub-questions, whose findings were established in their respective sections.

As a brief review, the leaders work as an open systems organization structured with norms established by organizational affiliations (cultural capital). These social structures were termed the *emergent network function cycle* and are depicted in Figure 12 in the interview chapter. In brief, the leaders in USER continually share information about observed problems in USER, their USER initiatives, formal networks, or opportunities with one another. These knowledge exchanges happen in many different venues, but primarily occur in steering committees, advisory boards, or other small USER meetings throughout a given year. The knowledge exchanges provide a space for leaders to share information, wrestle with consensus, and strategize paths forward for both formal networks, and USER in general. Throughout their time working in USER and with knowledge exchanges, the leaders work in tandem to confront their concerns, and build a common approach or understanding to address their concerns. Once new approaches, strategies, or even new formal networks are implemented, they become a new form of knowledge embedded in the social networks of the emergent network and may be activated to address future problems.

In sum, this collection of leaders serves as a collaborative group of individuals working across many sectors of higher education and higher education advocacy to offer services to

reform undergraduate STEM education. They act as an open, loosely connected, organization who share knowledge related to USER, lean on one another for meaning-making, and co-construct strategies or innovations for pushing USER forward. The evidence provided in the findings herein support the existence of a collaborative inter-organizational emergent network operating across leaders of formal networks in undergraduate STEM reform, who perpetually cycle through knowledge sharing and innovating.

How does this Emergent Network affect Formal Networks in USER?

The final research question concerns the impact of the emergent network. Despite highlighting the existence and role of an emergent network in the previous sections, the effect of this network is not explicitly articulated. Results from the interviews presented several outputs which both directly and indirectly affect formal USER networks. The outputs were: (1) new formal networks; (2) proposals; (3) formal network governance structures; and (4) formal network sustainability strategies. Directly affecting formal USER networks, formal governance structures and sustainability strategies presented ways formal networks could more effectively organize to grow and operate. New formal networks and proposals were additional outputs from these participants that created new opportunities for involvement and brought more individuals into USER.

Beyond the scope of research questions, evidence suggests the emergent network function cycle operates differently at different levels of the emergent network. At the periphery of the social network, individuals are either entering or exiting the network. These individuals rely more on their social capital as a means of holding influence and seek to grow their organizational and cultural capital through USER socialization, new formal networks, or other grants. If they are exiting, they remain close to specific influential central actors with high

organizational and cultural capital. Central actors are primarily funders or actors working at high profile institutions. These individuals leverage their cultural capital, organizational capital, social capital to attract new knowledge to the space and connect otherwise disparate actors into the emergent network functions. Central actors are often ex-officio attendees of the various and numerous meeting venues for the emergent network. People in the meso-level of the social network are primarily faculty involved in the leadership of formal networks. These individuals confer with their central-actor funders and a few of the peripheral actors for more information on how to properly organize and operate their networks.

Despite the interconnectivity, different capital manifestations in the interviews demonstrated a form of hierarchy within the network. Based primarily on organizational affiliations and funding dollars, large funding organizations bestow credibility through legitimizing proposals in the space. Funders serving as the central actors supports this point. Organizational capital, in the form of position affiliation and funding, has a large role in how individuals in the network operate. The resources from organizations carry influence in allowing different leaders to pursue their proposed ideas. Cultural capital, primarily in the form of linguistic and symbolic capital, similarly carry weight through organizational affiliation by lending organizational legitimacy to those affiliated with the organization. In sum, the participants in this study serve as a collaborative inter-organizational emergent network. Despite originally establishing the bounds of the study as an emergent network *across* formal networks in USER, this emergent network operates as a group across USER.

Theoretical Implications and Contributions

Aside from highlighting the dearth of research, few empirical research studies mention, much less explore, emergent networks and their function (Isett, et al., 2011; Popp, et al., 2014).

Whereas some works target the network structures (Ahuja, Soda, & Zaheer, 2012; Provan & LeMaire, 2012; Uzzi, 1997), many of these sought to map emergent networks through unbounded social network analysis across multiple domains. To date, this is the only known study applying multiple methods to interrogate the structural and enacted functions of an emergent network in higher education. As such, its findings are a first step towards establishing a clearer picture of how emergent inter-organizational networks operate. The results from this research show many different layered processes embedded within the informal-relational structures of emergent network. They also suggest the necessity of complex relations to form an emergent network. More importantly, this work adds to the existing knowledge of emergent inter-organizational networks in four fundamental ways.

Capital and embedded networks. First, both strands of the study highlighted the roles of social, cultural, organizational, and intellectual capital in the emergent network. In short, an individual's symbolic cultural capital, organizational resources, and social integration (i.e., socialization and social capital) impact how individuals engage in the network and its functions. These forms of capital govern how individuals interact, who seeks whom within a network, and why. In part, various forms of capital also implicate the structure of the network.

As noted in the data integration sections, forms of intellectual, symbolic-cultural, and organizational capital inform aspects of the peripheral, meso, and central actors of the network. Objectively, concepts of capital seem reasonable, as individual reputations and organizational legitimacy are not *left at the proverbial door* when networks convene. Most work on inter-organizational networks focuses on organizational issues, cost-benefit analysis, reasons for convening a network, or how to effectively manage a network from formation to sunset. Future

studies should further explore the roles of capital deployment, particularly in emergent networks, where formal bylaws do not govern individual engagements.

Further, this study departs from the literature in highlighting an inter-organizational network spanning inter-organizational networks. Tangential to the conversation on the role of capital, this study introduces the concepts of multiple organizational affiliations. Whereas traditional inter-organizational network explorations studied formal networks (Isett et al., 2011; Popp et al., 2014), this research begins to uncover a network embedded within inter-organizational USER networks. Situating a study in this fashion provides insights into the role of individual capital, but also may suggest formal network self-perpetuation or disparate bureaucratization hosted in the informal relationships of lead participants, where individual knowledge brokers form relationships with power-holders to perpetuate their capital. This finding is certainly supported by the finding of these leaders producing more networks and proposals.

Neo-institutionalism. Tenets from this work also add to the literature on neo-institutional theory of organizations (DiMaggio & Powell, 1983). This theory posits environmental peer pressure (also referred to as isomorphism) pushes individual organizations to become increasingly similar. Environmental forces push conformity regardless of the organization's origins in three forms of isomorphic behavior: coercive, normative and mimetic. Although any isomorphic behavior can push conformity, all three can be present in a particular organization. In this framework, organizations seek environmental legitimacy as it bestows the power for an organization to achieve its goals (DiMaggio & Powell, 1983).

There are several aspects of neo-institutional theory apparent in the emergent network findings. Several participants highlighted the knowledge sharing across the emergent network to

aid in the founding or development of formal networks. The primary driver cited for this action was to gain resources from funders. This *mimicking* of formal networks for greater network sustainability reflects mimetic isomorphism occurring across the emergent network. Similarly, many of the value structures, knowledge forms, and disciplinary backgrounds inform formal network structures. Many of the formal networks cited in this study either began or continue to maintain a grant primary-investigator form of leadership, and reflect legitimate *normative* behaviors associated with structure in the STEM disciplines. Finally, Jennifer captured the final form of coercive isomorphism when discussing the role of funding organizations in USER. She bemoaned the absence of uniformity across USER and said "[we have] a lack of isomorphism, but a desire to be more isomorphic." In her experience, the funding organizations exercise their power by awarding funding to certain primary-investigators or networks. Funding these actors pressures those in the resource environment to act similarly or risk funding.

Given the discussion of individual participants' capital manifestation, all networks participants (emergent and mandated) seek legitimacy in their organizations through funding to achieve their goals. In this sense, cross-organizational "affiliations and dollars" were a source of organizational legitimacy. The prevalence of isomorphism, or the convergence of behaviors and practices, in USER seemingly calls into question the innovative rationale for creating inter-organization networks. If formal networks are conforming to legitimate and normalized behaviors, their capacity to *think outside the legitimacy box* may be inhibited. Nevertheless, organizational affiliations and dollars may provide the necessary social leverage for individuals and organizations to effectuate change in USER. Indeed, the literature is undecided on how isomorphism and innovation intersect, so future research in USER should further investigate the effects of isomorphism on reform efforts. Given the exploratory nature of this study, future

research should further probe manifestations of capital, legitimacy and the roles of isomorphic behavior in USER efforts.

Methodological contribution. Recognizing the nuances of relationships was critical to the findings in this study. The methodological approach used provides more robust findings for emergent networks. Prior network research either employed social network analysis to define structures (Galaskiewicz, 2007; Gulati et al., 2011) or interviews to interpret the individual's experiences in networks (Provan & LeMaire, 2012). Although each of those approaches provided some insights into the functions and roles of networks, they were generally limited by their methodology in that they only investigated small pieces of an emergent network and were unable to more fully describe the whole. Whereas social network analysis could inform interconnectedness (Ahuja, Soda, & Zaheer, 2012; Uzzi, 1997), actor selection (Daly, 2018), or actor influence (Daly, 2010), the approach could not inform the content of information flows, or how capital is actualized in a network. Social network analysis is also limited by the dynamic nature of relationships. Similarly, interview data provide "thick and rich descriptions" of phenomena, but those experiences may lack resonance across the social network. Plainly, people experience and define relationships differently.

Using a combination of nominations, social network analysis and interviews to interpret, analyze, and reinterpret the data provided an abundance of findings. Investigating emergent networks with a mixed methods design provided multiple avenues to avoid the shortcomings of previous research. but also provided reliability and triangulation measures beyond those married to specific methodologies. For example, the interconnectedness of actors found in the social network analysis was confirmed and expanded upon in the qualitative strand of the study. Instead of relying on traditional balance or robustness tests for validity with the social network data, I

asked the participants to further detail their responses. Similarly, the social network analysis provided a more complete picture of actor connectedness beyond what any individual could explain or draw. Future research into emergent networks should rely, and improve upon, the mixed methods approach used in this study.

Undergraduate STEM education reform. In terms of USER-specific implications, this study offers insights into the deployment and use of formal networks operating in undergraduate STEM reform. As mentioned in the introduction, inter-organizational formal networks are a popular organizational strategy used by USER funders to leverage change in higher education. Despite networks' increased use, scholarship on their role and functions considerably lags behind their use (Isett et al., 2011). Although scholarship on formal networks has begun to better develop our understanding (Gehrke & Kezar, 2016; Kezar, 2014), this study provides insights into the social mechanisms that drive, shape, and support formal networks operating in USER. Knowledge of the existence and role of the emergent network should inform funders, faculty, and other affiliated individuals on how they limit, perpetuate, or substantiate efforts in social relationships before any formal actions occur. These findings may also aid actors in USER better identify their processes and information flows for better inclusion in emergent network discussion.

Practical Implications and Contributions

The conclusions from this study also have tangible implications for those working to reform undergraduate education. Given inter-organizational networks implicate a cross-section of organizations and sectors, the findings from this study resonate with a broad range of stakeholders. As stated, formal networks are strategies used by stakeholders in higher education to improve undergraduate STEM education. Although not strictly organized or funded, emergent

networks co-exist with the formal and offer benefits to those working in reform. The emergent network acts as an open-system organization which leverages change through several actions. These functions promote alignment across USER efforts by engaging USER leaders in (1) knowledge exchanges, (2) consensus and coalition building opportunities, and (3) innovations. Emergent network functions transcend traditional organizational and formal network boundaries and allow those involved to communicate across USER regardless of sector or organizational memberships. The following sections highlight implications for how various stakeholders may be more intentional in recognizing and incorporating the emergent network into the USER efforts.

Undergraduate STEM education reform funders. Given the findings of this study, there are several considerations for organizations which provide USER funding. Much of the funding efforts in USER have been dedicated to creating and sustaining formal networks. While these efforts are important to synchronizing and diffusing reform efforts to member campuses, little attention has been given to the informal relationships generated through these formalized networks. Indeed, the findings from this study support the co-existence of an informal, emergent network which operates alongside, and supports, the operations of their formal counterparts.

Funders should be more cognizant of this social phenomenon, however somewhat paradoxically, they should not move to formalize the emergent as a formal network. The transient nature of individuals in the network combined with the organic relationships found therein limit the ability to *mandate* that type of collaboration. Instead, funders should seek opportunities to enhance the functions of the emergent network. For example, the emergent network function cycle begins, and is sustained by, continual knowledge exchanges. Funders should continue to foster opportunities to bring together small groups of leaders in USER through roundtables, small

conferences, or task forces. Funders should also replicate convenings similar to the grant advisory board meetings or formal network steering committees comprised of formal network leaders to discuss current concerns in USER efforts and strategize potential strategies. These convenings should be small, but with a pre-set agenda to focus participants on specific aspects of change efforts.

The findings also indicate funders' power extends beyond the formal grantor-grantee relationships. Grant funded projects (or even formal networks) have the potential to build inter-personal relationships with participants and generate more USER innovations. Indeed, the creation of a new formal network may be the result of an emergent network operating across USER. Second, connections with funding organizations provide human capital to grantees. This capital allows grantees to interface with others in USER more regularly. Given this phenomenon, funders have the power to bring individuals to the proverbial table and participate in the emergent network functions.

Formal network administrators. Individual formal network leaders, staff, and administrators also may utilize the findings of this study. Several participants directly cited one role of the emergent network was to strategize and support formal network improvement. Support took the form of assisting formal networks with financial sustainability, leadership transitions, organizational transitions, or formal network governance concerns. The emergent network offers a wealth of knowledge, consensus, and innovations to aid formal networks. Formal network leaders should be aware of the emergent network and the potential benefits they offer to network stability. In actuality, many formal network leaders may participate in the emergent network already but may not label the interactions as such. Formal network administrators should use the conclusions of this study in two distinct manners. First, recognize individuals in their formal

network who may have connections to the emergent network, and utilize their connections to aid their formal network. Second, formal network leaders should encourage participation, consensus, and interpersonal development of those within their network. For larger networks, this may mean creating opportunities for the network to feel smaller to participants (e.g., break-out groups, roundtables, committees, etc.). Developing these relationships within a formal network will lead to more network stability, but the relationships generated may endure to be part of a future USER emergent network.

Reform-minded faculty. Individual faculty members also have several factors to consider in light of this study. The emergent network is an amalgamation of reform-minded faculty who have actively engaged in developing relationships with others working in USER. Faculty who want to become involved in the emergent network should seek to fully engage with their formal network affiliations, build relationships with those involved and assist with formal network operational concerns. Gaining experience in formal network operations may lead to individuals in the emergent network seeking to incorporate that specific knowledge into their processes.

Limitations

Although careful attention was given to the research design, data collection, and analysis, several limitations were inherent in the process of conducting this study. The first potential limitation concerns the nominations process. Although multi-round nominations processes are viewed as a mechanism for avoiding selection bias in participants, they are not free of limitations or confounding biases (Avella, 2016; Henderson, 2018). Delphi Method limitations broadly fit within three critical themes: (1) lack of clear guidelines; (2) lack of continued participation; and (3) no evidence of reliability (Avella, 2016). Attending to the lack of proper guidelines, the

nominators were provided specific instructions on how they should interpret the questions posed. The second limitation was not of concern, as 100% of the nominators participated in the second round of the process. The third limitation does present an area of concern. Despite using the Delphi Method, few strategies exist to mitigate nominators from conferring with others on whom they should nominate. This may bias some of the reliability and validity of those nominated to participate. Although some *cross talk* may occur, it would be remiss not to acknowledge some bias with the process. As with any study in a relatively explored arena, this work begins inquiry into emergent networks and to inform more robust analyzes in the future.

Another limitation concerns social network response rates. Whereas more traditional quantitative analyses maintain a lower threshold for responses, the interdependent relationships embedded in social network requires near 100% participation (Wasserman & Faust, 1993). Nineteen initial nominees met the threshold for inclusion in the study, but only seventeen elected to participate. The two non-consenting participants represent a potential hole in the social network. Of the 17 consenting participants, their response rates for the social network survey was near 90 percent. Multiple strategies were employed to identify non-respondents' place in the network(s) including using symmetrized data and transposed adjacency matrices (Borgatti, Everett, & Johnson, 2018; Morrie & Deckro, 2013).

Future Research

The findings in this study confirm the existence of a collaborative emergent inter-organizational network operating in undergraduate STEM education reform. These findings indicate a highly interconnected group of individuals who carry power in the form of funder affiliations and grant dollars. They confer in various closed-door forums about the state of USER, and often create additional networks or other initiatives. Despite the abundance of

evidence indicating an emergent network, several themes were not included in this work as they did not address the research questions or were not fully defined through the interview data. More work should be conducted to identify additional individuals in the emergent network zone. Interviewed participants indicated between 30–50% of formal USER network leaders were represented in this study. Subsequent studies should include or incorporate their social connections and experiences as they pertain to emergent network functions.

This exploration offers several additional routes for further inquiry. Exiting the emergent network is not addressed in this study. Emergent network boundaries are undoubtedly fluid, with individuals entering and exiting regularly. As this study focused on individuals within the emergent network, it is limited to those who were considered leaders at the time of the study. Questions about the process, conditions, and experience of exiting an emergent network are still outstanding. Research interrogating this phenomenon will almost certainly uncover more information on the role of human capital deployment in the emergent network (i.e., what happens when an individual is no longer grant-funded or otherwise unaffiliated), and the intentionality of the exiting process. More in-depth work must further interrogate themes identified in Chapter 5, particularly USER socialization and consensus building. Although this study identified the processes in the emergent network, it fails to provide greater depth or context to the processes.

Conclusion

Inter-organizational networks continue to be a strategy employed by organizations across different domains to tackle complex and systemic "wicked problems" (Rittel & Weber, 1973). Although the benefits and challenges associated with the formalized networks are becoming clearer, research on emergent networks, embedded in social relationships, remains sparse and limited to specific domains. Just as formal networks exist across multiple disciplines, emergent

networks also exist, albeit more tacitly. Indeed, emergent networks very well may be *the original* inter-organizational network prior to any formalized and funded effort. The findings and subsequent implications highlighted in this study indicate emergent networks as a guiding hand, in many ways shaping reform efforts in undergraduate STEM education reform. The emergent network functions to produce and share knowledge, establish consensus and meaning, before driving new approaches to reform efforts. Despite the abundance of information uncovered from this study, more research must be conducted to fully uncover the network way of working.

APPENDICES

Appendix A: Social Network Survey

Start of Block: Introduction

Greetings Participant,

Thank you again for offering your time to this project. As previously mentioned, this study explores the interconnectedness of highly involved leaders working in undergraduate STEM education reform networks. The following survey will prompt you to provide some basic demographic information. These demographic questions are optional but your contributions will greatly add to this study's richness. Following the demographic questions, the survey asks you to indicate your level of acquaintance with each of the other nominated leaders in undergraduate STEM education reform networks.

All of your submissions will be kept **anonymous**. If you have any questions or hesitations, please contact Levi Shanks at shanksle@msu.edu at your earliest convenience.
Cordially,
Levi

What is your preferred gender identity?

- ○ Man
- ○ Woman
- ○ Preferred Gender Identity _____
- ○ Prefer not to respond

Please indicate your age range.

- ○ Under 30 years old
- ○ 30 - 39 years old
- ○ 40 - 49 years old
- ○ 50 - 59 years old
- ○ 60 - 69 years old
- ○ Over 70 years old
- ○ Prefer not to respond

With which racial or ethnic group do you identify? *(Choose all that apply)*

- ☐ Native American or Alaskan Native
- ☐ African American
- ☐ East Asian or Asian American
- ☐ Caribbean / West Indian
- ☐ Indian (Subcontinent) or Indian American
- ☐ Latinx or Hispanic
- ☐ Middle Eastern
- ☐ Multiracial
- ☐ Native Hawaiian or Pacific Islander
- ☐ White
- ☐ Prefer not to respond

From what institution did you attain your terminal or most recent degree?

_____

Please indicate the institution type in which you are currently employed.

- ○ Two-year Community/Technical College
- ○ Four-year Private Primarily Undergraduate College or University
- ○ Four-year Regional Comprehensive College or University
- ○ Four-year Public Research University
- ○ Four-year Private Research University
- ○ I do not work at a college or university.

End of Block: Introduction

Start of Block: Block 1

Are you currently involved with any undergraduate STEM Education Reform Networks? If you are unsure, please check the sample list below.

- ○ Yes
- ○ No

Please indicate between 1 and 5 Undergraduate STEM education reform networks in which you are currently involved, or have been involved with in the last 5 years. The order is not important. (*NOTE: If you are involved with more than 5 networks, please list the 5 in which you are most involved).*

- ○ Network 1 _____
- ○ Network 2 _____
- ○ Network 3 _____
- ○ Network 4 _____
- ○ Network 5 _____

Suggested Undergraduate STEM Education Reform Networks to consider:
(NOTE: Your responses are not limited by this list, it is provided simply to aid your brainstorming.)
Accelerating Systemic Change in STEM Higher Education (ASCN)

Association of American Universities (AAU) STEM Network Initiative

The Bay View Alliance (BVA)

BEACON

BioQuest

Center for the Integration of Research, Teaching, and Learning (CIRTL)

National Academies Roundtable on Systemic Change in Undergraduate STEM Education

Network of STEM Education Centers (NSEC)

Partnership for Undergraduate Life Sciences (PULSE)

Process Oriented Guided Inquiry Learning (POGIL) Project

Professional and Organizational Development Network in Higher Education (POD)

Project Kaleidoscope (PKAL)

Science Education for New Civic Engagement and Responsibilities (SENCER)

Science Education Resource Center (SERC)

End of Block: Block 1

Considering the columns below, please indicate the individuals with whom you interact regarding undergraduate STEM education reform network related business. If you have not interacted with that person, please leave their selections blank.
(NOTE: These individuals do NOT necessarily need to belong to the same network(s) as you).

	Spoke about STEM network business (e.g., network initiatives, functions, or agenda items)	**Discussed STEM network problems (e.g., funding, sustainability, network scaling).**	**Sought advice from this person to aid my network.**
Participant Redacted			
Participant Redacted			
Participant Redacted			

Participant Redacted			
Participant Redacted			
Participant Redacted			
Participant Redacted			
Participant Redacted			
Participant Redacted			
Participant Redacted			
Participant Redacted			
Participant Redacted			
Participant Redacted			
Participant Redacted			
Participant Redacted			
Participant Redacted			
Participant Redacted			
Participant Redacted			

End of Block: Block 2

Start of Block: Block 3

Considering the prompts from the previous question, are there any *leaders* in undergraduate STEM education reform networks with whom you regularly interact that **were NOT listed**?

- ○ Yes
- ○ No

Please nominate 1 - 2 person(s) you believe should be included in this list.

- Nominee 1 _____
- Nominee 2 _____

End of Block: Block 3

Appendix B: Project Overview for Participant

Research Project Summary

This research study proposes to investigate the connections among individual leaders operating in undergraduate STEM education reform faculty networks. Although many different networks exist in STEM reform, research and literature review point to a collection of informal relationships which share network information across field of networks. This exploratory investigation seeks to establish the existence of these social relationships and their purposes in serving undergraduate STEM education reform networks goals, needs, and functions.

Participant Commitment & Considerations

Participation in this study is divided into two data collection phases. Total time estimated for participation in this study is about one hour. The details of each data collection phase are listed below. As part of this study, ***participants will be identified to one another.*** The names of each willing participant will be populated into a survey that allows others to indicate their level of acquaintance with one another. Although names of participants will be shared, individual responses in the survey ***will not be shared.*** These practices are in accordance with common social network research and with prior approvals of the Michigan State University IRB.

Data Collection 1: Social Network Survey

(anticipated participant completion time: 10 minutes)

After all participants in the study are established, the research will begin by mapping the social connections among members engaged in undergraduate STEM education reform. You will be sent a survey through Qualtrics which asks you to provide your name, basic demographic information, and your STEM network affiliations. In addition to those prompts, you will also be asked to indicate your level of social interaction with other participants within the study. The purpose of the social network survey is to establish relationships among network leaders and conceptually interpret how these relationships function.

Data Collection 2: Semi-Structured Interviews

(anticipated participant completion time: 45 minutes)

Following the social network survey, participants may be contacted to set up an interview to discuss their responses. These interviews will focus on:

1) Relationships indicated in the social network survey
2) Context and nature of the relationships established in the survey

3) Perceptions of whole network responses through visuals
4) Additional thoughts from participants on the study

Additional Questions?

Thank you again for your generosity in participation. I look forward to learning together about the role of networks in advancing improvement in undergraduate STEM education. If you have any additional questions, please do not hesitate to reach out with any questions or concerns as they arise. Contact information is listed in the body of the email.

Appendix C: Sample Interview Protocol

Interviewee: _____ **Date:** _____

Interviewer:
_____

Social Network Analysis Data

Current Institution:

Total time in STEM Reform:

Current Network Involvement:

Centralization	Centrality Scores	QAP Probe
Density: .75/.69/.24	*Degree (in):* 14 / 14 / 6 (11)	*Advice Homophily:* STEM Tenure
Reciprocity: 1 / 1 / .29	*Between:* 2 / 5.5 / 5	*Business Heterophily:* Inst. Type
$\bar{d}$*:* 12 / 11.17 / 6.52	*Closeness:* 18/ 18 / 38	*Problem Homophily:* Same Network

Introduction

Hello and thank you again for your participation in my study on informal networks in STEM education reform! As my previous correspondence indicates, I am investigating the interconnectedness of people working across multiple STEM initiatives. Do you have any questions about the study so far? You were sent the consent form with your invitation to participate, at the beginning of the survey, and I want to remind you of it again today. If you consent, I would like to continue our conversation with a recording of our discussion. Do you consent?

I have planned for this interview to last no longer than one hour. During this time, I have several questions regarding your work in STEM education reform, and those with whom you regularly work. I also have some questions drawn directly from the survey you took last month.

We have quite a bit to cover! If our time starts to run a bit short, I may interrupt you in order to make sure we complete the protocol.

Foundations

In reviewing some of the names of people in the study, please tell me a bit more about the people you know.
Where did you meet?
How did you meet?
How often do you interact?
Which STEM networks do you believe to be on the forefront of undergraduate education reform?

Information Sharing

How often do you talk about STEM networks?
What about the networks do you discuss?
How (or in what location) do these discussions take place?
Is there anyone on the list with whom you regularly seek advice?
If so, can you provide an example?

Network Learning

Are there any participants you consider a "thought partner"? Why?
How have you collaborated with others in this list to improve your STEM networks?
Which STEM networks

Network Impact

How have your discussions with others in this study impacted your network?
How have your discussions with others in this study aided your network through difficult transitions?

Conclusion

Thank you! I anticipate having a fully-transcribed copy of this interview in about a week. Would you like a copy of our conversation?

In the interest of interviewer fidelity, I may reach out to you in a few weeks to clarify or confirm some of the aspects of our conversation. Would that be alright? What is the best method for contacting you?

Thank you again and have a great day!

Appendix D: Variable Codebook

Table 14. *Appendix D: Social Network Analysis Variable Codebook*

Variable Label	Variable Description
Age Range	Participant age range (binned by decade)
Business Network	Individual participant responses in the "Spoke about Network Business" prompt.
Ethnicity	Participant preferred ethnicity
Gave Advice Networl	Individual inversed participant responses in the "Sought Advice" prompt.
Gender	Participants preferred gender identity
Position	Categorical variable denoting institutional position
Primary Organization	Participant employer
Problems Network	Individual participant responses in the "Discussed Network Problems" prompt.
Same USER Network	Binary variable denoting if participant shares a USER Network Membership witl another.
STEM Tenure	Continuous variable for years spent working in USER.

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