Mapping Networks to Help Education Leaders Gain Insights Into Complex Educational Systems

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Abstract: Developing an understanding of education as a complex, adaptive system can be useful in helping leaders understand the impact of various interventions on the system as a whole. This paper describes the design of two learning opportunities, which draw on Actor Network Theory, for assisting state science coordinators in exploring complex educational systems in their state. We respond to a call for research on how representational tools can help education leaders develop understandings of complex systems. The authors conducted a design study to address the question, *how do state science education leaders use representations of complex systems to understand their networks and identify leverage points for change?*

Introduction and framework

Understanding large educational systems as complex adaptive systems can provide insights that can help leaders anticipate both intended and unintended consequences of policies they devise (Maroulis et al., 2010). Tools such as agent-based models and network maps have the potential to facilitate this understanding (Daly & Finnigan, 2010; Penuel, Harrison, et al., 2015). Thinking about complex systems requires both domain knowledge and an understanding of systems concepts, which may violate pre-formed intuitions. However, developing this understanding may prove difficult, as "learning about these systems challenge cognitive, metacognitive, and social resources" (Hmelo-Silver & Azevedo, 2006, p. 58). Designing for change in educational policy requires paying specific attention to the implementation of interventions (Penuel, Fishman, Cheng, & Sabelli, 2011), the relationships between and coordination among different actants in a system (Jackson & Cobb, 2013), and the coherence within the system (Forman, Stosich, & Bocala, 2017; Fuhrman, 1993; Linn, Kali, Davis, & Horwitz, 2008). Still, a complex systems approach can be helpful in identifying specific leverage points, or places where it may be especially productive to focus efforts, in systems, because of the disproportionate effect interventions at those points may have. Policy efforts that focus on these specific leverage points can be helpful in achieving large scale change (Bryk, Gomez, Grunow, & LeMahieu, 2015).

Due to their potential utility in helping education leaders re-imagine and re-organize educational systems, there is a need to further explore the pedagogy, and the design of activities intended to use representational tools to help teach complex systems thinking related to change in educational systems (Jacobson & Wilensky, 2006). Work by constructivist learning theorists has demonstrated the utility of simulations and visual representations for learning. For example, NetLogo, Logo and Turtle programing have been used to help learners foster a deeper understanding of networks (Wilensky & Rand, 2015; Colella, Klopfer & Resnick, 2001; Papert, 1972). In addition, research in the learning sciences has already identified several aspects of good pedagogy for teaching about complex systems, such as the importance of scaffolding, collaboration, discussion, and reflection in learning (Danish, Saleh, Andrade, & Bryan, 2017; Yoon et al., 2017). Researchers have found that explicit instruction is necessary to help novices make sense of complex systems (Hmelo-Silver, Marathe & Liu, 2017).

This paper addresses both the call for more attention to learning complex systems in education, as well as the need to research how representational tools can help develop understandings of complex systems. It addresses the question, *How do state science education leaders use representations of complex systems to understand their networks and identify leverage points for change?* This work is part of a larger research-practice partnership in which state leaders have multiple opportunities to map and analyze the social networks that represent the complex science education systems in their states.

This study employed a mixed methods design which included both qualitative and quantitative data collection and analysis (Leech & Onwuegbuzie, 2009). We analyzed two techniques we constructed that were grounded in Actor Network Theory, which we call *state influence charts* and *actor network maps* to capture the ways in which state science education leaders perceive who has power and necessary relationships to make change in science education. Actor Network Theory (ANT) is concerned with the relations between both material objects and concepts within a network (Latour, 1987, 2005; Sismondo, 2003). ANT posits that there is no unmediated activity within a system, rather, all actions impact and are changed by other actors in the system. Actors—that include human and non-human kinds (e.g., policies operating in a context), have *interests* that need to be accommodated, and that can be managed and used. Actors work to establish networks that support and constrain activity flowing through that network. ANT involves working to understand the interests of a variety of actors, and translating (both in place and in form) those interests so that actors work together or in agreement (Sismondo, 2003). We use ANT-inspired tools to describe a network as it is, in order to capture an image of the underlying system the produces observable results. Our project is concerned with the political and programmatic work of bringing interests and elements of a network into alignment, for the purposes of increasing coherence and equity in state science education systems. The influence charts and actor network maps capture key decision makers, allies, influential processes, organizations and artifacts, as well as connections between these items in order to make visible the potentially invisible systems of influence in each state.

Description of tools

Network influence maps

The research project associated with this work is organizing networks of science networks, designed to improve equity in science instruction in ways that align with the vision of *A Framework for K-12 Science Education* (National Research Council, 2012). To this aim, the research team is working together with state based science teams to build networks to support coherent and equitable implementation of the new science standards. The project, which began in the Fall of 2016, has included several activities designed to help science coordinators build capacity for change in their state. Some of the activities have included statewide focus groups, the development of rapid assessment tools such as practical measures, and the co-design of professional development resources. The research team has hypothesized that there are many components of coherence in state science education, including the degree to which influential actors within each state are 1) connected and 2) moving in the same direction. State influence charts and actor network maps provided state leaders with an exercise to explore the connectedness and trajectory of important elements of their state systems.

During the summer of 2016 a group of 13 U.S. State Science Coordinators participated in a brief training on how to complete their state influence chart. The purpose of the chart was to guide the science coordinators as they selected a broad team to assist them in implementing a coherent and equitable plan for science teaching and learning in their state. The chart included spaces for coordinators and one to two other team members to list the name and organizations of people who they might want to join their efforts, Table 1. It also included space to write how influential each potential team member was in their state, what aspects of the state science system they had influence over, and how familiar each person was with the *Framework for K-12 Science Education*. Lastly, state coordinators were asked to indicate whether or not the people they listed in their state influence charts knew each other, entering a "1" if the key influencers knew each other, a "0" if they did not and "IDK" if the state coordinator did not know if the potential team members knew each other. The maps were intended to be "living documents" updated as more information was discovered and participants' roles change. After completing an initial chart, state coordinators met with peers from other states to discuss their charts, the rationale for including people in the chart, and to reflect on what changes they would make to their own charts based on insight from other states. Then state teams revised their influence charts once more during the meeting.

Table 1: Example list of connections in state influence chart

	Person 1	Person 2	Person 3	Person 4	Person 5	Person 6	Person 7	Person 8	Person 9
Person 1		1	1	0	IDK	0	1	1	1
Person 2	1		1	1	1	0	IDK	0	1

Actor Network Diagrams

State Science Coordinators returned to Boulder for a meeting in Fall 2017. We designed an activity in which members of each state team, including the state science supervisor and one to two other state leaders, completed a hand drawn actor network, Figure 1. Using an interview protocol the research team provided, teams brainstormed a list of actors and drew connections between them on paper. We asked state teams to respond to the prompt: “Why does formative assessment in K-12 science classrooms look the way that it does?” Team members were asked to individually brainstorm and then collectively list up to nine actors of their state science systems and to categorize them accordingly: organization, person, process, or artifact. Items categorized as artifacts included the local curriculum or state science standards, while teacher evaluations were an example of an element state teams categorized as a process. Teams were then directed to classify the elements they listed as supportive, a hinderance, or neutral to their efforts to improve state science education. Afterwards, they also entered the information into an online spreadsheet. State teams then used the actor maps to develop detailed action plans related to promoting coherence and equity in state systems. At a later date, the research team will analyze states’ action plans in light of the information they provided in their actor network maps.

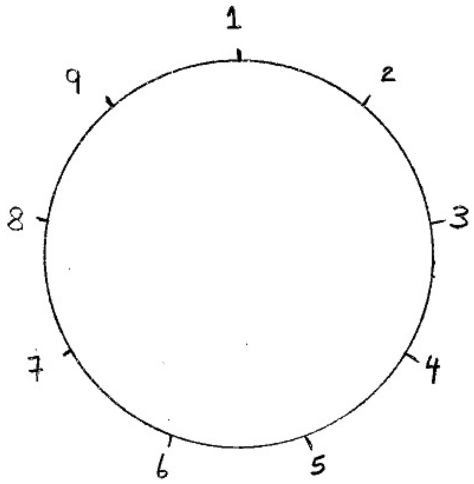

Figure 1. Hand drawn map structure.

The research team used photos of the hand drawn maps to complete any missing elements in the spreadsheets once the activity was over. The spreadsheets were used to make digital maps with an online program called Kumu. Kumu makes a social network map by showing connections between elements, two examples of state maps are below.

Methods and analysis

Once the digital version of the actor network maps were created, they were sent to State Science Coordinators in a questionnaire, along with their state influence chart. The questionnaire was sent to the twelve state leads who attended the meeting (1). State science leaders come from a variety of institutions in their state, including state departments of education, local universities, and state boards of education. The questionnaire asked state leaders to compare and contrast their state influence charts and actor network maps, and to share with us what they had learned from these network mapping activities. Questionnaire items included questions such as, “What revisions would you like to make to your Actor Network Map?” and “What stands out to you about the State Influence Chart?” Nine state leaders responded to the questionnaire request. State leader’s survey responses were coded for content to identify broad themes in the text. Some themes that emerged included that the mapping activities were positive experiences for participants, that they helped state leaders identify leverage points of support or opposition in the system, and that state leaders planned to use the mapping activities in conjunction with other practices and activities of the partnership network to plan and make decisions. The original seven categories were combined into three for parsimony: seeing the whole system, planning for the future, and identifying structural gaps.

Findings

Supportive, hindering, and neutral actors, processes and organizations

The hand drawn maps provided more information than we had originally anticipated because they allowed participants to create novel connections. For instance, several state coordinators listed organizations that took on more than one role as both supports and hindrances. In all, 15 items were listed as both supporting, hindering and/or neutral to efforts to improve science education. We did not instruct state coordinators to give elements more than one category because we limited the Kumu spreadsheets to include only one classification. However, state coordinators mapped complexity in their state systems beyond the constraints of the representational system we provided them. They recognized nuance and contingencies in relationships that allowed for organizations to both support and hinder their efforts towards science reform. They described how organizations often have variable interests across individuals, and actors can have shifting interests over time, or variable context-driven interests. We take this to mean that there is significant systems complexity at levels of detail that lie beyond the constraints the activity design imposed on the teams.

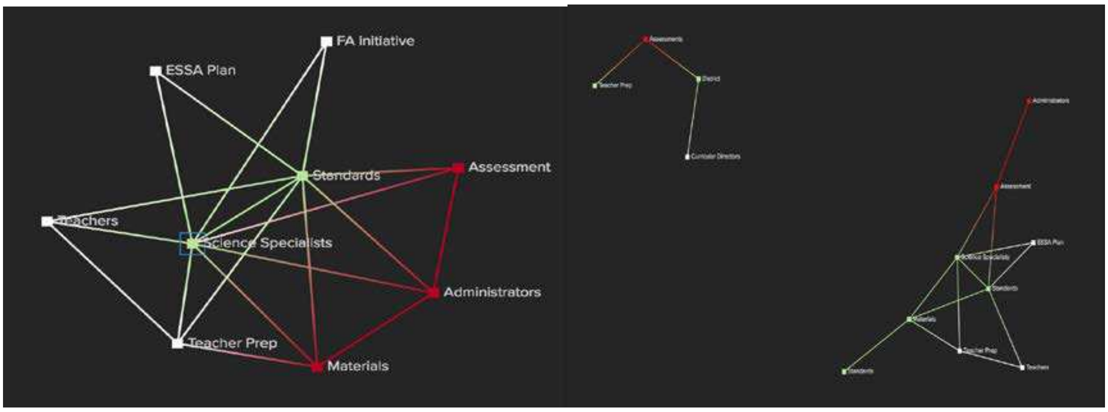

Figure 2. example actor network maps. The map on the left represents a somewhat more coherent state with connections between the elements, while the map on the right represents a state with more isolated elements (actants in ANT terms), suggesting incoherence within the state science system. The red elements show misalignment with goals of state leaders, so neither system is coherent with respect to vision for equitable teaching and learning.

Questionnaire findings

Our questionnaire findings suggest that representational tools can help develop understandings of complex education systems of which they are part. State science leaders identified several ways that the social actor mapping and state influence chart experiences were positive, with one member calling the activity "reassuring" because she discovered more support in the system than she had originally thought was there. State leaders continued to use ANT-related exercises after the Boulder meeting to organize work in their state. For example, one state leader requested the Kumu spreadsheet so that she could create her own account and lead her team through the data during a meeting. Another science leader completed the mapping activities with others in her state in order to inform decisions regarding leadership for their advisory committee, and to help decide how to redraw regional boundaries for their STEM networks.

Overall, the mapping experiences helped state participants see their state system as an integrated whole, the activities helped them identify incongruencies in state science systems, and the mapping and charting activities helped teams determine their next steps toward improving coherence.

See the system as a whole

Respondents felt that the actor network mapping activities helped them see the big picture regarding their state science systems. It was useful for participants to step back to see their entire network as an integrated whole, rather than simply focusing on the parts that they interacted with on a day-to-day basis. One respondent wrote, "It helps me look at all the actors at once and to think about how we can move between them and shift them from hindrance to support." This state science coordinator reflected on his opportunity to think about the system of science education in his state as a complex whole, rather than a series of discrete, disconnected parts. Similarly, another coordinator stated:

> It was useful to discuss who isn't part of the conversation and why we haven't engaged them. It was also critical to see who is influencing the system for better alignment or how [they are] trying to influence a message that may not be in alignment with our vision and mission.

The respondent noticed actors who were a part of the system, and yet had not been engaged in the state science coordinator's work. The actor network map was useful in identifying parts of the system that their efforts had left untouched. In addition, the state leader identified potential leverage points, by finding actants in their map that may be at odds with the work they were trying to accomplish. These state leaders benefited from the visual representation of the science networks in their state. These representations helped them to locate isolated actants, and started the conversation regarding how better to integrate fragmented sections of the network.

Identify incongruencies

The mapping activities were helpful for illuminating structural gaps in state science systems. One respondent mentioned that there was a disconnect between two major elements on her map. She said, "If we were to look at this, the biggest thing that stands out is that our two major PD opportunities...that get to teachers are completely disconnected." The recognition of this major discontinuity was facilitated by the visual representation of her state's science network. Without this activity, the fact that the two primary providers of professional development activities in her state were disconnected ─not from the state leader, but from each other ─might have gone unnoticed. Building coherence in this network will require connections among all of the major actants, not just between the actants and the science leaders themselves. As mentioned earlier, one participant was surprised to find as much support in her network as she did. Another noted that some of the more influential actants of the network were not having the impact that perhaps they should. The science leader wrote:

> It was interesting that not all of the groups/individuals on the influence map are included in the actor map. That is really interesting and we need to consider how to ensure the people who have the most influence are actually acting in our system.

The participant noticed that potentially influential actants were in fact acting in isolation to the rest of the network. This illuminated an incongruence between what science leaders assumed, and what was actually happening upon further inspection. Taken together, the mapping activities provided an opportunity to reflect on whether or not the system was behaving as imagined.

Identify next steps

As a result of the mapping and charting activities, state participants noted some concrete next steps that they could take to build capacity and coherence in the state science systems. For example, participants stated that they needed to expand or extend their networks, and that they would use the charts and maps in order to identify the people to whom they should reach out. One leader noted that he needed to address isolated actants in his actor network map, stating, "I would prefer to see a system that is more tightly clustered. The long tail to the right suggests that I need to do more to bring coherence across influencers." The same state leader also noted how the maps informed his plan for moving forward in his state. Referring to the state influence chart, he mentioned, "There are a lot of organizations and individuals listed on the document that have not been brought into the work. I need to revisit the document and see how I can draw more people into the work."

The social network chart and actor map provided a stepping off point for a plan to bring about more coherence in the science network, first by identifying potentially influential people, and then by recognizing that those people had not been recruited into the work. Another state leader responded that the maps helped to think about "specific leverage points" in their system; people and elements that they should directly target for support in their efforts. Similarly, another state science coordinator recognized the need for targeted outreach to enhance her work, stating, "We need more intentional interactions with our messaging to actively seek more champions to elevate the urgency of science education." The representations of complex systems not only helped state science coordinators visualize actants and clusters of actants of their state science networks, they also provided directions for state coordinators to plan their next course of action.

Limitations

There are some limitations to our activity design. One respondent reported having difficulty enlarging and reading the map, some wanted to list more than the nine elements we constrained them to, and another wanted more time to complete the mapping activity. These are ideas worth exploring. In particular, the research team could assist participants in using their computers' zoom functions to increase the size of the maps. Given the time constraints at our meeting, we were not able to spend more than 90 minutes on the actor network mapping activity, however, we have continued to work with states who are interested in further developing their maps. Given additional time, the research team could have noted moments of agreement or disagreement as state teams negotiated regarding which elements to include in their maps. Our continued work with states can serve as an additional source of validity, as different state team members review the maps and serve as member checks. Despite these limitations, all respondents reported gaining something of use from completing the mapping activities.

Importantly, respondents found the actor network mapping activity to be more informative than the influence chart creation, as the actor network maps included more varied kinds of actants (artifacts, processes, organizations, and people, rather than just people and organizations). However, respondents found that they would need to go back to revise their influence charts after taking into account their actor network maps. Respondents noticed that people who were influential in the state science systems, represented by their actor network maps, were not listed as potential team members in their state influence charts. As the charts were designed to help state leaders compose their science education team, the lack of coordination between the charts and the maps suggests that the two activities can be conducted in concert. Additionally, the actor network mapping activity may be improved in future iterations by encouraging science coordinators to first list all of the influential actants possible before narrowing down the selection to the final nine. This would help to ensure that the nine elements listed were indeed the most influential, rather than simply the first recalled, and the larger list would be a valuable set of data to collect. Participants found it informative to take the entire science network into account in order to build a more effective team.

Discussion

This paper addresses both the call for the use of complex systems in education, as well as the need to research how representational tools and practices can help develop understandings of complex systems. We use a complex system approach to understand state systems of science education, in response to tendencies to imagine science reform as simple and straightforward matters of implementing guidance from research. As one respondent noted, "the system is dynamic and fluxes in one portion of the system impact all other parts of the system." State science coordinators learned about their networks, the interconnections and disconnections, through using visual representations of their systems. Though state leaders may have had access to all of the information, it was distributed among members and not organized in a way that allowed leaders to view their networks as a whole. The network maps were a helpful tool for mediation that provided the scaffolding necessary to help state leaders to learn about their own complex science systems.

Conclusion

This paper demonstrated a use of complex systems thinking in education and showed that state science leaders can use visual representations of their actor network and state influence charts to better understand their science systems and plan future actions to improve coherence. It helped them identify organizational complexity, new actors, cross-actor tensions, and structural holes in the network to attend to in their improvement work. These interventions are relatively simple and provide affordances for state leaders to think holistically and programmatically about their educational networks.

Endnotes

(1) States included were Arkansas, Iowa, Kansas, New Jersey, Michigan, Minnesota, Oklahoma, Oregon, Pennsylvania, South Dakota, Utah, Washington

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