Mapping Network Health in Rural Educational Collaborations: A Social Network Analysis Method

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Abstract: Connected learning depends on diverse partnerships, yet we lack systematic methods to understand how cross-sector collaborations function and evolve over time. This paper introduces a novel methodology for evaluating interorganizational collaboration in education, with a focus on rural and under-resourced communities. Using the West Virginia Statewide Afterschool Network's (WVSAN) STEM Lens initiative as a case study, we integrate social network analysis (SNA), longitudinal relationship tracking, and topic-based coding to examine how partnerships develop during program implementation. Our mixed-methods approach captures collaboration structure, intensity, and content over time through monthly interaction logs and pre/post network surveys. Analysis applies established SNA metrics and codes interactions into eleven collaboration topics to assess shifts across implementation phases. This methodology offers a scalable way to investigate the "relational infrastructure" behind educational initiatives, moving beyond outcomes to illuminate enabling processes. By identifying who collaborates, how, and to what extent, the approach provides actionable insights for funders, researchers, and practitioners. As educational reforms increasingly rely on cross-sector networks, making relational work visible is essential for advancing equity and improving system-level change.

Introduction

Educational initiatives increasingly depend on interorganizational collaboration to coordinate resources, expertise, and programming across diverse settings (Bryk et al., 2010; Penuel & Gallagher, 2017). This is particularly true in learning ecosystems shaped by the principles of connected learning, which emphasize linking youth's interests, relationships, and opportunities through equitable and cross-sector networks (Ito et al., 2013). In fields such as STEM education, career readiness, and out-of-school learning, partnerships among schools, community organizations, universities, and employers are essential to expanding access and supporting learner-centered, socially connected experiences (Ching et al., 2015; Arum & Stevens, 2020). The need for such collaboration is especially acute in rural communities, where statewide initiatives must bridge geographic and institutional divides to provide meaningful pathways for youth participation and opportunity (Schafft, 2016; Howley & Howley, 2014).

While the value of collaboration is widely acknowledged in connected learning research and practice, the mechanisms through which partnerships function—and the conditions under which they support equitable outcomes—remain under-examined (Ito et al., 2019; Penuel, Briggs, & Davidson, 2017). Most evaluation approaches emphasize individual or program-level outcomes, offering limited insight into the collaborative processes that actually sustain and scale learning opportunities across institutions. There is a clear need for methods that move beyond descriptive accounts and can rigorously assess collaboration as a dynamic, systemic driver of educational change (Tseng, 2012; Coburn & Penuel, 2016).

This paper presents a methodological approach rooted in connected learning's systemic orientation, using social network analysis (SNA), longitudinal relationship tracking, and topic-coded communication logs to examine the structure and evolution of interorganizational collaboration. Drawing on the West Virginia Statewide Afterschool Network's (WVSAN) STEM Lens initiative, we show how SNA can surface patterns of coordination, identify key actors, and offer diagnostic indicators of network health. Rather than focusing solely on outcomes, this approach foregrounds the relational infrastructure that supports the movement of people, ideas, and resources within an ecosystem of learning—core tenets of the connected learning framework.

The WVSAN initiative sought to broaden rural students' exposure to STEM careers through a statewide network of partners, including schools, 4-H programs, businesses, and government agencies. Applying our methodology to this case illustrates how SNA can illuminate the "connective tissue" of educational initiatives—how organizations align goals, coordinate actions, and co-implement programs across contexts (Daly & Finnigan, 2011). Through monthly relationship tracking, topic-coded interaction logs, and pre/post network surveys, we captured not only who collaborated, but how, when, and to what effect. In what follows, we present a replicable methodology for tracking and analyzing interorganizational collaboration, define key metrics for network structure and function, and describe the kinds of insights this approach can generate. Grounded in WVSAN's real-world context, this paper offers both conceptual and practical guidance for those working to build and sustain the connected learning ecosystems that educational equity demands.

Background

Cross-sector collaboration is foundational to the connected learning framework, which calls for integrated learning opportunities supported by partnerships among formal and informal institutions (Ito et al., 2013; Watkins et al., 2021). By emphasizing shared purpose, peer-supported participation, and interest-driven engagement, connected learning positions interorganizational networks as key levers for addressing systemic inequities and expanding access to opportunity. In this view, schools, nonprofits, cultural institutions, and civic organizations are not isolated service providers but part of an interdependent learning ecology that must coordinate to support holistic, youth-centered development (Ching et al., 2015; Arum & Stevens, 2020). Yet despite widespread recognition of the need for collaboration, traditional program evaluations often overlook the "relational infrastructure" that undergirds effective partnerships (Bryk et al., 2010; Henrick et al., 2017). Trust-building, role negotiation, knowledge exchange, and strategic alignment—the very mechanisms through which connected learning networks function—are rarely made visible or systematically assessed (Kania & Kramer, 2011; Penuel & Gallagher, 2017). As a result, researchers and practitioners lack tools for understanding how learning networks evolve, where breakdowns occur, and how relational dynamics shape implementation quality and equity of access.

Social network analysis (SNA), especially when integrated with longitudinal and qualitative methods, offers a promising avenue for investigating these dimensions. By mapping relationships among actors and tracking how those relationships shift over time, SNA provides a lens for examining how learning ecosystems function and adapt (Valente, 2010; Daly, 2010). It can surface central brokers, reveal communication bottlenecks, and highlight patterns of exclusion or over-reliance—insights that are critical for managing collaborative complexity in connected learning environments. This study contributes to that effort by introducing a methodological framework for analyzing interorganizational collaboration in equity-driven educational initiatives. Using the WVSAN STEM Lens initiative as a case study, we demonstrate how a combination of SNA, longitudinal relationship tracking, and topic-based coding can reveal not just who collaborates, but how, when, and to what extent. This approach expands the analytic toolkit available to researchers, network leaders, and funders seeking to assess and support the structural and processual dimensions of connected learning. As educational transformation increasingly depends on partnerships that bridge institutional and geographic divides—particularly in under-resourced communities—the capacity to diagnose and strengthen collaboration becomes central to achieving equitable, sustainable impact.

Participants & Organizations

The WVSAN STEM Lens initiative served as our methodological case study, involving 30 organizations across five rural West Virginia counties. These organizations represented six sectors: K-12 schools, 4-H Extension programs, other afterschool and nonprofit organizations, businesses, government agencies, and higher education institutions. Of the 30 participating organizations, 17 completed both pre- and post-implementation network surveys (response rate: 57%), providing sufficient data for robust network analysis. The sample consisted of all known organizational partners directly involved in the design or implementation of the STEM Lens initiative across its first year of operation (September 2024–May 2025). Organizations were included if they had engaged in program planning, professional development, or delivery of career exploration activities. No exclusion criteria were applied beyond organizational non-involvement.

Table 1. Participating Organizations by Sector.

4H Programs	Other Afterschool/Non-Profit	Schools
4H Greenbrier Co. 4H Pleasants Co. 4H Wood Co. 4H Marshall Co. 4H Gilmer Co.	Boys & Girls Club, Parkensburg 21CCLC Greenbrier Co. Boys & Girls Club, Pleasants Save the Children, Gilmer	Gilmer MS Greenbrier East MS Hamilton MS Moundsville MS Pleasants County MS
Business	**Government**	**Higher Education**
Hino Building Bridges 2 Careers Westlake Chemical Williams Energy First Settlement Physical Therapy WVU Medicine White Sulphur Springs National Fish Hatchery Southern West Virginia ENT & Endocrinology	WV Dept. Education WV Department of Environmental Protection	New River Technical & Community College WVU Extension Agriculture and Natural Sciences WV School of Osteopathic Medicine WVU Medicine WVU Innovation Center

Data Collection Design

Our data collection strategy employed a longitudinal, mixed-methods design spanning nine months (September 2024–May 2025) to capture both the structural evolution of collaborative networks and the substantive content of interorganizational interactions. This approach integrated two complementary data sources: monthly relationship tracking logs maintained by participating organizations and pre/post network surveys administered at baseline and mid-implementation. The dual methodology enabled granular insight into day-to-day collaborative activities while providing broader structural analysis of network evolution over time.

Organization Category	Organization/Group	County	People	Roles/Functions/Aims	[Month]		
					0 = No contact	1 = Low contact	2 = More contact
School District / School	Organization A				☐	☐	☐
	Organization B				☐	☐	☐
	.				☐	☐	☐
	.				☐	☐	☐
	.				☐	☐	☐
	Organization Z				☐	☐	☐

Figure 1. Sample of the relationship tracking log.

Monthly Relationship Tracking. Structured *Relationship Tracking Logs* documented the frequency, nature, and content of interorganizational interactions on a monthly basis, creating a detailed record of collaborative activities as they unfolded. The tracking log was developed collaboratively with the WVSAN team to capture interaction frequency and content across all partner organizations (Fig. 1). WVSAN staff maintained structured interaction logs documenting monthly contact with each partner organization. For each organization, staff recorded contact frequency using a standardized scale (0 = no contact, 1 = light contact, 2 = heavy contact) along with qualitative descriptions of interaction nature and content. Monthly debrief sessions between researchers and WVSAN staff ensured coding consistency and clarified emerging patterns.

Network Surveys. A structured interorganizational *Connected Learning Network Survey* (Table 2), adapted from prior work in interorganizational collaboration studies (ref), was administered retrospectively at two key timepoints, capturing participants' perceptions of relationship strength and information exchange patterns across the broader network. Respondents reported interaction frequency across three collaboration domains using a 5-point Likert scale (1 = once or twice, 5 = daily or almost daily). The

domains included *information exchange* ("How often has your organization shared information with [Organization Name]?"), *joint planning* ("How often has your organization jointly planned, coordinated, or implemented activities with [Organization Name]?"), and *resource sharing* ("How often has your organization shared or exchanged tangible resources such as staff, materials, or funds with [Organization Name]?"). Administration occurred at pre-implementation (March 2025) for retrospective reporting on relationships during the six months prior to initiative launch, and mid-implementation (March 2025) for current relationships during the first six months of implementation.

Table 2. Sample items included in the Connected Learning network survey.

Relationship	Sample Survey Item
Information Exchange	*In the past 6 months, how often has your organization provided information with [Organization Name]?*
Joint Planning	*In the past 6 months, how often has your organization jointly planned, coordinated or implemented an activity, event, or programs with [Organization Name]?*
Resource Exchange	*In the past 6 months, how often has your organization shared or exchanged tangible resources such as staff, materials, or funds with [Organization Name]?*

Qualitative Content Analysis

Communication entries from relationship tracking logs underwent systematic content analysis using a comprehensive coding framework developed through iterative review of collaboration literature and inductive analysis of early data. The framework encompassed eleven categories that captured the full spectrum of collaborative activities observed in multi-organizational educational initiatives: *Communicate-Coordinate*, *Plan & Set Goals*, *Joint Implementation*, *Share Knowledge*, *Provide Training/Professional Development*, *Share Resources*, *Problem-Solve Together*, *Monitor & Evaluate*, *Build Relationships*, *Advocate Together*, and *Other*. Each category was defined with specific behavioral indicators and example activities to support consistent application across coders and timepoints. Monthly log entries were then analyzed using the eleven-category framework, with individual entries eligible for multiple codes to capture the complexity of collaborative interactions. Inter-rater reliability was established through double-coding of a subset of entries, with discrepancies resolved through discussion and consensus.

Social Network Analysis

For each of the three collaboration domains captured in the network surveys—information exchange, joint planning, and resource sharing—we constructed directed weighted networks at baseline and mid-implementation timepoints. These networks represented the full ecosystem of organizational relationships, with edge weights reflecting the frequency and intensity of reported interactions. *Network analysis* focused on five key structural metrics that illuminate different aspects of collaborative capacity and network health. *Network density* measured the proportion of actual ties to all possible ties, providing an indicator of overall connectivity within the collaboration. *Reciprocity* assessed the degree of mutual relationships between organizations, revealing the extent of bidirectional exchange versus one-way information flows. *Centralization* indicated the concentration of ties among key organizations, highlighting potential bottlenecks or coordination hubs. *Transitivity* measured the frequency of triadic closure, indicating clustering patterns and the formation of collaborative subgroups. Finally, *weighted degree* captured the total interaction volume for each organization, identifying the most active network participants. By comparing network metrics across the two timepoints, we tracked structural changes in collaborative patterns throughout the implementation period. This longitudinal approach revealed how networks evolved from initial planning phases through program implementation. Changes in centralization patterns, for example, indicated whether collaborative leadership became more or less concentrated over time, while shifts in density revealed whether the overall network became more or less connected.

Analytical Integration

The integration of qualitative content analysis with network structure analysis provided a comprehensive view of collaborative evolution. This dual lens enabled us to identify not only when collaboration

intensified or diminished but also how the nature of collaborative work shifted across implementation phases. For example, increases in network centralization could be interpreted differently depending on whether content analysis revealed a shift toward coordination-intensive activities (suggesting appropriate structural adaptation) or toward routine information sharing (potentially indicating inefficient concentration of communication flows). The analytical framework was implemented using R (v4.3) as the primary platform for both qualitative coding analysis and network metric computation. The *igraph* package supported network construction and structural analysis, while *tidyverse* facilitated data manipulation and integration across sources. The *ggraph* package enabled network visualization and comparative analysis across timepoints. Google Sheets served as the initial data collection and organization platform, ensuring accessibility for practitioner partners.

Validity and Reliability Measures

Several steps were taken to enhance the validity and reliability of this study's findings. First, data collection instruments were co-designed with WVSAN practitioners to ensure construct validity and contextual relevance. This iterative process helped align tools with the realities of day-to-day collaboration and ensured their feasibility in practice. Triangulation across multiple data sources further strengthened the study. Consistent data collection procedures supported internal reliability, with logs submitted monthly and surveys reflecting two distinct timepoints—six months before and after the initiative's launch. Methodological rigor was also supported through transparent coding and established SNA metrics. Collaboration topics were inductively derived and formalized into a shared definitions, with regular debriefs to ensure coding consistency. Standard metrics—such as density, reciprocity, centralization, and transitivity—were used to assess network structure, enhancing external reliability and enabling comparison with similar studies. Together, these features demonstrate how network analysis, when embedded in routine data collection and stakeholder engagement, offers a valid and reliable tool for evaluating interorganizational collaboration in education.

Findings: Network Evolution and Structural Changes

Our analysis revealed four key patterns in how the STEM Lens network evolved over the implementation period:

- **Enhanced connectivity and density.** The network demonstrated growth in both size and interconnectedness. Average weighted degree—measuring how many organizations each participant connected with and how frequently—increased from 18.71 at baseline to 21.76 post-implementation, representing a 16% growth in collaborative connections. Network density similarly increased from 0.140 to 0.203, indicating that previously isolated organizations became more embedded within the collaborative ecosystem. This density increase suggests the initiative successfully created new pathways for information sharing and joint action among previously disconnected actors.
- **Strategic Emergence of Central Connectors.** While the network began with relatively distributed leadership, a small set of organizations—notably WVSAN and key 4-H partners—evolved into high-volume connectors, facilitating communication and coordination across the broader network. This centralization served important functional purposes, streamlining decision-making and ensuring consistent information flow. However, it also raised sustainability concerns, as the concentrated workload on central actors could create single points of failure within the collaborative structure.
- **Dynamic Shifts in Collaboration Content.** The coded log data revealed a clear temporal progression in collaborative activities that aligned with programmatic phases. During the fall planning period, "Plan & Set Goals" activities dominated interorganizational interactions, accounting for 42% of coded communications. As the initiative moved into spring implementation, these planning activities declined to 18% of interactions, while "Jointly Develop & Implement" activities increased from 23% to 39% of all communications. Notably, "Coordinate Activities" remained consistently high across all phases (25-28% of interactions), underscoring the ongoing foundational role of coordination in sustaining multi-organizational collaboration.
- **Asymmetric Information Exchange Patterns.** Network reciprocity measures revealed a more complex picture of collaborative engagement. While overall reciprocity values remained modest (0.31 at baseline, 0.34 post-implementation), this apparent limitation masked important functional specialization within the network. Some organizations served primarily as information hubs,

broadcasting resources and updates to multiple partners, while others functioned as specialized implementers, receiving coordination from central actors while contributing domain expertise. This asymmetric pattern, while potentially concerning from an equity perspective, appeared to reflect rational role differentiation rather than exclusion from meaningful participation.

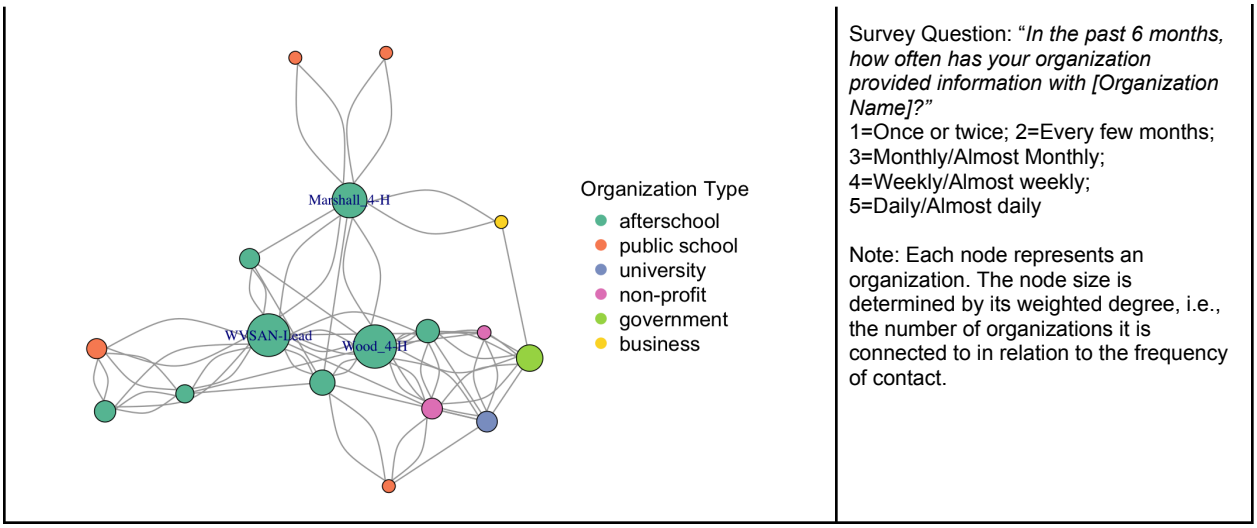


Figure 2. The WVSAN network for exchanging information.

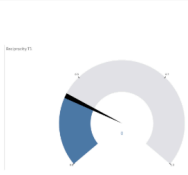
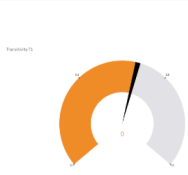
	DENSITY OF RELATIONSHIPS	RECIPROCITY OF RELATIONSHIPS	CENTRALITY OF RELATIONSHIPS	TRANSITIVITY OF RELATIONSHIPS
	Are ***all*** the organizations exchanging information with each other?	Are all the collaborators receiving ***and*** sending information?	Are there a small number of organization doing the majority of the information sharing?	Do organizations share information across larger groups or in isolated pairs?
Before the start of STEM Lens	0.140	0.254	0.162	0.432
				

Figure 3. Key metrics for understanding the WVSAN network for information exchange.

Discussion

One of the most significant contributions of this network-based approach is its capacity to surface collaborative patterns that typically remain implicit in multi-stakeholder initiatives. While conventional evaluation might have noted that the initiative successfully coordinated activities across multiple organizations, our network analysis revealed the specific mechanisms through which coordination occurred: the emergence of strategic central connectors, the functional specialization of different organizational roles, and the temporal evolution of collaborative focus from planning to implementation. Further, combining social network analysis with coded interaction logs creates a dynamic picture of how networks evolve in response to programmatic demands. The findings suggest several principles for designing and supporting effective interorganizational collaborations in education: First, the emergence of strategic centralization in the WVSAN network—while functionally beneficial—highlights the need for deliberate attention to workload distribution and sustainability planning from the outset of collaborative initiatives. Program designers should anticipate that certain organizations may naturally emerge as central connectors and plan accordingly to support these critical roles while preventing burnout. Second, the functional specialization revealed through reciprocity analysis suggests that effective collaboration may not require all partners to engage in identical ways. Rather, networks may benefit from recognizing

and supporting different organizational strengths—some serving as information hubs, others as specialized implementers, and still others as bridge-builders connecting previously disconnected sectors. Despite its strengths, this network-based approach carries several limitations that merit acknowledgment. The reliance on self-reported data through surveys and contact logs introduces potential bias, particularly social desirability bias in reporting collaborative activities. While our triangulation of multiple data sources helped mitigate this concern, future applications would benefit from incorporating additional objective measures such as meeting attendance records, email communication analysis, or document co-creation tracking.

Conclusion

As collaborative strategies become increasingly central to educational improvement—particularly in equity-driven and place-based reform efforts—the need for methodological tools that can capture the complexity of interorganizational relationships will continue to grow. The integration of social network analysis with longitudinal tracking and content coding represents a methodological advancement that bridges traditional evaluation approaches with emerging systems science methods. The approach presented here offers a replicable framework for understanding how educational collaborations form, evolve, and contribute to systemic change.

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