2006-352: RICH NETWORKS: EVALUATING UNIVERSITY-HIGH SCHOOLS PARTNERSHIPS USING GRAPH ANALYSIS

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Rich Networks:
Evaluating University-High Schools Partnerships Using Graph Analysis

Introduction

Educational partnerships created between institutions of higher education and K-12 educational communities are complicated entities that defy easy assessment. Members of the partnership often propose concrete educational objectives at the onset, with baseline measurements and evaluation parameters dutifully defined. However good partnerships have a tendency to grow and develop in wholly unanticipated directions, forming networks and having effects far beyond the scope of the initial project. This growth, fueled by institutional strategic needs that are complementary and nurtured by crucial champions on both sides, is the basis for a partnership that can be sustained beyond the time limits of the initial project's external funding. For Principal Investigators, project managers and program evaluators, the critical questions become: *How can I analyze the partnership in ways that capture all important components and relationships*? and *How can I predict whether a particular partnership is growing and gaining a life of its own, or whether it is sustained only by a few key individuals and the direct infusion of external cash*?

This paper investigates using graph analysis to study the network of interactions from one specific university-high school partnership program—the Student and Teacher Enhancement Partnership (STEP) program. The study analyzes the partnership networks between the Georgia Institute of Technology and Westlake High School, a 99% African American high school in metro-Atlanta, over a three year period and uses the results to assess the extent, impact, and likely future of the partnership. For each year, the partnership can be modeled by using a variety of graphs; in each case the vertices are the different "players" in the partnership (university faculty, graduate students, high school teachers, high school classes, clubs, etc.) and the edges connect participants who interact, with edge weights related to the strength of that interaction. These models then allow classical graph theory analysis to measure densities, connectedness, and other graph properties. In addition, social science graphical tools and summary measures can be used to generate visualizations of the partnership network. This method of analysis holds promise as an effective instrument for assessing the development and health of educational partnerships, thereby assisting with the answers to the critical questions posed above.

Background of Partnership and Evaluation Plan

The National Science Foundation's GK-12 program, funded through the Graduate Education directorate, provides support for institutions of higher education to place graduate and undergraduate students into K-12 classrooms for ten hours per week. Georgia Tech's Student and Teacher Enhancement Partnership (STEP) GK-12 program[1] was funded in 2001 for three years with a continuation for another five years (as STEP Up![2]), and partners Georgia Tech graduate and undergraduate students with teams of teachers at metro-Atlanta high schools with three broad goals:

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[1] NSF Award Number 0086420
[2] NSF Award Number 0338261

- To broaden the education of Georgia Tech graduate and undergraduate students to include intensive experiences in educational pedagogy and process;
- To encourage the participation of Georgia Tech faculty and students in K-12 education through the nurturing of university-school partnerships; and
- To assist K-12 schools in improving K-12 STEM education.

In addition, the 5-year project renewal required a large degree of project institutionalization, and STEP pledged to:

- Solidify and expand the existing partnerships that were formed between Georgia Tech and Atlanta-area high schools;
- Institutionalize K-12 teaching internships as a valued component of graduate and under-graduate education, and develop the necessary funding strategies to make this possible; and
- Continue to work to help create a university campus climate that encourages active participation by students and STEM faculty in the challenges of K-12 education.

The evaluation for STEP was designed to assess these various, distinctive impacts of the program. Because a major focus of STEP is to build partnerships between high schools and Georgia Tech centered upon STEM education, one evaluative goal was to map the development, or demise, of partnering activities stimulated by STEP. The evaluation was also designed to assess the effectiveness of Fellow interactions with high school students and teachers, to track the institutionalization efforts over time, and to monitor impacts that this experience has on the lives and careers of Fellows, teachers, high schools, and university faculty. However this paper will primarily address techniques used to map the development and growth of a partnership and to explore what can be learned by analyzing university-school partnerships as social networks.

Graph Theory and Social Network Analysis

Many researchers with mathematical training will recall graph theory, with its powerful ability to represent a set of vertices (nodes, points) in graphs representing different types of relationships (edges, lines, arcs, ties). (A comment here about vocabulary - in the mathematical literature, a graph is represented by its vertex and edge sets, a directed graph is called a network and is represented by its node and arc sets. In the social science literature, a social network can actually be directed or not, uses vertices and nodes interchangeably, and usually uses the term *ties* for the edges/arcs. Since this paper is at the intersection of the mathematical and the social science fields, we will be fairly loose with our language and use all of these terms interchangeably. Without exception, we consider undirected social networks.) An empty graph represents a set of vertices between which there are no relationships; a complete graph represents a set of vertices in which each vertex is linked to every other vertex. In practice, most graphs represent intermediate levels of linkage among vertices, where some vertices are linked and others are not. This is particularly true—and theoretically and empirically relevant—in the case of representing social relationships. In the past century, social scientists have adopted the powerful tools of graph theory to the evaluation of naturally and policy-induced social interactions. In this section, we briefly define and summarize social network measures that can be calculated using extant data sources and readily available commercial software.

Social network analysis seeks to understand how the relationships among individuals and institutions are structured; how those structures affect the participants and vice versus; and how the structures facilitate or impede valued outcomes. To put this in empirical context, we are interested in understanding how a policy intervention between a university and a high school has fostered new social relationships developed to enhance science and mathematics education. This policy intervention, the STEP program, was designed to improve the scientific resources, human and material, available to the high school. The most crucial component of the intervention is linking personnel from the university with personnel and students from the high school. As such, the level of analysis we seek to explore is how the relationships develop between and among members of each major institution, and how they evolve over time.

In a policy intervention such as this, one would expect early on to see evidence of two separate domains of the network: one representing relationships within the university, and the other representing relationships within the high school. As the intervention proceeds, the *bridge* between the principal boundary spanning actors is likely to be evident at the intersection of the two major modes of the network. Because sustainability is an important long-term objective of the STEP program, an important measure to examine is the extent to which this two-mode network becomes a more fully integrated one-mode network, and a network that is less reliant on the original policy *bridge* to stay connected. Evidence of this would include reducing the *geodesic distance* among members of the network, and increasing the *connectivity*, *closeness/centrality* and *density* of ties among relevant actors in the network. Further, policy-relevant *subgroups* may emerge or strengthen in different parts of the overall network. Where subgroups develop, their relationship to the larger network as a whole can be analyzed; further, the characteristics of their internal relationships can also be determined using the measures just mentioned.

Social Network Measures and their Definitions

Although social network analysis introduces a new set of terminology for graphical representation, the definitions are fairly straightforward and intuitively appealing.

Perhaps the most important initial measure is *size*. In most partnership-based policy interventions, a major objective is to increase the size of networks. In people-based networks, one aspect of size is the number of people who are involved in any way with the network. In social network terminology, these people are nodes. The people need to be available for the possibility for a tie, or relationship, to exist between them. This is the simplest type of measure to calculate: what is the number of distinct people in the network? The size of the network is an important control for many social network measures. Complexity increases with size because the opportunities for forming ties increases with size.

A *bridge,* or bridging tie, is a line that forms a critical path within the network: without it, the network is partitioned. In a policy-driven intervention, one would expect the bridge between parts of the network to be augmented by new ties that do not require the bridge to exist. A specific measure of this concept is *Point Connectivity*: it indicates how many ties would have to be removed for the network to become disconnected. Low point connectivity indicates that the network is vulnerable to becoming disconnected by losing just a few key connections. High point connectivity indicates that there are many redundant ties in the network, and that a great number of ties would have to be broken for a node to become disconnected from the network.

A measure of the richness of the relational environment is captured by *density*. *Density* is a measure that ranges between 0 and 1, where 0 indicates an empty graph, and 1 indicates a complete graph. The density is the number of all actual ties divided by the total number of possible ties, and can be interpreted as a proportion or percentage. A density of .50 means that 50% of all possible ties in the graph are present.

Average Distance measures the average of the shortest lengths of paths between all pairs of nodes of the network. Dense networks tend to have shorter distances, while sparse networks will have longer ones. It is based on the shortest path between any two nodes; as such it is a measure of efficiency in the network. For example, an average distance of 2 would imply that information would have to flow through 1 other person to be delivered throughout the network. In a fully connected network (i.e. in which all nodes are *reachable*), the network has the capacity to diffuse information eventually throughout the network.

Degree Centrality is one measure of the extent to which network activity revolves around only one node. Expressed as a percentage, Degree Centralization of 90% would indicate that the majority of the network revolves around just one node. Expressed in terms of Freeman's degree centrality, it indicates the number of ties to each individual node. People with many ties can be thought of as particularly influential or powerful in the network, while individuals with few ties are not particularly influential or powerful in the network as a whole.

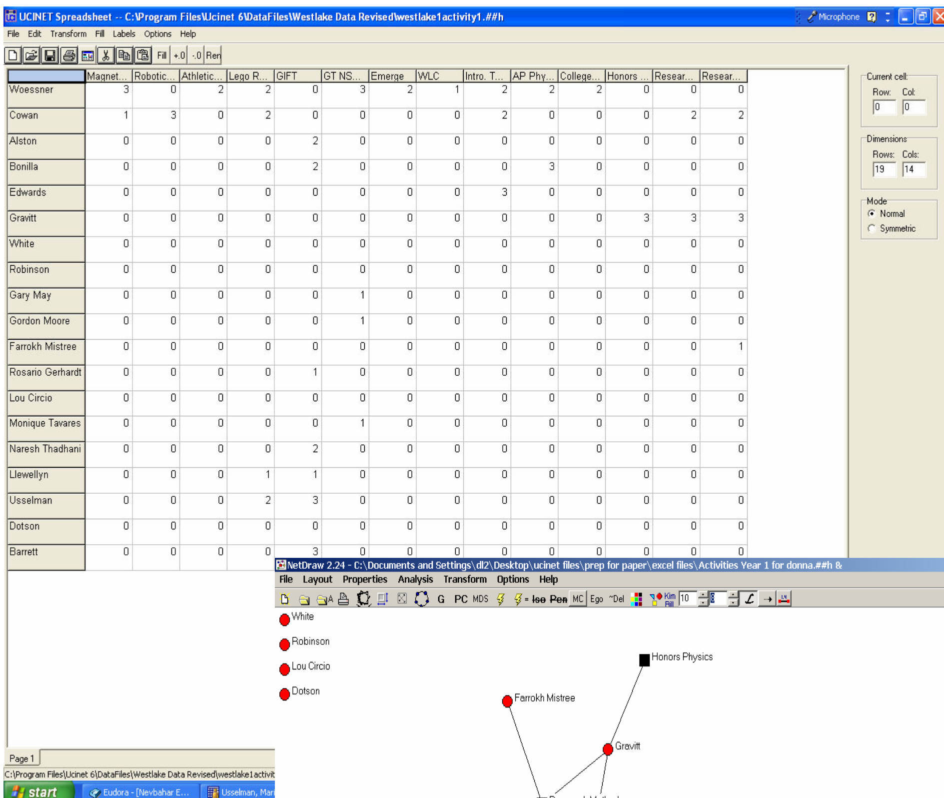
Social Network Data Requirements

In graph theory, relationships are stored in an adjacency matrix. Similarly, the most common way to store social network data is in an adjacency, or sociometric matrix. The data we present in this analysis were collected from extant data contained in annual reports and other readily available data. Specifically, all GK-12 programs are required to submit basic network data to NSF in the form of lists of GK-12 Fellows and teachers, linked with the classes in which they are collaborating. We utilized this data as the basis for the university-school network, adding additional data gleaned through STEP Fellow journals, directly from teachers, and from our knowledge of connections that were created over the years. People, or "actors", within the network were classified as either Georgia Tech actors, or Westlake actors, and "activities" consisted of academic classes, school clubs, after school enrichment activities, programs hosted by Georgia Tech, etc. Actors were linked both to other actors, and to the various activities. Each connection was listed as a number between 0 and 3. Because we were retrospectively using data not collected for this purpose, this "weighting" of the connections was fairly subjective (0=none, 1=low, 2=medium, 3=high). As will be discussed later, fairly simple data collection tools will be used in the future to create a better defined weighting scale. For the summary measures of network characteristics, we rely on binary matrices that are not affected by the measurement scaling problem.

These actors ("nodes") and relationships ("ties" and "activities") are stored in sociometric matrices, easily constructed using spreadsheet programs such as Excel, that are imported directly into commercially available social network analysis and visualization software. In this analysis, we use UCINET (Borgotti, Everett and Freeman 2002) and NetDraw (Harvard: Analytic Technologies, Borgatti, S.P. 2002), but there are a number of other analytic programs available. Figure 1, on the following page, shows an example of a non-symmetric two-mode matrix in

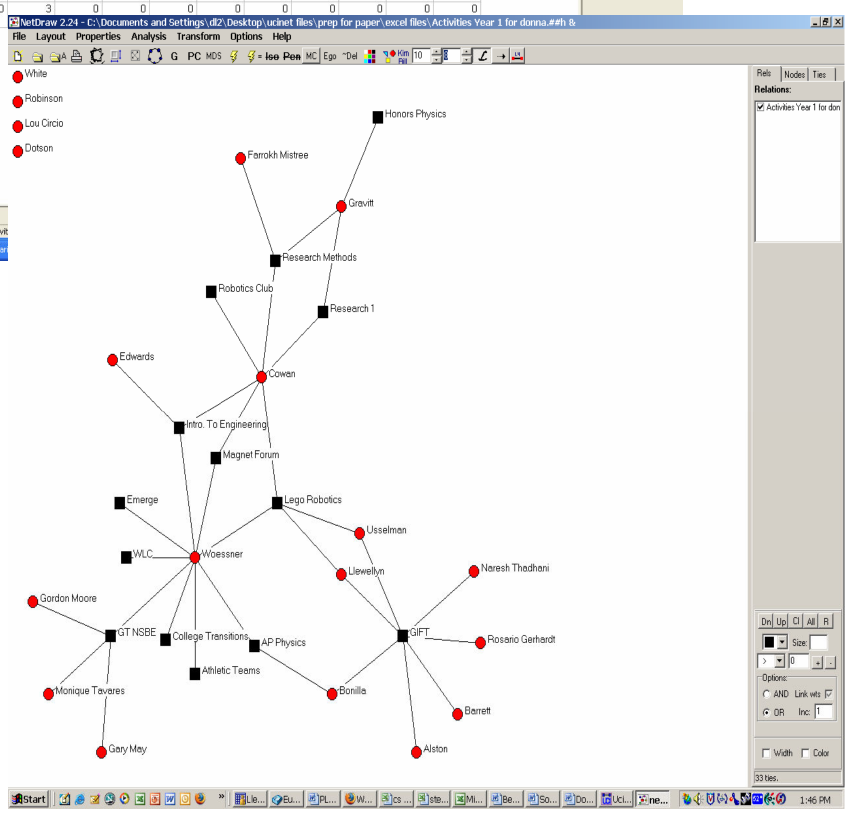
UCINET. The two modes are represented by actors and activities, and the values indicate the intensity of activity between actors and activities. The bottom panel of Figure 1 represents this matrix as a graph, as created by the UCINET software. Additional "attributes" can be added to the nodes, such as their position in the partnership ("teacher", "Fellow", "STEP administrator", "Georgia Tech faculty", etc.), thereby creating the diagrams in Figures 2-6.

Figure 1—Screen Shot of UCINET 6 Social Network Analysis Software
http://www.analytictech.com/ucinet.htm



	Magnet...	Robotic...	Athletic...	Lego R...	GIFT	GT NS...	Emerge	WLC	Intro. T...	AP Phy...	College...	Honors ...	Resear...	Resear...
Woessner	3	0	2	2	0	3	2	1	2	2	2	0	0	0
Cowan	1	3	0	2	0	0	0	0	2	0	0	0	2	2
Alston	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Bonilla	0	0	0	0	2	0	0	0	0	3	0	0	0	0
Edwards	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Gravitt	0	0	0	0	0	0	0	0	0	0	0	3	3	3
White	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Robinson	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gary May	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Gordon Moore	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Farrokh Mistree	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Rosario Gerhardt	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Lou Circio	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Monique Tavares	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Naresh Thadhani	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Llewellyn	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Usselman	0	0	0	2	3	0	0	0	0	0	0	0	0	0
Dotson	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barrett	0	0	0	0	3	0	0	0	0	0	0	0	0	0

<u>Ucinet for Windows: Software for Social Network Analysis.</u> Harvard, MA: Analytic Technologies. Borgatti, S.P., Everett, M.G. and Freeman, L.C. 2002.



<u>NetDraw: Graph Visualization Software.</u> Harvard: Analytic Technologies. Borgatti, S.P. 2002.

An Empirical Demonstration: The Case Study of Georgia Institute of Technology and Westlake High School

With complete actor-by-actor, Georgia Tech actor-by-Westlake actor, and actor-by-activity matrices constructed, the analyst can use either summary measures or diagrams to represent the relationships in the data. These diagrams are illustrated in Figures 2-6. Beginning first with the more intuitively appealing graphs, note that it is possible to see changes over time in the network. At the top of each figure is the network in the first year of the STEP program at Westlake; at the bottom of each figure is the network in the third year of the program.

Figure 2 shows all of the relationships in the Georgia Tech/Westlake social network. The most apparent longitudinal dynamic over time is that the size of the network has increased greatly, with attendant increases in the number of ties that have been created between individuals. To the extent that creating and extending a STEM education network is a valued outcome, these graphs tell a compelling story: new people are linking into the network, and a greater diversity of ties is present for those who were already part of the network in Year 1. The size of circles is proportional to the number of ties to each node. Over the two year period, Usselman and Llewellyn, the STEP program PI and co-PI, remain in important positions in the network, but note the development of additional centers through which ties flow in Year 3. This suggests that the original policy architects remain important, but less central, actors in the network. Again, to the extent that sustainability in the network over time is valued, a greater number of important nodes increase the likelihood that the network will persist over time. Finally, note that administrators tend to occupy more central positions in the network, with professors occupying the positions most distant from the center, and teachers and Fellows occupying intermediate positions. The software used for the diagrams, Netdraw, attempts to locate the vertices with the highest degree (the largest number of edges leading into/out of them) in the center of the graph, and then progressively moves the more isolated vertices to the periphery. The analysts, however, also have the freedom to move vertices around to make the visualization fit with their understanding of the organization of the represented social network.

In Figure 3 we remove ties among actors belonging to the same formal institution. Although an important policy objective is to develop network capacity for STEM education within the high school and within the university, the primary policy objective is to build network capacity between these two institutions. This figure, then, enables us to examine that set of relationships. This representation also suggests a great increase in the size of the network, and illustrates how individuals within the network can increase in importance over time. Note in particular the node occupied by Edwards, a Westlake teacher, who links six new members to the network. This is one of the ways in which the decentralization evident in Figure 2 is occurring: some members of the network begin to perform roles that had once been the domain of the network founders.

Figures 2 and 3 represent the relationships contained in a person-by-person matrix. By contrast, Figure 4 represents the two-mode network constituted by the person-by-activity matrix shown in Figure 1. In this figure, the increase in relational ties is evident, as is a new type of tie—that of activities of the network, and the ties between people and activities. In a sense, one can think of these activities as avenues through which ties are established and developed. Over the time period, there are more people involved, more people involved with ongoing activities, and more

Figure 2—Georgia Tech/Westlake complete Social Network Years 1 and 3

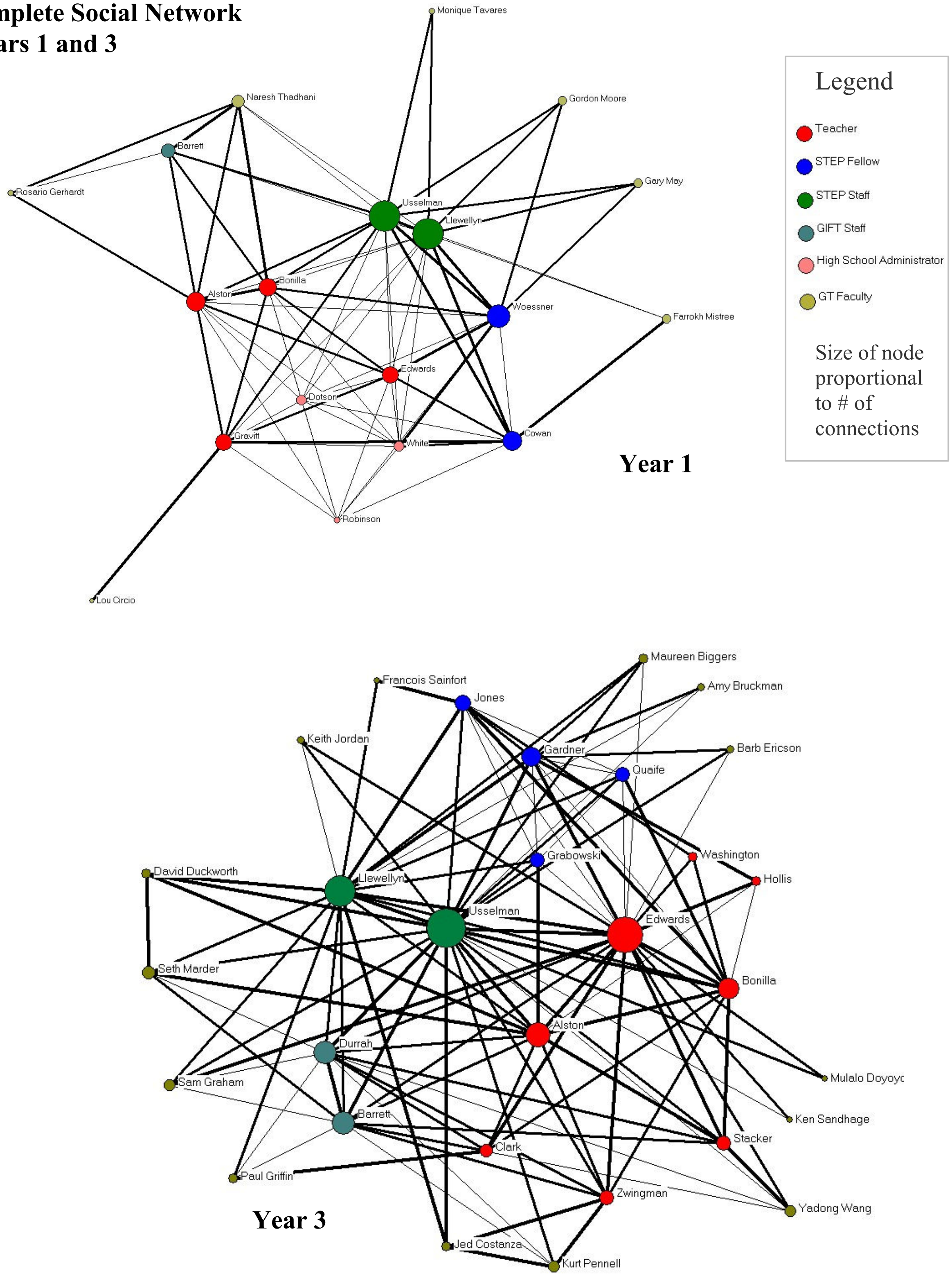


Figure 3—Social Network between Georgia Tech and Westlake. (People at the same institution are not connected.) Years 1 & 3

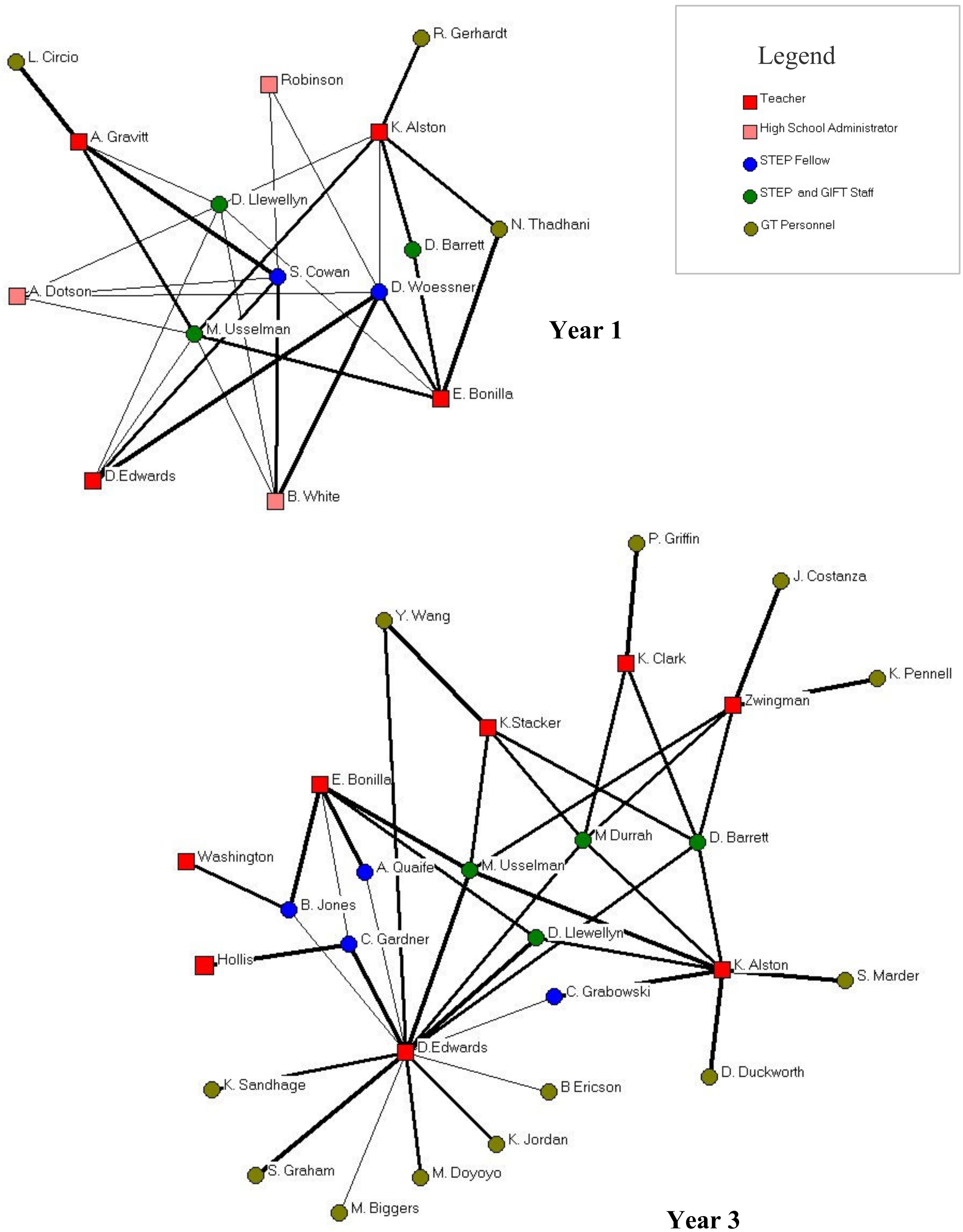
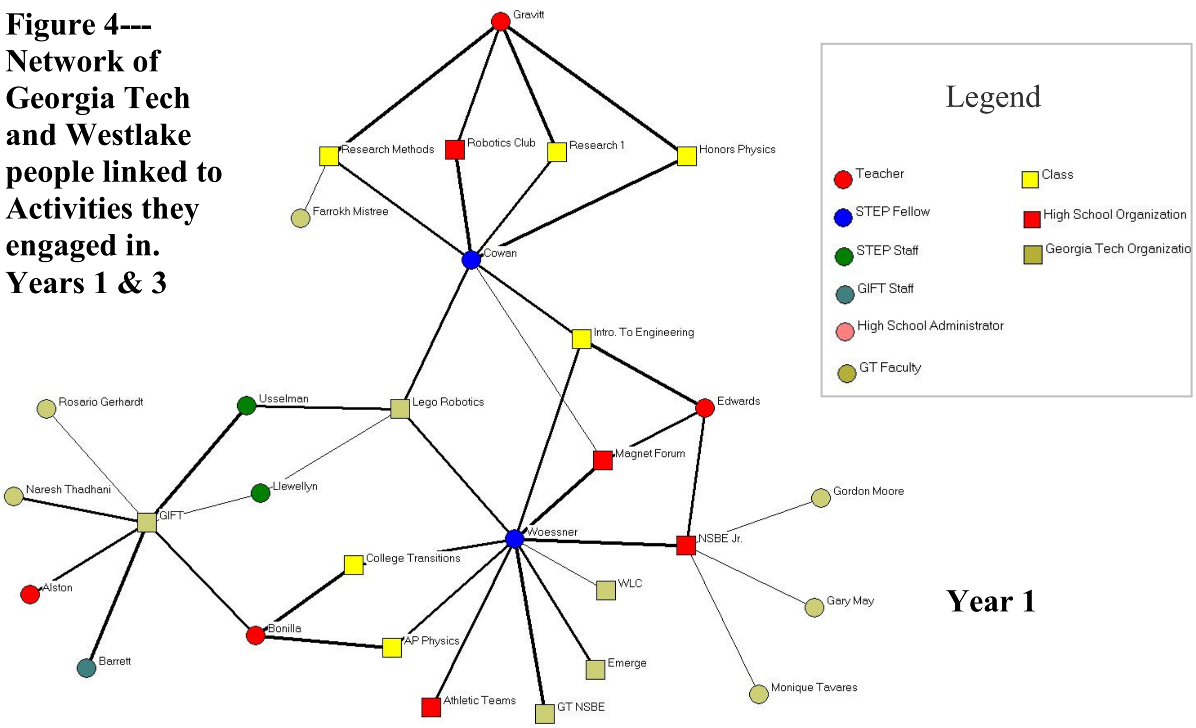
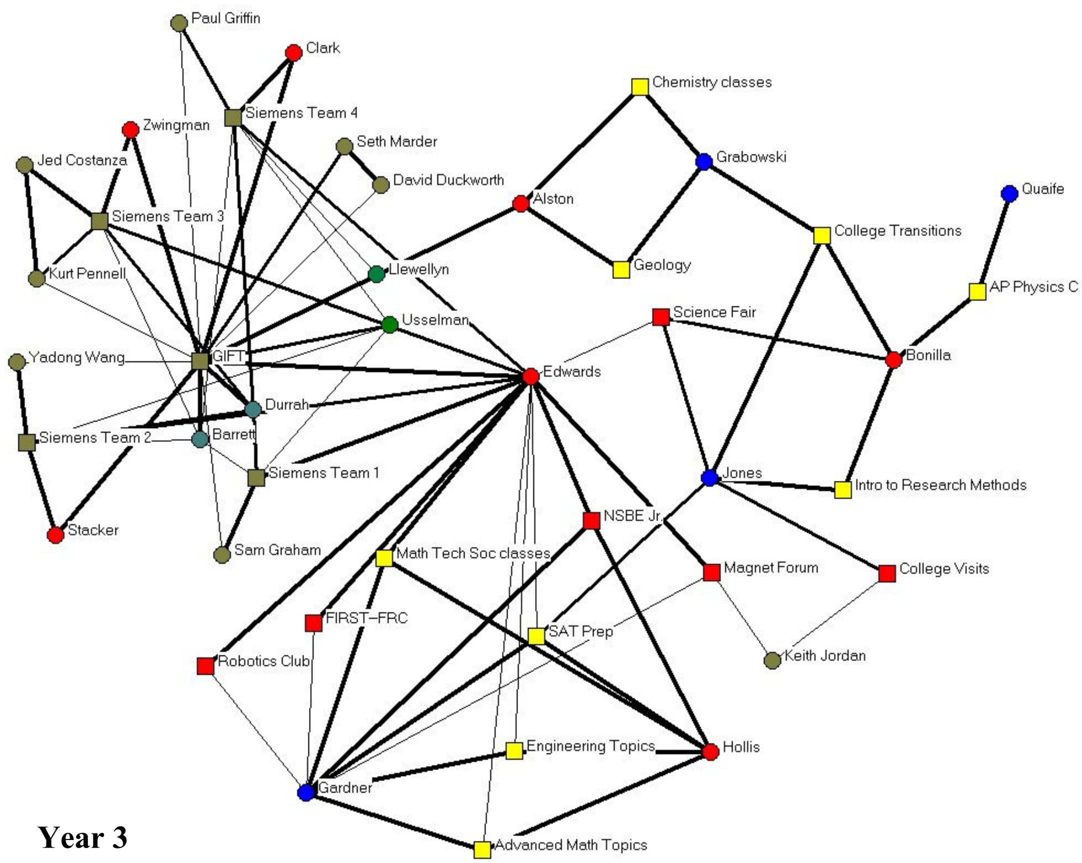


Figure 4---Network of Georgia Tech and Westlake people linked to Activities they engaged in. Years 1 & 3





Year 3

activities occurring in the partnership. This indicates an increase in both the capacity of individuals and programs to facilitate STEM improvement outcomes.

Figure 5 shows how social networks can be partitioned into smaller subsets based on formal roles in the network. In this conceptualization, we include only members of the network who are not staff or Fellows of the STEP program or of Georgia Tech's Georgia Intern-Fellowships for Teachers (GIFT) program, a RET (Research Experience for Teachers) program which many of the teachers became involved in. Within UCINET, this is achieved very simply by deleting specific actors. Again, we observe a noteworthy increase in the size of the social network, an indicator we argue is evidence of increasing capacity to sustain the network over time since these linkages are independent of the STEP and GIFT administrative staff. There is also a change in the degree of connectedness of some members of the network such that their importance and centrality increase over time; note, for example, the Edwards node as evidence of this phenomenon.

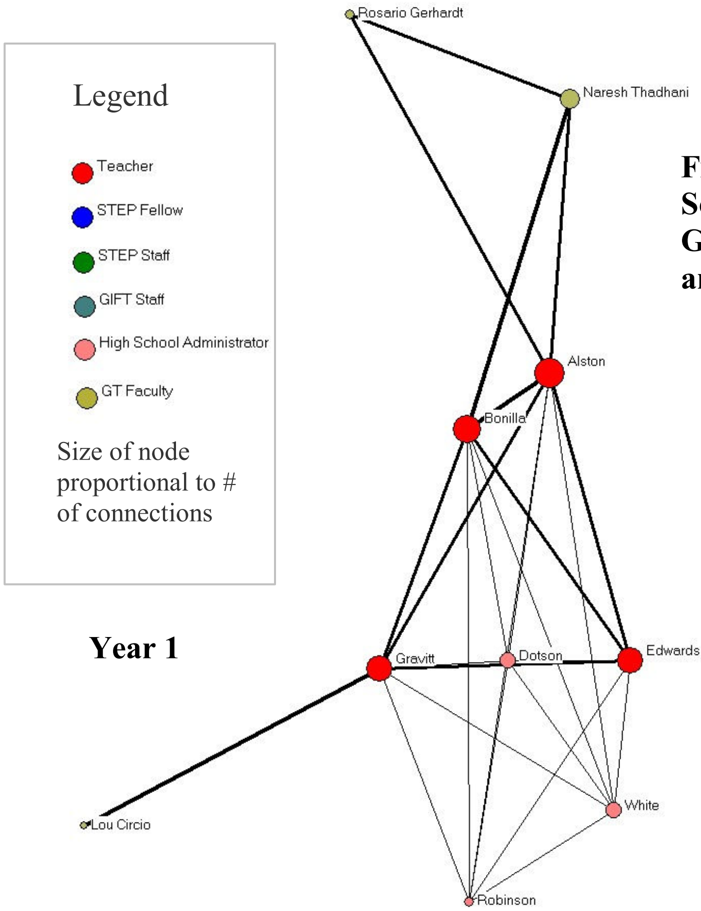
Figure 6 partitions the social network into a view that includes only the graduate STEP Fellows and their ties. This type of network is referred to as an egonet, and is achieved within UCINET with a simple key-stroke. Because STEP Fellows complete one year assignments, the separate years depicted in this figure are cross-sectional, and should not be interpreted longitudinally. What is particularly striking is the central role played by the Fellows in facilitating the relationship between the Westlake and Georgia Tech communities. Despite recruiting new Fellows and professor-mentors each year, the structure and size of the Fellow social networks is remarkably consistent. The increasing size over time of the complete Westlake-Georgia Tech network is not reflected in the egonet of the STEP Fellows.

Mathematical Analyses

Each of the social networks depicted in the Figures is based on person-by-person and person-by-activity matrices. These same matrices can also be analyzed for aggregate characteristics of the network using standard social network measures that can be calculated easily with the UCINET software. Table 1 reports examples of these summary characteristics for the binary person-by-person matrix of the entire social network (Figure 2). The results are reported for Year 1 and Year 3 of the program intervention, which corresponds to the figures and their analyses already presented.

The first indicator, size, is a simple measure of the number of nodes in the network. As already discussed, the overall size of the network increased over the three years of the intervention, from 19 to 30 distinct actors. In the first year of the intervention, we observe a fairly dense network, where 43% of all possible ties are evident. After the growth of the network, however, the density declines to 27% of all possible ties being evident. This is an indicator of a growing and diverse network where potential relationship ties have not yet necessarily been fully realized. It is expected that a social network will go through alternate phases – growth in size followed by an increase in density. In the growth phase, the network increases its capacity for relationships, while in the increasing density phase, those relationships are increasingly formed and strengthened. One sees in this example that many more Georgia Tech people have become involved in the network (3 non-STEP administrators or Fellows in Year 1 to 12 in Year 3). This

Figure 5—Georgia Tech/Westlake Social Network with STEP and GIFT administrative personnel, and STEP Fellows removed.



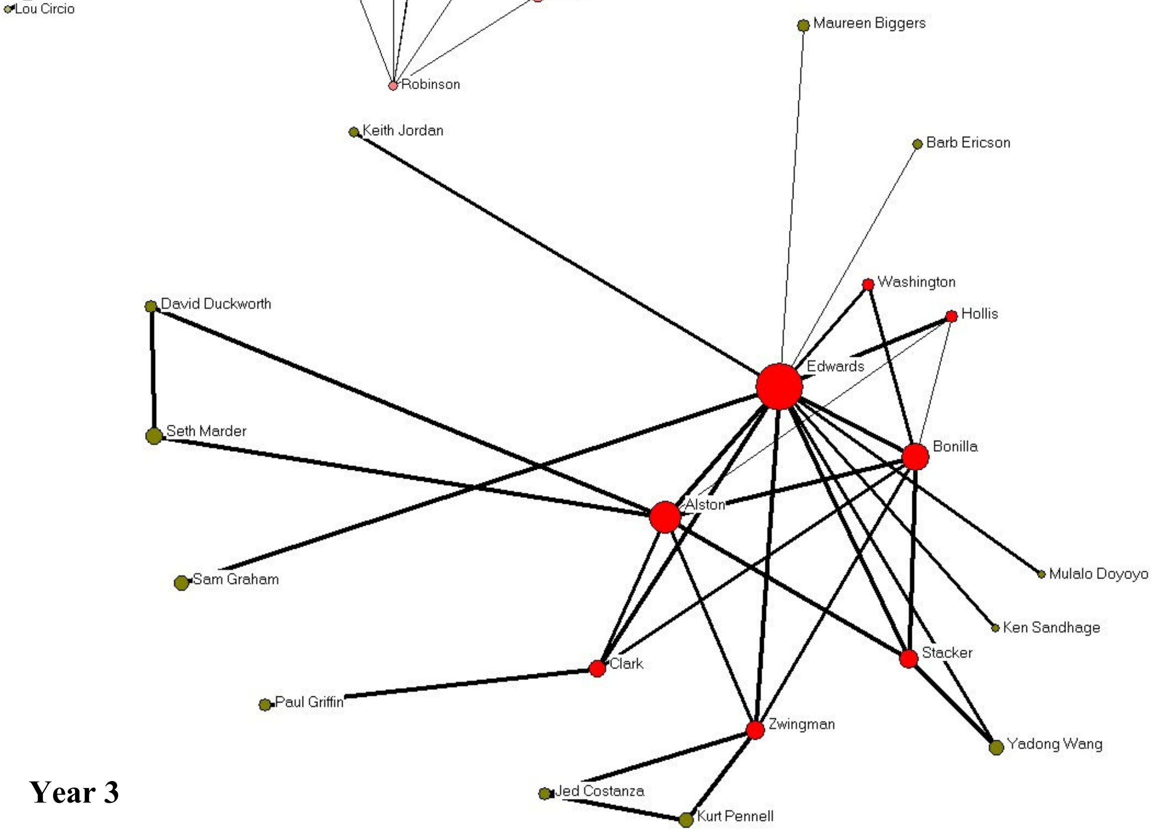
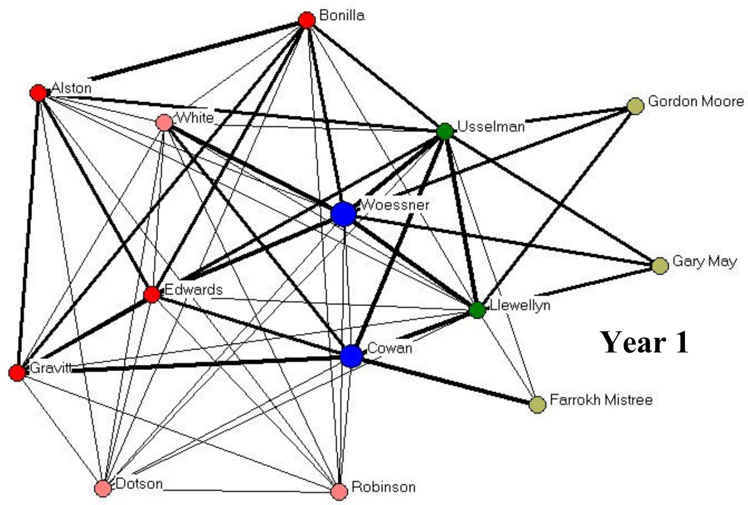
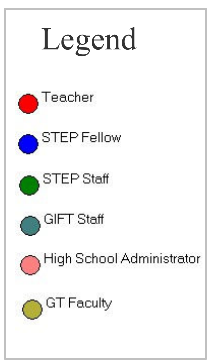
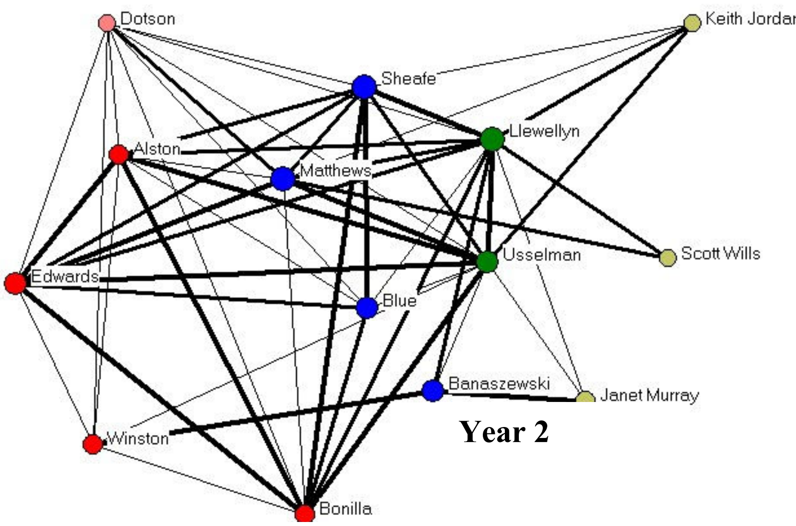
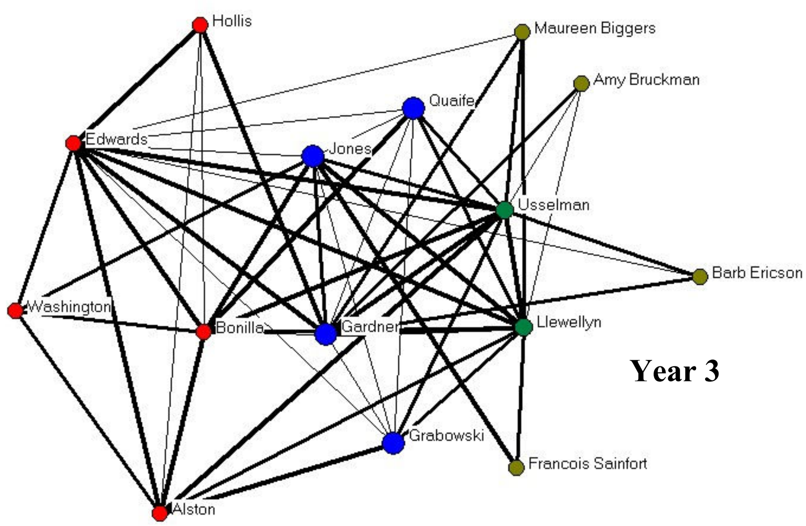


Figure 6—STEP Fellow Egonets. All nodes that are not directly connected to the Fellows are removed.









increased capacity has not yet been fully taken advantage of through increased ties with multiple Westlake individuals – rather in most cases these Tech actors are only connected to one or two Westlake actors.

Another approach to understanding the flow of information within the network is conveyed with the distance measures. For example, the average distance between nodes of the network is almost two, indicating that many actors may not be in positions to influence one another directly, a dynamic that is also apparent in the figures: for a typical network member, he or she will receive information through actors more central to the network. The Degree Centrality is a characteristic of each individual: a Degree Centrality of 0 indicates that the network as a whole is not organized around that individual; in year 1, a degree centrality of 15 indicates that the network as a whole is very much organized around that node of the network. What this summary measure (7.79) masks is the fact that the distribution is bimodal, with a few actors very central to the network, and with many individuals not being particularly central to the network as a whole.

The final indicator, Point Connectivity, is not easily summarized in a single measure. It is a person-by-person measure of how many ties would have to be removed for that person to be disconnected from the other person. The Point Connectivity of two non-adjacent nodes is the number of nodes that must be deleted so that no path connects them - that is, it is equal to the number of vertex-disjoint paths connecting the two vertices. This gives a sense of the redundancy of the network - if the Point Connectivity between a pair is high, then several people can drop out of the network and those two would remain connected. If the Point Connectivity is low, then that connection is much more vulnerable.

The range of Point Connectivity for all of the people in the social network ranges from 1 to 15 in Year 1, and from 1 to 19 in Year 3. For those with a point connectivity of 1, only one relationship would have to be disrupted for them to be disconnected. By contrast, for dyads with a point connectivity of 15, fifteen people would have to removed from the network before the focal person became completely disconnected from the network.

Table 1: Summary Table Of Social Network Indicators

People by People	Year 1		Year 3	
	Interpretive Range[1]	Value	Interpretive Range[1]	Value
Size	n/a	19	n/a	30
Density	0 to 1	0.43	0 to 1	0.27
Average Distance	0 to 3	1.65	0 to 3	1.78
Degree Centrality	0 to 15	7.79	2 to 24	7.73
Point Connectivity	1 to 15	n/a	1 to 19	n/a

[1] The interpretative range refers to the feasible values for each indicator. For example, density by definition is the percentage of the complete graph present and hence always falls between 0 and 1 (inclusive).

To study this a bit further, consider in particular the network represented by Figure 3. Recall that in this diagram, the only ties represented are those between Georgia Tech and Westlake – all "internal" relationships have been deleted. In graph theory, this is a bipartite graph –the set of vertices is made up of two disjoint set of vertices and edges only exist between these two sets. To make the analysis a bit clearer, within these two groups, we will group people by role. We define four roles:

- Within Georgia Tech:
    - Program Administrators (STEP or GIFT staff)
    - Fellows (STEP Fellows in their active year of work)
    - Other Tech (all other people at Georgia Tech)
- Within Westlake:
    - All Westlake people are grouped together

The measure of interest is the Point Connectivity between individuals in one subgroup across to a subgroup on the other side of the graph. In particular, one could think of a network as being "rich" if for any subgroup, there are several players within that subgroup who have high Point Connectivity with players in a subgroup on the other side. The rationale of this definition is that it means that there is enough redundancy in the social network that more than one player in any one subgroup can drop out without disrupting the whole network.

Looking at our networks, here is the range of Point Connectivity between Westlake and different Georgia Tech subgroups:

Table 2: Point Connectivity between Westlake HS and Georgia Tech Subgroups

Year 1		Program Admin.	Fellows	Other Tech
Range	Westlake	2-4	2-4	0-2
Number of pairs at highest or near highest level	Westlake	10	8	7
Year 3		Program Admin.	Fellows	Other Tech
Range	Westlake	1-5	1-2	0-2
Number of pairs at highest or near highest level	Westlake	4	24	6

Notice that in all cases, there is some level of redundancy - each of the subgroup to subgroup sets has a number of pairs that have a Point Connectivity of at least 2. This means that no connections between groups are particularly vulnerable to being broken if only one person leaves the network. In the cases of STEP Fellow to Westlake connections, the individual point connectivities decreased, but all of the Fellows had a point connectivity of at least two with all except two of the teachers. The decrease was due to the graduation from the program of a Fellow who had a particular zeal towards the act of connecting with people at the school. The two fairly isolated teachers who each connected with only one fellow through only one class clearly were not central players in the program.

The size of the network grew substantially between Years 1 and 3 in the "other Georgia Tech people" to Westlake connections. It is not surprising that the Point Connectivities did not grow at this time. Recall discussion above about the alternating phases of growth and increasing density - it is expected that this additional capacity of interested Georgia Tech people will get further utilized by Westlake in the future. For Program Administrators, all of the connectivities had at least a value of 2, except with the same two teachers for whom the fellows were not strongly connected. It is clear that these two teachers are only peripherally involved in the workings of the network and their connection is rather vulnerable. Other than these two teachers, there is only one other teacher with a point connectivity with a value of 2; with each STEP program administrator, the rest of the point connectivities with Westlake people are of values of 3 or higher. This shows these to be very secure connections. This analysis all illustrates that the network is indeed growing in richness through time.

Implications For, and Insights From, the Program Evaluator

A primary evaluation criterion for the STEP program is the development of a partnership between Georgia Tech and the associated high schools. From this perspective the use of graph theory and the tools of social network analysis provide a powerful set of indicators for observing growth in the relationship between the two institutions. While this does not provide sufficient evidence to determine whether a partnership has developed, it does provide evidence of growth in the level of connectivity between actors.

The term "partnership" is currently in vogue in education circles as a vehicle for stimulating and implementing innovations in professional and curriculum development, as well as engaging schools with universities and the surrounding community. *Partnership* is often defined as collaboration amongst actors who share similar or complementary goals (Sirotnic and Goodlad, 1988). Collaboration is predicated upon mutuality in the exchange of resources and communication through the partnership and a shared sense amongst the partners that their identity and capacity to achieve their individual missions is enhanced through participation (Brinkerhoff, 2002). It is not uncommon for partnerships to be strengthened by partners having some shared exposure to liability or a common threat (Carroll and Steane, 2000).

This conceptualization of partnership provides several factors that one might assess in the evaluation of partnership growth through the STEP program. We can (and do) assess the level of collaboration, the perceptions amongst partners of mutuality in interactions on STEP related activities, the perceptions amongst partners that their identity (either as an individual or an organization) is enhanced through participation, and the sense of shared burden or liability in the relationship.

The chief utility of social network analysis is that it provides a graphical and mathematical indicator of the types and amounts of connection that are occurring with STEP. The differences between Years 1 and 3 in the above figures provide evidence that the size of the partnership is growing in the number of connections between actors. The actor-activity matrices also provide evidence of the ways in which the connections increase and decrease according to the interests of the actors through which the connections are taking place.

For example, the change in the Georgia Tech –Westlake graphs from Year 1 to Year 3 indicate that teachers are taking advantage of additional opportunities from their exposure to Georgia Tech personnel such as the GIFT program. However, the replacement of one Fellow who was very active in making connections (particularly outside of the classroom through extra-curricular activities), with another who was less active is matched by a decline in the number of links in the associated matrix.

Social network analysis could also be used to demonstrate mutuality in the relationship. The above analysis does not take advantage of those aspects of graph theory that are directional in nature. The edges to the graphs can be endowed with a single arrow on one end of the edge, indicating that the relationship was unidirectional (i.e. communication from one actor to another with no return communication), or with arrows at both ends of the edge indicating a reciprocal relationship (i.e. the flow of communication was two-way).

Another aspect of the changing relationship that social network analysis has difficulty in observing are the perceptions of the individual actors with regards to identity enhancement or the shared sense of liability or threat. These are assessments made by participants concerning their perceptions of the quality of their relationship. However, one might be able to come closer to measuring qualitative assessments by asking respondents to provide a weight of a particular connection in terms of the identity enhancement.

One of the goals in building a partnership between Georgia Tech and Westlake is to improve the likelihood that the relationship will be institutionalized beyond the life of the NSF grant. Evidence of the growing points of connectivity outside of the STEP program personnel are indicative that progress is being made in building this aspect of the partnership. Removal of STEP personnel still does diminish point connectivity among actors. However, the growth in relationships between faculty at both institutions indicates that ties have been forged beyond the funded relationship. This gives no indication as to whether the connectivity will be sufficient to achieve institutionalization at some future date. However, the growth in relationships through STEP and outside of STEP should be considered positive developments towards the goal of institutionalization by creating internal constituencies in both partner organizations.

One concern from an evaluation perspective with the current approach of developing these graphs is the egocentric nature of the exercise to date. As was noted above, the matrices have been constructed largely through assignment by a single individual while using narrative evidence from STEP Fellow journals and conversations with teachers to supplement the record. However, this limitation is merely an artifact of the preliminary nature of the research as team members assess the feasibility and value of relational data and social network analysis. The quality of the evidence can be buttressed by drawing upon findings case studies and site observations to confirm the graphs.

Implications For, and Insights From, the Program Administrators

Much of this paper has concentrated on the use of these social network tools to assist in assessing the strengths (and perhaps weaknesses) of the networks that result from a GK-12 program. However, there is another very beneficial use of these tools. The program management (PI, Co-PIs, project directors, etc.) can use these methods as a form of compass when looking at their partnerships. The visualization helps to validate (or call into question) the management's intuition about why certain partnership teams are working well or struggling. The sense one has about why certain Fellows appear to be very successful, why particular teachers are getting a lot from their participation, or why teams are feeling underutilized or overwhelmed can all be tested by studying the social networks that represent their work. The data that is needed is already at hand, and it is very easy to get the basics out of the software. UCINET and Netdraw are very affordable and after just a bit of experimenting, one can create illustrations and calculate the basic measures. The effort is minimal compared with all of the required reporting for these programs and the payoff is potentially greater understanding, and at least an indication of next moves to improve the program's partnerships.

As mentioned earlier, GK-12 programs are required to submit basic network data annually to NSF, though it is not labeled as such. Many GK-12 programs also require Fellows to regularly reflect in electronic journals. One of the changes in data collection procedures that STEP will implement, in order to improve the quality of the available network data, is that Fellows will be required to fill out a simple online dataform monthly, in conjunction with submitting their journals, that simply indicates which people at the school they have interacted with, with a measure of frequency (to allow better quantification of the strength of the tie). The form will also request information about any other Georgia Tech faculty, staff or students who have visited or otherwise interfaced with the school. As part of the annual teacher survey, data fields will be added that encourage teachers to report all their connections with Georgia Tech. These rather simple changes in data collection should allow us to easily create and analyze social networks for each of our partner schools, and begin to try to correlate network, or partnership, health with desired partnership outcomes.

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