Ripple Effects: Small-Scale Investigations Into the Sustainability of Ocean Science Education Networks

Abstract

Developing effective networks is critical to the success of educational programs, the spread of excellence across scales of educational practice, and the sustainability of communities devoted to a shared mission (Austin 2000). Yet common metrics have not been established to evaluate the evolution of these networks. The evaluation of consortia in general has tended to look at the effects of the efforts of individuals or individual organizations rather than attempting to investigate the structures of networks (Cross, et al. 2002). Here, we present a pair of case studies utilizing social network analysis (SNA) to examine the health and sustainability of two ocean science education networks: the Center of Ocean Sciences Education Excellence Ocean Communities in Education And social Networks (COSEE OCEAN), and the New England Ocean Science Education Collaborative (NEOSEC). In this paper we analyze these two networks at both the network and node levels.

Educational networks appear to be structured much like corporate ones, yet there have been relatively few attempts to look at the structure and dynamics of these systems and the resulting effects and sustainability of these communities through a network lens (Durland & Fredericks 2005). Over the last year COSEE OCEAN has assembled an interdisciplinary team to look at the effectiveness and sustainability of two networks of education communities developed to increase ocean literacy among multiple audiences.

It has been well documented that the United States has slipped from first place in the areas of science and math education and discovery (Holdren et al. 2010). One initiative developed to address this issue is the Centers for Ocean Sciences Education Excellence (COSEE): a large-scale experiment by the National Science Foundation (NSF) intended to enhance ocean science education and increase awareness of the importance of ocean science research.

Now entering its 10th year, the COSEE Network comprises 14 centers around the United States coordinated by a national COSEE office, and serves to bring scientists and educators together to produce high quality and high capacity educational resources based on current ocean science. One of those centers, COSEE OCEAN, has stated its mission as “leveraging, enhancing, and engaging existing STEM networks.” The Center’s goals include connecting existing educational networks and ocean scientists with educators to better communicate ocean science to their audiences. The analysis of the COSEE OCEAN network described below was an attempt to begin to study the impact of the formation of COSEE Centers on those goals. A similar analysis was then performed on the New England Ocean Sciences Education Collaborative (NEOSEC), a 5-year-old ocean science education network comprised of more than 40 institutions, with a stated goal of advancing ocean literacy in the region. While the two networks are quite different in formation and evolution, case studies of the two suggest that successful educational networks may share some common characteristics and metrics.

COSEE OCEAN

As a first step and well-controlled example, we analyzed COSEE OCEAN, measuring the structure of relationships among participants both before COSEE OCEAN was established and after it had been in operation for nine months. This study examined the interactions between 14 individuals making up the network. The COSEE OCEAN project brought together many of these individuals for the first time. A survey was conducted asking about the frequency of interactions among network participants at two time points - July 2010 and June 2011, with a scale ranging from 0 (“I don’t know this person” to 5 (“I interact with this person on a weekly basis”). Data were downloaded by Davis Square Research Associates (DSRA) for cleaning in Excel, and most analyses were conducted in UCINet and SPSS, with additional visualization support done in NetDraw.

Node-Level Metrics

In the sociograms included in this study, longer lines mean greater social distances (less collaboration), while shorter lines depict a closer social tie. No lines at all mean that there is no measured social relation.

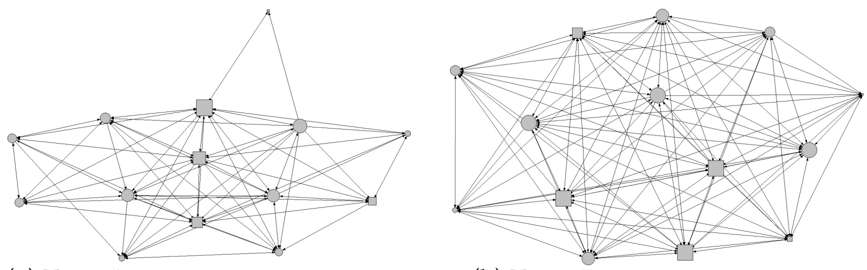
Metric	Time 1 (Mean)	Time 2 (Mean)
Centrality Out	8.50	12.50*
Power Out	1696.73	2500.46*
Eigenvector Out	0.65	0.90*

Table 1: Node Metrics. Calculations are mean values for all network nodes (*significant at $p<0.05$ (paired samples t test).

In Table 1, *Centrality Out* refers to the number and strength of ties that each actor claims to have with all other actors in the network. In education projects one would prefer to see this value increase with time. *Power Out* refers to the number and strength of ties with others who in turn have less centrality. Actors with strong power values tend to have a number of others who depend on them for information. Increase in the value here indicates some actors are more active than others in the network. In other words, some network actors increased their frequency of communication with others at a higher rate. Also, Time 1 shows more even distribution of power, while in Time 2 there is a greater power concentration revealing some nodes as more active than others.

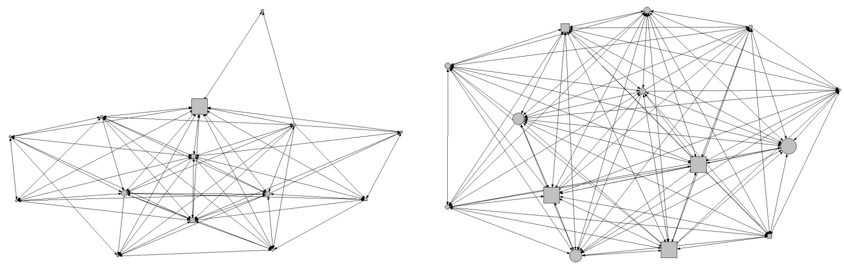
Eigenvector Out refers to ties with others who in turn are well-connected. A person with high eigenvector values–considered to be more “popular” than one with low eigenvector values–would be communicating frequently with others who are also communicating frequently. A person with low eigenvector centrality would be communicating with others who report low levels of communication.

The pre-post effect sizes are at or close to a robust 0.66 (eta squared), meaning that the differences from Time 1 to Time 2 are of a sizable magnitude. Descriptively, the project leaders-reported lower values on the pre-test and higher values on the post-test relative to all others; however, the differences were not significant (ANOVA).



(a) Time 1 (b) Time 2

Figure 1: Time 1 (a) and Time 2 (b) centrality out sociograms represent changes in centrality by node size. (project leaders=squares/all other actors=round). Centrality Out shows a significant increase in overall centrality, as well as a marked narrowing of the range of values from Time 1 to Time 2.



(a) Time 1 (b) Time 2

Figure 3: Time 1 (a) and Time 2 (b) sociograms illustrate betweeness differences for the COSEE OCEAN network at Times 1 and 2 (project leaders=squares/all other actors=round). The larger nodes have greater betweenness indicating that they appear more frequently in the shortest possible path between one node and another.

Network-Level Metrics

Metric	Time 1	Time 2
Density	1.46	2.55
Centralization (Out)	35.65%	38.18%
Transitivity	41.75	74.48

Table 2: Network metrics.

In Table 2, *Density* is a function of the observed ties divided by possible ties. Data here show gains from Time 1 to Time 2, indicating a strong increase in the number and strength of interactions among actors. Whether this is a dense network or not is a point around which there is little consensus among network analysts, however, the increase seen here is striking. *Centralization* of a network is the extent to which the network resembles a star network with a single actor in the center and no connections among the other actors. The network shows a high level of centralization, indicating that influence flows out from actors who are advantageously placed in the network. *Transitivity* refers to the number of 3-person ties, a situation generally associated with higher degrees of association. Similar to density, an increase in triadic associations is indicative of a "tightening" of the overall network, frequently an indication of increases in collaborations.

COSEE OCEAN Conclusions:

The interactions among participants in the COSEE OCEAN network significantly increased in frequency and social complexity over the June 2010-June 2011 year. Overall gains in centrality as well as increases in the size of the participants' ego networks clearly show that the network is becoming a highly interactive structure. The eigenvector out value shows that not only are more people interacting with more people, but, the interactions are among highly interacting individuals. The measured increases in transitivity add additional support to this conclusion.

On the other hand, centralization values remain high, indicating that information may be originating from a small number of nodes. This finding is corroborated by the increases in the power value, suggesting that the network's centers of influence are fairly limited. This finding suggests that some actors are in positions of considerable influence, while others are not. Conversely, this finding indicates that the actors with greater influence are also more exposed to other network actors, perhaps limiting the efficiency with which the more influential participants can act. This finding is further supported by the measured increases in the densities of the ego networks (data not shown), a phenomenon generally linked to less flexibility among those with dense ego networks. In general, network actors with greater power are thought to have rather less accurate perspectives on the network structure.

NEOSEC Analysis

A second case study is the New England Ocean Science Education Collaborative (NEOSEC), of which COSEE OCEAN is a member. Founded in 2006, NEOSEC is a diverse, networked collaboration of 43 institutions from across New England, including aquaria, museums, universities, government entities and science and research centers.

The SNA was conducted by DSRA based on the Himmelman model (Himmelman 2002) to assess the increase in collaboration among members. The intent was to investigate the following questions: "What changes can be seen in the interorganizational collaborations within NEOSEC?"; and, "are there organizational characteristics that affect participation in the network?"

The sample is organizational members of NEOSEC (N=43) (in NEOSEC, individuals act as representatives of their institutions), with 38 of these submitting analyzable responses after the data were cleaned (for a final response rate of 88%). The survey, developed collaboratively by NEOSEC, DSRA, and the authors, asked about depth of interactions with fellow Collaborative members at two time points – 2005, prior to NEOSEC forming and then again at August 2011. It utilized a scale ranging from "We did/do not know of this group" to "We had/have sustained collaborations with this group." The data were collected online, then downloaded to be cleaned in Excel. All analyses were conducted in UCINet and SPSS, with network visualizations done in NetDraw, Gephi and Pajek.

Node-Level Metrics

An ego network is composed of a single network actor, referred to as the *ego* (in this case, a single NEOSEC member institution) and the other network actors with whom the ego claims to have a relation, with these latter known as the *alters*.

	Mean	Std. Deviation	Effect Size
T1_Ego_Density	72.85	6.66	
T2_Ego_Density	88.51*	1.38	0.88

Table 3: Summary of ego network density gain (*significant at $p<0.05$ (paired samples t test).

In Table 3, *Ego density* refers to the extent to which the alter organizations are linked to one another. Note that the gains seen here are significant, and with a sharp downward turn to the standard deviation. The effect size here is also very large. What this means is that the NEOSEC member organizations are interacting more with other organizations that are in turn interacting with one another. Looking at the gains in ego density by (geographic) state, we found no significant differences (Kruskal-Wallis). The changes in standard deviations convey the very sharp increases in ego network densities.

We theorized that meeting attendance and funding levels might have significant relations to network effects and calculated the correlations (Pearson) between these two variables and ego network density gains (Table 3). Limiting the analysis to only those organizations that participated in joint projects with federal funding to NEOSEC, we found a non-significant (Pearson) and negative correlation between funding score and meetings attended (-0.127). We were led to conclude that these three variables (funding, attendance, and egonet density gains) are only weakly related for funded projects. For funded projects the results (not shown) are quite similar, with low (0.161) correlations between meetings attended and ego network density gains. A multiple regression (not shown) using state, meetings attended, and composite funding as independent variables and ego network density gains as the dependent variable yielded similarly inconclusive results.

		Meetings Attended	Composite Funding	Ego Network Density Gain
Meetings Attended	Pearson Correlation	1	-0.127	0.176
	Sig. (2-tailed)		0.652	0.529
Composite Funding	Pearson Correlation	-0.127	1	-0.336
	Sig. (2-tailed)	0.652		0.220
Ego Network Density Gain	Pearson Correlation	0.176	-0.336	1
	Sig. (2-tailed)	0.529	0.220	

Table 4: Correlations between meeting attendance, funding received, and centrality gains for organizations taking part in jointly funded projects.

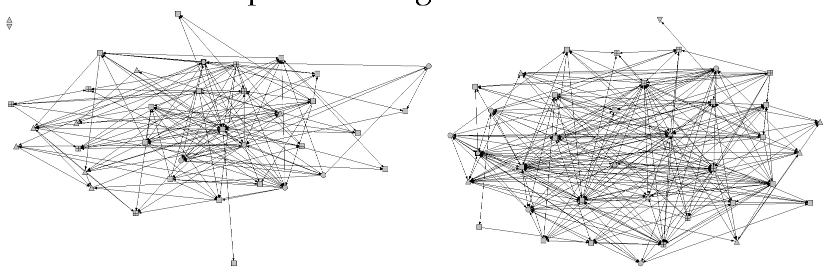
Network-Level Metrics

In this section we present findings from the analyses of the pre-post changes in the overall NEOSEC network. It should be noted that the selection of the analyses presented involved considerable judgment on the part of the analyst based on the suitability of the data for the analysis, as well as the degree to which the findings would be viewed as helpful to NEOSEC. What follows is believed to support an informed process of reflection and new lines of inquiry.

Metric	Time 1	Time 2
Density	1.49	2.26
Centralization	36.29%	31.16%
Hierarchy	0.05	0.00

Table 5: General network-level metrics

In Table 5, *Density* is the number and strength of ties compared to the number and strength of possible ties. Density can be quite sensitive to context, and thus what might be seen as fairly dense in one context (e.g., a law firm) might be viewed as rather sparse in another (e.g., a family reunion). For NEOSEC, the density values show a robust increase on the order of 52%, and while one might interpret these values in different ways, the observed increase is sizeable. *Centralization* is the extent to which the network resembles a "hub and spokes" network. These values remain somewhat high, indicating that one or more organizations are more central than the others. There has been some decentralization between 2005 and 2011; however, overall the network retains a rather centralized structure. *Hierarchy* refers to the extent to which paths are not reciprocated, indicating "pecking order" among organizations. The virtual disappearance of hierarchy indicates that there is a general equivalence among the organizations, in which a more peripheral organization can easily reach a more core organization. The Time 1 value is very low, suggesting that the organizations had a fairly good familiarity with one another prior to the genesis of NEOSEC.



(a) Time 1 (b) Time 2

Figure 4: NEOSEC sociogram by state. Time 1(a) depicts the overall structure with nodes shaped by state. Note that there is some state-level clustering and a rather distinct set of core organizations in the center of the sociogram. Time 2(b) reveals a continued state-level clustering, however there were no significant (Kruskal-Wallis) between-group differences in terms of centrality gains. Even a cursory visual comparison between Time 1 and Time 2 reveal an increase in the overall density and complexity of the ties between the organizations. The core appears to persist, but previously peripheral organizations now have numerous ties to other organizations.

NEOSEC Conclusions

The NEOSEC network has grown significantly in its overall cohesion in the patterns of relations among member organizations, and in the ego network density of individual organizations. Its network density values show a sharp increase relative to the period prior to the start of the network and the hierarchy values (referring to non-reciprocated ties) for all practical purposes disappeared. The centralization values do indicate that some members were strong network actors before NEOSEC and that they remain so. Change in the coreness values was not significant from Time 1 to Time 2, indicating that organizations that were central before NEOSEC remain so, even as the network becomes more complex.

Dyadic measures (not shown) indicated significant increases with very good effect sizes, meaning that organizations have more and stronger ties with other organizations that are in turn better connected with others. This underscores the conclusion that the network grew in ways that involved all network members. The ego network density values increased sharply as well, though we found no significant relations here to the state in which the member operates, the levels of funding, or the number of NEOSEC meetings attended.

Discussion

The growth and development of highly structured or loosely organized networks in education result in communities that either last or not, depending on a host of internal and external parameters. To date we have found that education networks studied evolve from minimally-interacting individual nodes; to increased communication; to a flexible, sustainable network. Critical components are: an increase in face-to-face interactions and resulting knowledge, shared goals and vision, paid staffing, and opportunities for collaboration.

To measure the growth of the COSEE OCEAN group we relied on the frequency of communication as a relational domain, while for the NEOSEC group we extended this domain to include a modification of the Himmelman model on inter-organizational collaboration.

Examination of the two networks through the SNA lens revealed many aspects of network structure and its evolution over time. The NEOSEC network has evolved from a loosely affiliated set of disparate organizations into a tightly knit network. Similarly, COSEE OCEAN coalesced into a tightly structured group without any individual isolated or dependent on just one other actor. While some actors are more central than others, the overall cohesion of the group has significantly increased.

While COSEE OCEAN was formed in response to an NSF request for proposals, no single identifiable factor appeared that drove NEOSEC members to develop their relations with others. In any case, the NEOSEC network is both a remarkable achievement in itself and a valuable asset for building the overall regional capacity for expanding ocean literacy in New England. This network responds to opportunity and has a high degree of trust, leading to enhanced sustainability. In both networks, the observed, meshed cohesion creates support structures for taking on complex projects that take advantage of each actor's capabilities.

We believe that in both instances network analytical investigation revealed important findings about the growth of the networks, findings that could not have been gathered with comparable rigor in any other way. In neither case do we assume that the measured ties are the only ties that exist between actors; however, we do assume that these ties are important to network functioning and that they are critical indicators of network vitality. The programmatic implications of the findings are currently under consideration, but even a cursory look at the data shows which individuals or groups are most active and which have assumed a more peripheral position. With these insights in mind we are better able to plan activities, adjust strategies, and meet overall educational goals.

As we examine how education networks function, we are developing metrics to characterize networks that govern these functions. By examining a small, focused, but diverse set of networks of different scales within the ocean education arena, our goal is to use SNA to uncover the secrets to effectively building sustainable education networks. SNA offers an approach to study the scaling of educational network structures that may be well suited to identifying bottlenecks in network structure. It can serve as a diagnostic tool for optimizing network structure to achieve learning goals. The ultimate goal is to aid in the development of networks of engaged ocean scientists and educators - a powerful force for discovery.

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