Advancing Learning Visualizations: Situated Action Networks as Scalable Representations of Learning in Social Settings

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Abstract: We propose a distinctive method, Situated Action Networks (SANs), rooted in socio-cultural theories of learning that affords visualization and analysis of learning in a way that is theoretically robust yet scalable to large data sets. While visualization is increasingly looked to as a key means of understanding learning, there are few tools at learning scientists' disposal that are simultaneously scalable yet also aligned with sociocultural perspectives. Situated Action Networks attempt to address this by appropriating techniques from social network analysis while aligning them with Cultural Historical Activity Theory. They accomplish this by (1) elevating learning activities to the forefront of learning visualizations, allowing for rich qualitative analyses of learning and (2) creating theoretically aligned indices that afford quantitative analyses within and across learning environments. Using data on collaborative learning dynamics between informal learning organizations as they engage in joint projects, we show the affordances of this method for understanding learning.

Keywords: learning visualization, Cultural-Historical Activity Theory, Social Network Analysis, Situated-Action Networks, sociocultural learning theory, sociocultural learning methodologies

Introduction

Analysis and visualization of large-scale learning data is an increasingly viable and powerful means of understanding the dynamics and environments that support learning activity (Siemens & Baker, 2012). In this paper we propose and show the affordances of a distinctive method, Situated Action Networks (SANs) that can be applied to these ends in a way that is aligned with sociocultural theories of learning. We aim to fill a key gap—many learning visualization techniques that operate at scale are not aligned with sociocultural learning perspectives, and those currently used by sociocultural learning theories cannot operate at scale and have limitations even in their affordances when it comes to qualitative analyses.

SAN appropriates methods from Social Network Analysis (Marin, Wellman, Scott, & Carrington, 2011) and retrofits them in a way that aligns with and solves a number of analytic challenges (Spinuzzi, 2011; Witte & Haas, 2005) associated with Cultural-Historical Activity Theory (CHAT, Cole, 1996; Engeström, 1987; Vygotsky, 1978). To illustrate this technique, we use data on collaborative learning dynamics between informal learning organizations as they engage in joint projects, and we empirically show the affordances of this method for understanding learning. We find that SANs have two key affordances. They (1) elevate learning activities to the forefront of learning visualizations, allowing for rich qualitative analyses of learning and (2) create theoretically aligned indices that afford quantitative analyses within and across learning environments.

Elevating Activity and Mediational Means within CHAT Representations

As the study of learning has shifted from looking at learning as a phenomenon specifically concerned with individuals' minds to a process that is fundamentally rooted in social processes (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991), researchers have turned to sociocultural theories of knowledge and learning. CHAT (Cole, 1996; Engeström, 1987; Vygotsky, 1978) provides a sound theoretical framework to ground the interpretation of small-group collaborative learning situations, as well as an expansive lens towards larger transformations of social practices. A central tenet in CHAT is its focus on mediation and object-directed activity. Mediated activity has been conceptualized as a triangle representing a higher-level/cultural path between the subject—i.e., the collective or individual participant—and the object—i.e., the intended goal or motive of the activity. CHAT triangles have been useful in that they have provided a theoretically robust framework that allows rich analyses of complex socio-cultural contexts while, at the same time, provide a common grammar for many sociocultural learning theorists.

However, various researchers (Spinuzzi, 2011; Witte & Haas, 2005) have questioned its methodological utility. For if the object of an activity is not empirically bounded, then it runs away, merging itself with other activity systems or as part of larger activity systems (Spinuzzi, 2011; Witte & Haas, 2005). In a sense, learning activity is invisible as it is everywhere and nowhere. Further, the data is not scalable as it does not afford an easy

way for comparisons. To overcome this limitation, various alternative approaches have been proposed (for instance see Spinuzzi, 2011), but in this paper we align our own with Witte's (2005) proposal to focus on mediational means as the primary methodological tool to leverage our understanding of learning. We can think of two reasons for doing this. First, we want to observe and study mediational means to compare and contrast across activity systems or the change of one activity system over time. Second, the very nature of a human motive cannot be observed directly, but has to be inferred from the participants' actions and/or from intersubjective accounts. Therefore, we believe a promising approach to visualize learning should start by identifying the concrete, observable mediational means, and then test the hypotheses about the possible motives/subjective goals that underlie that activity. By focusing on the mediational means at the outset, without pre-defining an assumption about the relationship between mediational means and goals, we can more accurately model the complexity of activity systems in situ.

Our Situated Action Networks (SAN) approach (Andrade, 2015) tries to strengthen this sociocultural tradition by drawing on Social Network Analysis and retrofitting it to make it more theoretically aligned with CHAT. Social Network Analysis is useful for creating visualizations and quantitative descriptors of social structures. Although other approaches have either used or adapted social network analysis to analyze learners' data (see i.e., Oshima, Oshima, & Matsuzawa, 2012; Shaffer et al., 2009; Suthers, 2011), SAN provides an explicit account of how to integrate social network measures and reframe them to be meaningful within a CHAT framework. In a previous paper, Andrade (2015) introduced the approach and some of the technical details using the example of a pilot apprentice learning how to land an airplane in a computer simulation. Briefly, SAN is intended as a functional model that takes action as the unit of analysis. When action is the unit of analysis, participants and tools (or as we refer here, mediational means) are placed in the model at the same level, that is, as nodes in the graph. The actions represent edges (or links) between one actor node and one mediational mean node. SAN models the activity system by representing the functional link between the social structure and the mediational means. Goals and motives are then hypothesized from the observed actions. SAN aims to take best of both worlds—rich and theoretically rigorous representations of learning on the one hand and scalable techniques for representation and analysis on the other. In doing so, it maintains the ability to look qualitatively at individual or small numbers of representations, in combination with additional qualitative data of the context in question, facilitating rich analyses of learning activity. But it also adds the ability to quantitatively analyze, through use of indices, across multiple representations in ways that allow for powerful pattern analyses.

As our early work focused on short timescales and micro-analysis (see Andrade, 2015), this paper focuses on application of the technique to longer timescales and meso-level analyses with data from informal learning organizations, which illustrates how this method is flexible and scalable. First, we outline the methods.

Methods

As this paper is primarily methodological in nature, we outline the process we went through as we developed the SAN technique, including the rules used to visualize activity and the attempts at creating theoretically meaningful indices that can be used for quantitative analysis. Our technique was one of methodological exploration; we took early experiments conducted by the first author to develop SANs (Andrade, 2015) and actively built on them using a larger data set. We engaged in the following activities as part of that process, each of which we detail in depth within the findings: (1) experimented with a variety of representational forms to see what each afforded in terms of analysis, (2) conducted pilot qualitative analyses on various SANs, (3) brainstormed various quantitative indices that we saw as theoretically aligned with CHAT and (4) conducted interpretation and analysis based on the application of indices to empirical data.

The data we used comes from Hive Research Lab (Santo, Peppler, Ching, & Hoadley, 2015), where we analyzed 94 collaborative project proposals produced by out of school learning organizations, members of the Hive NYC Learning Network (hivenyc.org), focusing on developing educational initiatives that align with Connected Learning approaches (Ito et al., 2013). Supplementary qualitative data included 20 one hour interviews with out of school educators discussing their collaborative work. The proposals were submitted in response requests for proposals by the Hive Digital Media and Learning Fund, a collaborative donor fund, over the course of a four year period, 2012-2015. The projects were always collaborative, with at least two organizations playing roles within a project.

As we will share in more detail in the findings section, the project proposals and interviews were first analyzed in order to develop a coding scheme of the mediational means these organizations used within projects in order to achieve project goals. One researcher coded the full corpus of proposals while a second coded 30%. The researchers discussed disagreements, which helped further refine the coding scheme. Although a second round of discussions to find interrater agreement is still under way, we are confident in the face validity of the coding scheme as we performed member checking and included organization member's feedback. The coded

proposals formed the basis for the generation of SANs which were then subjected to further analysis detailed below.

Constructing Situated Action Network Visualizations

We delineate a series of steps involved in creating a SAN. First, tally the occurrence of actions, that is, the use of mediational means by actors. In practice, this means tallying up who is doing what action. For instance, we tallied up which organizations were designing the educational initiative and which were evaluating it (see table 1). Second, bound the activity system. This sometimes is easy, as is our case here because the project submissions defined which organizations were involved in what. Sometimes this requires a little more work, as the object or other elements in the system change. Sometimes, when studying how the system transforms through time, the analyst has to meaningfully decide boundaries. For instance, in previous work when we studied the way an apprentice learned how to land a plane, each attempt was regarded as its own SAN (Andrade, 2015). Third, preprocess the raw data into an appropriate format. This procedural step transforms the raw data frame into a square symmetric matrix in which rows and columns are actors and mediational means, and the entries to the matrix are tallies of the links between actors and means (see Figure 1.a). This matrix looks very much like a regular adjacency matrix, but it is a very sparse matrix with many zeros (on the diagonal, and between actor-actor and means-means entries). Fourth, use a computational package to visualize the graph (see Figure 1.b). We use *igraph* in *R* for this. Some additional procedural decisions are involved here. First, different node shapes can differentiate between actors and means (e.g., rectangles and circles). Colors can differentiate types of mediational means (e.g., community or design oriented) or kinds of actors (e.g., lead or non-lead). Edges can have different widths according to tallies and/or weights assigned to them. Fifth, try different visualizations to help refine the displayed elements and try different configurations so that particular pieces are highlighted, get peer feedback, and revise the visualization.

Table 1. Raw Data Matrix

Organization	Project Title	Year	Design	Evaluation
Science Exploration Center (SEC)	Hive Awesomeness	2014	1	0
SciMapping (Sci)	Hive Awesomeness	2014	1	1

$$g = \begin{cases} & Des & Eval & SEC & Sci \\ Design & 0 & 0 & 0 & 0 \\ Evaluation & 0 & 0 & 0 & 0 \\ SEC & 1 & 0 & 0 & 0 \\ SciMapping & 1 & 1 & 0 & 0 \end{cases}$$
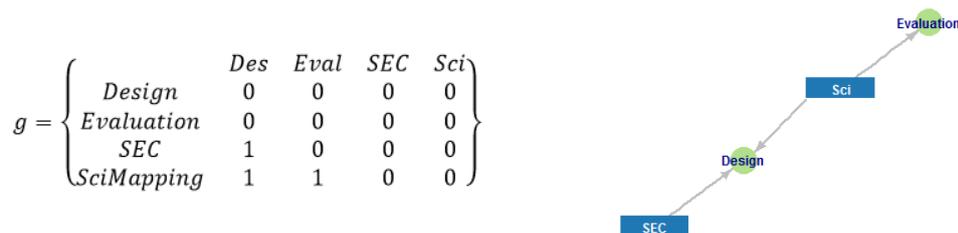
Figure 1. Left: (a) Adjacency Matrix. Right: (b) Visual Representation

Findings

Qualitative Affordances of Situated Action Networks

In exploring the methodological affordances of SANs, we will first examine how they can support various forms of qualitative analyses and theory building. We see three specific analytic affordances from a qualitative perspective that SANs support: (1) prompting the identification of meditational means within a context, (2) identifying new qualitative patterns by looking *across* SANs, and (3) identifying new qualitative patterns by looking *within* SANs. Below, we explore each of these affordances.

SAN Approach as Prompt to Identify Mediational Means within a Context

Prior to and in order to create SANs, the method asks a researcher to identify the primary mediational means within the context of investigation. To accomplish this, we first began with an in-depth review of the study's qualitative data. We identified particular resources that organizations used as mediational means to achieve specific goals, means that together supported the project's broader object(s). For example, in some projects an organization would utilize design expertise that would shape the curriculum associated with an

afterschool program, another organization would utilize its existing networks to recruit educators that would participate in professional development, and a third might provide the physical space for program. In all, 21 mediational means were identified across the 94 project proposals, falling into the broad categories of expertise-related (leveraging specialized knowledge or competencies), network-related (leveraging access to particular networks of either young people or educators) and resource-related (leveraging provision of material or intellectual property). For each of the codes, an associated description and set of examples from the data sources was compiled into a coding guide.

This process took tacit understandings of the data and formalized them into a consistent list of mediational means that were then clear to the research team. Following this step, the coded data were then used to generate SANs. Additionally, through the full application of the codes to the data, the research team gained an additional 'felt sense' of how certain mediational means were used in relation to one another, an understanding that played a critical role in unearthing further qualitative insights that we detail next.

Identifying New Qualitative Patterns by Looking Across SANs

Once the full data set was coded and the SANs generated, the research team then sat down and began to look across the SANs to make sense of them. During this process, we utilized qualitative understandings gained both through our fieldwork as well as the process of generating and applying the mediation means codes to the data. When we say 'looked' here, we mean that in a very literal sense—the similarities and differences between SANs were brought into sharp relief through the visual representations with certain structural features clearly standing out. As we looked across the SANs, initially tacit hypotheses about common configurations of mediational means were clarified through these empirical representations.

Specifically, we looked to see how hypotheses regarding common objects that might be achieved by certain collaborative configurations might be confirmed, augmented and highlighted through the SANs. Put simply, we sought to see what kinds of broad goals were trying to be achieved through distinctive forms of organizational collaboration, and how these might be characterized into typical models. Upon investigation of the SANs in relation to these hypotheses, six new categories of objects, with associated collaborative partnership configurations, were identified, each representing different objects and utilization of mediational means. Below, we detail two of these categories. For each, we first describe the nature of the distinctive object, highlight how the visual features of that SAN assisted the research team in identifying them, and engage in a brief theoretical treatment of the SAN.

Collaborative Design and Implementation Partnerships

One of the first configurations immediately identified by the research team was that of **collaborative design and implementation**, wherein many or all of the mediational means relating to the creation, development, execution and reflection are shared amongst key actors. The 'starfish' visual structure of this kind of configuration was immediately evident across a range of the SANs, and mapped immediately onto qualitative understandings of our team. In the project presented in Figure 2 below, two organizations, the Reese Music Institute and Rhythm Central are all co-engaged in their use of mediational means within a project that involves a series of day-long workshops that engage youth in digital hip hop music production and remix. See Figure 3 below for the legend.

Within the SAN, edges (connecting lines) indicate which actors (circles) are engaged in which mediational means (hexagons), with thicker lines indicating substantive action and thinner lines indicating lighter action. Here, the fact that all mediational means nodes are shared by both actors (indicated by edges going from each actor to all action nodes) shows a high degree of shared object across actors and mutual involvement in transforming all facets of the activity system at hand—both of the organizations are equally involved in the design process, internal training for teaching artists, recruitment of youth, facilitation of the program, etc. The overall structure of visual parallelism in the representation reflects this shared object and joint involvement in transforming the associated activity system.
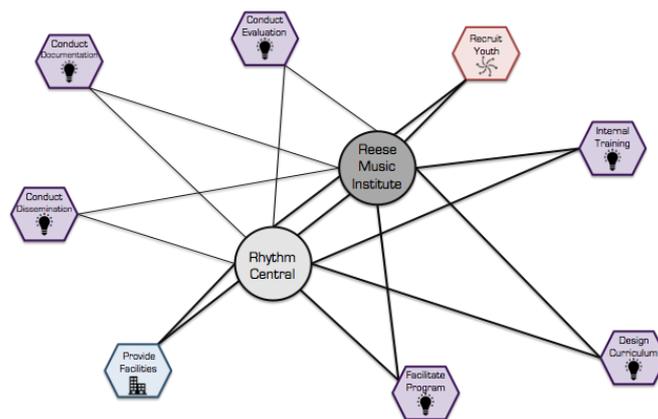
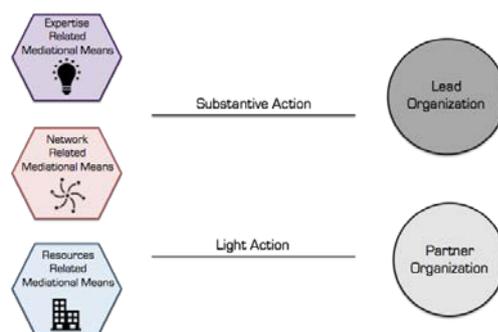Figure 2. Collaborative Design and Implementation Partnership

Figure 3. Legend for Situated Action Network visualizations

Program Refinement and Spread Partnership

As a contrast to the above where mediational means are largely shared across actors, the second configuration we share, **program refinement and spread partnership**, highlights a highly specialized division of labor. Like the first example, this configuration was immediately evident through the highly visible clusters of specialized activity. In this configuration, the lead organization is aiming to circulate a tool and curriculum to new contexts, and collaborating organizations act as sites of adoption. In this example shown in Figure 4, the Science Exploration Center (SEC) is aiming to refine and spread a program it developed that focused on neighborhood-based citizen science that uses sensor technologies to have youth engage in environmental investigations and advocacy. SEC utilizes a number of mediational means relating to supporting other organizations, Children's Benefit Group and Whitman College, to act as adoption sites. SEC designs curriculum, creates additional materials to support adoption such as rubrics and educator tip sheets, and then trains the adopting organizations through professional development activities. The adopting organizations similarly have a specialized cluster of activities—providing networks of youth and educators, providing the spaces where the program will be implemented, and engaging in the actual facilitation of the program. Two other organizations, SciMapping and the Teaching Capacity Institute (TCI), each play distinct roles around technology development and formative research and refinement activities, respectively. These supporting organizations make viable, along with SEC, the process of model circulation to new activity systems associated with adopting organizations.

From a CHAT perspective, this configuration is characterized by a highly specialized division of labor, as indicated by the various unconnected clusters. While of course each of the actors is working on the same larger project and shared object, each is leveraging specific mediational means it has access to that tackle a distinctive aspect of the work, impacting different parts of the related activity system(s) and indexing different degree of agency and ownership over the learning process. SciMapping is only working on the technological aspect of the initiative, while both SEC and TCI are involved in the larger tool of the curricular model in which this technology is being utilized. TCI plays a role providing feedback loops, through formative research, about how the project is playing out in new activity systems where it is being adopted, supporting refinement of the tool, but is in a technical assistance role here that has somewhat less ownership over the object—it is assisting SEC and Scimapping with their broader shared object of bringing the program to new contexts.
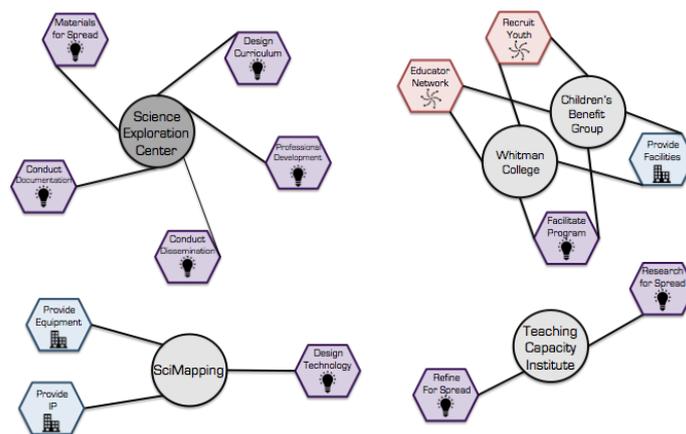
Figure 4. Program Refinement and Spread Partnership

Each of the configurations shared above, along with others, was identified through a process of drawing on rich qualitative understandings of underlying data in combination with a visual examination across the 94 action networks generated. This sense-making led to the identification of new categories that helped us understand what kinds of problems these collaborative configurations were solving. From a CHAT perspective, we were able to understand what kinds of objects this collective of SANs were addressing.

Identifying New Qualitative Patterns by Looking Within SANs

A final qualitative affordance of Situated Action Networks lies in the way they support identification of new qualitative patterns, and associated theoretical implications, by looking closely at a single SAN (as opposed to across multiple SANs). Close attention to specific SANs yielded consequential findings related to the nature of activity systems that spanned multiple organizations within a SAN. Specifically, we found that multiple related but distinct local objects can be at play within an activity system.

The example below took the form of an implementation site partnership, a particular configuration of mediational means noted briefly above. In this instance, the Sync Institute was the central organization, enacting its PhysComp Tinkering program at the Brooklyn Neighborhood Center (BNC) which acted as an implementation site. The Sync Institute engaged in a wide range of critical mediational means, including curricular design, technology design, program implementation, documentation, evaluation, and others. BNC simply provided its space and assisted in recruitment activities. It might be expected that the central learning process involved in such a collaboration would be centered on the Sync Institute's advancement of its prototype physical computing learning tool that it was developing to support beginner level hardware programming, and indeed, in interviews Sync Institute staff members shared that the implementation at BNC was contributing to a larger process of refining this invention. But interviews with BNC's staff revealed that their participation as an implementation site was actually part of a much larger and ongoing learning process the organization was engaged in and that it planned to create a maker space. Represented within this single SAN were both Sync Institute's object of learning in relation to its prototype as well as BNCs object of learning about if and how its young people and staff would be engaged and interested in 'maker' learning activities.

As the example shows and put most simply, organizations can hold differing, but overlapping, local objects as they participate within the same SAN. This finding is supported by the reality that it is rare for two organizations to come to a collaboration with the same prior knowledge and experience, and rarely are the exact same mediational means engaged in by two organizations in a collaboration. Looking closely at the SAN with rich qualitative data in hand allowed the research team to uncover and empirically examine this phenomenon of parallel objects within a SAN, of the unbounded and overlapping nature of activity systems, how an object in one system can be a tool in another, and other important nuances. This all points to the need for careful inquiry into the mediational means as an approach to bounding the activity system so that it can be empirically studied, elaborating on insights by Spinuzzi and Witte that have criticized CHAT methods. Having established multiple qualitative affordances of SANs, we now move to the quantitative affordances of the approach.

Quantitative Affordances of SANs - Network Indices Supporting Analysis at Scale

Previous adaptations—e.g., Epistemic Network Analysis (Shaffer et al., 2009), Knowledge Building Discourse Analysis (Oshima et al., 2012), Traces (Suthers, 2011)—have made use of traditional measures to describe the characteristics of a network such as centrality, in- and out-degree, or path sizes. We propose new coefficients

because traditional SNA descriptors are not appropriate for SAN—in that adjacency matrices are sparse as there are no connections within the same type of nodes (i.e., actor-actor or mediator-mediator). We propose three kinds of indices that describe different properties of the SAN: (a) global, (b) average egocentric, and (c) individual actor or mediator descriptors. Global indices describe the distribution of actions among participants, and differentiate among types of contributions by particular actors or mediators. By global descriptors we mean overall network composition measures. Average global descriptors do not capture the distribution of actions among actors, instead they reveal the overall number of actors, means, and actions in the network. On the other hand, an egocentric descriptor is an individual node measure, for instance, the number of other connected nodes or the sum of its edges (for weighted networks). The arithmetic average of an egocentric index describes the whole action network. In particular, we include two types of average egocentric descriptors. First, we pay attention to the extent mediational means are used across actors, called *shareness*. We chose this label to indicate that this index represents the average use of mediational means, that is, how much they are shared. Second, we pay attention to the extent to which actors act on various mediational means, called *participation*. This label represents the idea that the more an actor uses mediational means, the greater its participation is in the network. Taking the average, participation produces a general action network descriptor. Individual descriptors acknowledge that not all mediational means affect the course of the activity in the same way. For instance, one may want to distinguish between mediational means that have an effect on the activity object and those that affect other system elements, such as the community. Put another way, different mediational means shape the system in different ways, and therefore individual indices describe different combinations of mediators in the action network. Finally, one can use individual actor node indices. For instance, egocentric descriptors for the leading organization of the project provide valuable information about the way the project is enacted.

Table 2 SAN Descriptors

Descriptor Title	Theoretical Basis	Operationalization
Total # of Actors	Total number of actors in the network	# of actor nodes
Total # of Mediators	Total number of mediators in the network	# of mediators
Total # of Actions	Total number of weighted links in the network.	# of actions
# of Clusters	Number of connected components in the network (as originally intended in SNA). This index can inform whether there is specialization of some actor-mediator relationships.	
Average Shareness	Egocentric index measuring the degree to which a mediator is shared. It ranges between 0, for totally individual mediators, to the total number of actor nodes, for totally shared mediators. Normalized by dividing over the number of actors. A global measure is produced by taking the mean or median.	(Number of actions for ith Mediator node minus 1) / Total number of Actor nodes
Average Participation	Egocentric index measuring how busy an actor is. It ranges between 0, for totally free actors, to the total number of mediator nodes, for totally proactive actors (i.e., the actor participates in all mediators). Normalized by dividing over the number of mediators. A global measure can be produced by taking the average (mean or median).	(Number of links for jth Actor node minus 1) / Total number of Mediator nodes
Specific Mediator Leverage	It weights the number of specific mediational means to provide a proxy for the agency an actor has on a specific mediator of the activity.	$\sum$ [number of jth actor actions * specific mediator weight]
Specific Actor Degree	% of actor actions upon mediational means in the network	# of actor actions / total # of actions

Table 3 shows the results of applying the global and average egocentric descriptors to the two networks described above. It can be seen that these indices capture the greater integration in the Collaborative Design and Implementation Partnership type, where all mediators are acted upon by the actors. It also captures the specialized nature of the Program Refinement and Spread Partnership type, where there are three distinct clusters and therefore less shareness and participation than the first type.

Table 3. SAN indices for two network types

Network Type	Actors	Mediators	Actions	Clusters	Shareness	Participation
Collaborative Design and Implementation Partnership	2	8	16	1	0.50	0.88
Program Refinement and Spread Partnership	5	13	18	3	0.10	0.20

Conclusions and implications

We introduce a visualization technique to explore sociocultural learning activity that is both scalable and theoretically rigorous. Previous CHAT representations, such as Engestrom's triangle, while effective in delineating elements of a given activity, have very limited affordances to show distinctive relations within or across activity systems (cf. Witte & Hass, 2005; Spinuzzi, 2011). Essentially, they do not allow the researcher to consistently model the relationships between these elements in a way that is tailored to the particular situation. Situated Action Networks, as we have shown, produce robust visualizations of the observable activity system components—i.e., the actors and the mediational means these actors act upon. Through these visualizations, inferences can be made about the object of the activity (which is not directly observable), and how the mediational means interact with other vertices of the activity system. For instance, some mediational means are directed towards bounding the object of the activity, whereas others interact with the community within which the activity system is embedded. Furthermore, SANs can be described by quantitative indices, which would allow for meaningful scalable comparisons across activity systems or examine longitudinal changes of an activity system. In future work we intend to explore how statistical tools, such as regression and cluster analysis, can help find patterns across the collaborative projects presented here and the ways these indices relate to other key variables such as the size of the organizations involved and the intended learning outcomes.

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Acknowledgments