Paper ID #19072

Multidisciplinary Vertically Integrated Teams: Social Network Analysis of Peer Evaluations for Vertically Integrated Projects (VIP) Program Teams

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Abstract

Twenty-two colleges and universities have implemented the Vertically Integrated Projects (VIP) model, which consists of multidisciplinary teams, long-term large-scale projects led by faculty, the enrollment of students from different academic ranks, and the ability for students to participate for multiple years. At Georgia Institute of Technology, analysis of university exit surveys found VIP participation correlated with a meaningful effect size on three questions: the degree to which students' education contributed to their ability to work in a multidisciplinary team; their ability to work with individuals from diverse backgrounds; and their understanding of technology applications relevant to their field of study. Motivated by these findings, the VIP coordinators conducted a retrospective study of peer evaluations, applying social network analysis to quantify student interactions and identify patterns across the program. Results indicate that within the VIP Program, students interact more often with other majors and other races/ethnicities than their own major and race/ethnicity. Results support the findings of the previous study, providing evidence of VIP experiences related to working in diverse groups and in multidisciplinary teams. This paper reports the results of this analysis and plans for further work.

Introduction

Vertically Integrated Projects (VIP) is a project-based model for higher education that unites undergraduate education and faculty research in a team-based context. The VIP model was developed in 2001 at Purdue University, growing out of the Engineering Projects in Community Service (EPICS) program, which involved faculty led, project-based learning in vertically integrated teams, with "vertically integrated" referring to the inclusion of lower level and upper level students [1]. While EPICS projects focused on community service, VIP shifted the project focus to faculty research [2]. This increased both scalability and sustainability, as projects can be initiated in any discipline, and VIP teams' contributions to faculty research cultivates deep long-term faculty engagement.

The VIP model consists of seven key elements [3]. First, *projects are homed in faculty research*. This allows students to make meaningful contributions to ongoing projects, and it keeps faculty actively engaged. Projects are *long-term,* lasting many years, if not indefinitely. The long-term nature is similar to environments students will encounter in the workplace, with new-hires navigating existing projects. Projects are also *large-scale,* with an average team size of sixteen students. This allows faculty to tackle larger projects than otherwise possible with graduate students alone. Like most work environments, VIP teams are *multidisciplinary*. This is a particular strength of the program, as large-scale problems invariably cross disciplinary boundaries and require knowledge and skills form multiple domains. As already mentioned, VIP teams are also *vertically integrated*, enrolling lower and upper level students. This allows students to participate for multiple semesters, and it cultivates an environment of peer-leadership. Returning students assist in on-boarding new students, and take on increasing levels of responsibility. A key aspect of VIP is that the program is *curricular*, with students earning academic credit and letter grades. Students c*an participate for multiple semesters and years*, earning one to two credits each semester, and more credits when used to fulfill Senior Design or Culminating Design requirements. This allows students to apply their VIP experiences toward graduation requirements and increases student engagement.

The VIP program at Georgia Tech currently enrolls 640 students on forty-one teams, drawing instructors from five of the six colleges on campus and students from twenty-nine majors. Through the application approval process, approvers seek to maintain a mix of sophomores, juniors and seniors on each team, as well as a variety of majors. Typical teams consist of ten to twenty students, which ensures enough students return the following semester to maintain continuity. Newer teams are typically smaller, providing a more manageable size for new instructors. Larger teams, like section VPU in Figure 1, are led by multiple faculty members, typically from different departments. Figure 1 illustrates the multidisciplinary nature of the teams, showing enrollment by team and student major.

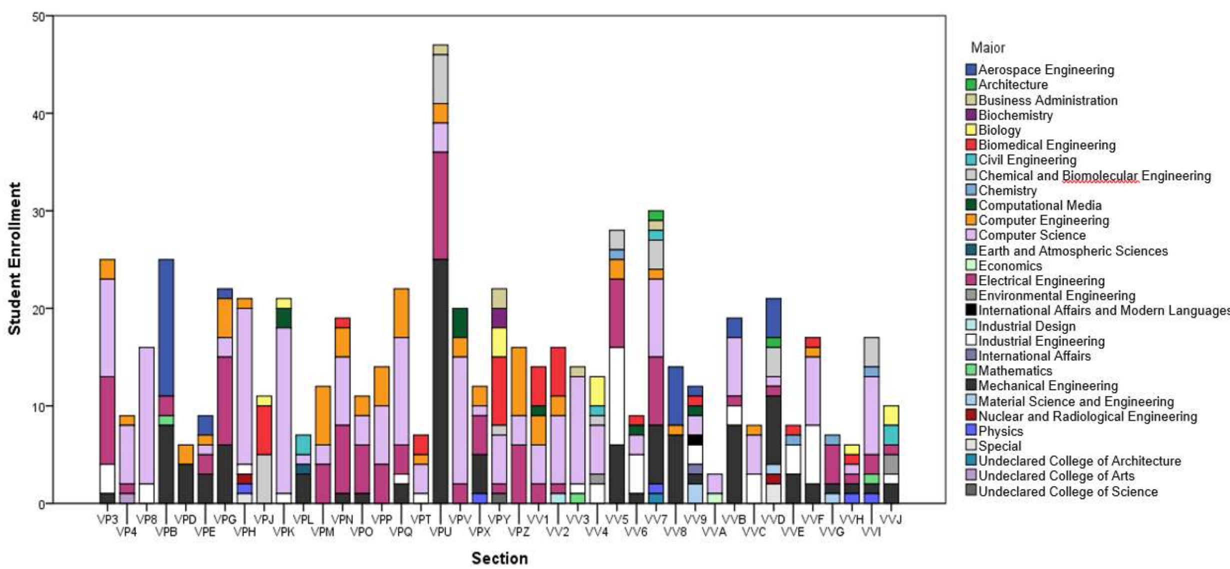

Figure 1: Georgia Tech VIP Student enrollment by team and academic major, Spring 2016

Course Elements

VIP courses are run much like research groups. Weekly team meetings consist of updates, planning and coordination. Students are usually divided into subteams, which either meet weekly outside of regularly scheduled class time or at the end of team meetings, depending on team size and meeting length. Students take the course for one to two credit hours per semester (three for Senior Design), and they are expected to put in three to six hours of work outside of the main team meeting each week, with the subteam meetings counting toward these totals.

In the first year of team startup, the onboarding process falls largely to the professor and graduate students. For this reason, some departments provide release time for one course in the first year of running a VIP team, to give faculty time to establish their teams. In the second and later semesters, instructors would have returning students assist in the onboarding of new students. Students may develop tutorials, startup modules, or quizzes on team documentation. As new students work through onboarding materials, they're encouraged to think about how they would improve them, so they can contribute to subsequent updates and revisions.

A key to successful teams is rigorous documentation. Unlike an academic lab, in which a student will document his or her work solely for the professor, VIP students' work advances a larger project and has an engaged audience. If a student writes code or modifies a piece of equipment, current and future students will need the documentation. To manage documentation, instructors and teams establish repositories that will not be affected by the academic calendar. At Georgia Tech, the VIP program provides team wikis, and teams have access to a campus hosted GitHub. In addition to serving as a team repository, the wiki also allows faculty to view contributions by user, which is useful in grading. Additionally, students maintain VIP notebooks in which they document their meetings, tasks and progress, and the notebooks are key to the feedback and grading process.

VIP students are graded and receive feedback twice each semester, at the middle and end of the semester. At both grading times, students turn in their VIP notebooks and complete peer evaluations on their teammates. Results of peer evaluations are not numerically tied to students' grades; instead, they provide another level of input for instructors. Students are graded in three equally weighted areas: teamwork, documentation, and contributions to the project. Feedback provided at midterms is advisory, and is intended to help students improve by the end of the semester. Expectations for students increases with academic rank, with the number of credits taken, and with the number of semesters involved with VIP.

Research Questions

The VIP model relies heavily on student-to-student interaction. Experienced students assist in on-boarding new students; subteams collaborate on specific aspects of the project; and students provide support and hold each other accountable. Teams resemble small start-up companies, with employees doing what needs to be done and learning as they go. The VIP team structure maps well to the concept of social networks, where ties between individuals allow resources to flow through the network [4]. In the case of VIP, these resources include technical knowledge and advice. In 2012, Melkers applied social network analysis methods to an evaluation of VIP [5]. Her study examined the degree to which enthusiasm, number of semesters of participation, seeking advice, and being a resource for others correlated with self-reported learning gains. Results indicated that students who serve as resources for other students did not report greater learning gains, but greater gains were reported for students who sought help from others more often. As would be expected, students who participated for more semesters reported greater learning gains, as did students with higher enthusiasm.

Seeking to quantify the impact of VIP participation on student outcomes, the Georgia Tech VIP Program requested an analysis of university exit surveys for VIP participants. VIP Program staff identified seventeen survey questions that related to aspects of VIP. Exit survey results were compared for VIP participants and non-participants. Results indicated statistically higher scores and meaningful effects on three items [6]:

To what degree did your Georgia Tech education contribute to your:

- Ability to work in a multidisciplinary team ($t(1982) = 4.437$, $p < 0.001$, $d = 0.313$);
- Ability to work with individuals from diverse backgrounds ($t(1987) = 3.271$, $p = 0.001$, $d = 0.231$);
- Understanding of technology applications relevant to your field of study ($t(2002) = 3.19$, $p = 0.001$, $d = 0.224$);

Motivated by these findings, this study sought to use social network analysis to quantify aspects of VIP participation related to the first two items above: working with individuals from diverse backgrounds, and working in multidisciplinary teams. Of particular interest is how often students interact with other students like themselves, as compared to interactions with students who are different from them with respect to academic major and background. We attempted to operationalize "diverse backgrounds" as race/ethnicity, gender, and student status as domestic or international. Based on these categorizations, we sought to answer the following research questions:

How do students in VIP teams interact with teammates with respect to the following student and teammate attributes:

- Academic major?
- Race/ethnicity?
- Status as domestic or international student?
- Gender?

Methods

This was a retrospective study of student peer evaluations administered in spring of 2016, making use of web-based peer-evaluation results, student demographic records, and VIP enrollment history. This study focused on the first question in the peer evaluation, which presents students with a list of teammates, and asks how often they interact with each. The lowest score corresponds with "I do not know this person," and the highest score corresponds with "more than weekly." After responses to the first question are submitted, names receiving the lowest possible score are not included in the remaining questions, so students do not evaluate teammates they do not know. Students can navigate back to this question to change their answers, effectively choosing who they do and do not evaluate.

In social network analysis, individuals are treated as nodes, and reported connections (interactions) are treated as ties. Analysis was conducted with UCINET, a social network analysis software package. The study focused on the question, "How often to you interact with each person below." On a Likert scale of one to five, one corresponded to not knowing the person. To handle the lowest score as no connection in UCINET, the responses were recoded from a scale of one to five to a scale of zero to four, with zero representing no connection. Data is handled in matrices, with rows typically representing "senders" and columns representing "receivers." In this case, the rows and columns represented reviewers and reviewees respectively. With a row and column for every member of the network, the matrices are square.

Because the research question focuses on student-level experiences, the initial analysis employed ego networks. While whole-network studies consider aspects of the full network such as size, density and connectedness, ego network analysis handles calculations for each node in a stand-alone system with ego in the center of a network of his or her connections. Calculations are made for each node based on its ego network, disregarding the composition of the rest of the network. A secondary analysis moved away from ego networks and looked at interactions within each team. This analysis sought to determine if interactions within a given team correlated with student attributes (major, race/ethnicity, etc.).

As done in Melker's study, the EI index was chosen to quantify student interaction between subgroups [5]. The EI index compares an individual's connections with individuals like themselves (internal ties) and his/her connections with those who are different (external ties). The calculation of the EI index is shown in Eq. 1, with variables defined in Table 1. The EI index ranges from -1 for someone who only interacts with people like him/herself, to 1 for someone who only interacts with people who are different. Zero would represent a perfect balance between internal and external ties. The standard EI index dichotomizes the data and does not take the strength of ties into account. A tie either exists or does not, with a value of one (exists) or zero (does not exist). To account for tie strength, UCINET offers a command line function that handles valued ties. In this case, the variables a and b represent sums of tie strengths instead of the number of ties. In the standard EI index, all ties are equal, with a value of 1 or 0. In the valued EI index, ties maintain their values, with 1 for infrequent interaction and 4 for interacting more than weekly. Both the EI index and valued EI index were used in the analysis, to provide a more comprehensive description of interactions.

Eq. 1.

$$EI = \frac{b - a}{b + a}$$

Table 1: Ties used in the calculation of EI index and Yule's Q

		Alter Attribute	
		Same as Ego	Different from Ego
Ego	Tie	a	b

To achieve valid results, analysis was only conducted for teams with peer evaluation completion rates of 80% or higher, the lowest acceptable threshold for Social Network Analysis. The initial data set consisted of 32 teams and 484 students. Of these, 24 teams had completion rates of 80% or higher, leaving 355 students.

Data in the analysis was reconstructed to minimize the effect of students who did not submit evaluations. In social networks, ties can be directed, with one student giving advice to another student, or undirected, with two students interacting. When working with undirected ties, answers from one student can be used to replace missing data for a non-respondent [4]. For example, if student X reports interacting with student Y, and student Y did not complete the survey, it would be reasonable to assume that student Y would have given a similar answer. The substitution is not perfect, as student X may value the interaction differently than student Y, but it is better than recording the missing tie as nonexistent or removing the node entirely [4].

Because the data used zeros to represent the absence of a relationship, zeros were maintained as values and were not replaced with corresponding teammate responses. So if a student indicated that he/she did not know another student, those values were left as zeros and not treated as non-responses.

Analysis across the full data set was conducted for each categorization: major, race/ethnicity, international/domestic status, and gender. In each analysis, an EI index and valued EI index were calculated for each student, and means were calculated for the population. While EI indexes offer insight into typical student interactions, standard statistical software packages cannot be used to determine whether differences between groups are significant. This is because conventional analysis methods assume that measurements are independent of each other. This is not the case in social network analysis, because measurements are done between students. Student A's network is interconnected with student B's, making them dependent. To determine whether differences between groups are significant, UCINET provides equivalent tests that utilize permutations [4, 7]. To determine if differences in student interactions were correlated with student traits, UCINET's Quadratic Assignment Procedure (QAP) was used. The QAP correlation yields a Pearson's coefficient along with a measure of significance [7]. Whereas EI indexes were calculated for individual students, the QAP method was applied to and reported for team networks. Team sizes are not reported to maintain confidentiality.

While EI indexes describe student experiences, the QAP correlation indicates whether interactions within a team correlate with the trait in question (major, sex, etc.), so the two were considered together. As an example, if a team had ten men and two women, we could consider a case in which all of the students interacted with all of their teammates. For the men, this would yield EI indexes near -1 (homophily). For the women, this would yield EI Indexes near 1 (heterophily). Because there are substantially more men than women, the mean EI index would be near -1. While the EI index describes the interactions, it does not necessarily imply preference or bias, because it does not take subgroup size into account. A QAP analysis would indicate whether there is a statistically significant correlation between interactions and gender. In the case of the hypothetical team, if the two women only interacted with each other, and the men only interacted with men, the QAP analysis would show statistically significant correlation between gender and interaction. If on the other hand the women were fully integrated into the team as considered above, a QAP analysis would show no statistical significance, despite the EI index being near -1. The EI index is important in understanding student experiences across the program, but the QAP analysis is important in identifying statistical significance based on team member attributes and team interactions.

Results

To measure interaction within and across groups, EI indexes were calculated for each student on each of four categorizations: major, race/ethnicity, sex and domestic/international status. Two EI indexes were calculated for each student, with a standard EI index and a valued EI index. For the standard EI index, ties are dichotomized, meaning students interacted (value of 1) or did not interact (value of 0). For the valued EI index, ties are weighted by tie strength, with tie strength corresponding to frequency of interaction (1 for infrequent interaction, and 4 for interacting more than weekly). An EI index of -1 represents perfect homophily, with the given student only interacting with classmates from the same category. For example, a computer science (CS) student with an EI index of -1 would have only interacted with other CS students. An EI index of 1 represents perfect heterophily, with the given student only interacting with students from other majors. In the previous example, the CS student might have interacted with electrical engineering and mechanical engineering students, and wouldn't have interacted with any other CS students. An EI index of zero would indicate a perfect balance, with equal interaction with similar and dissimilar teammates.

As shown in Table 2 and illustrated in Figure 2, on average, students interacted with students from other races/ethnicities slightly more than with their own race/ethnicity, with a mean EI index of .215. When the frequency of interaction was taken into account, the EI index decreased to .169, indicating slightly more frequent interactions with students of the same ethnicity. The difference (.046) did not bring the index below zero, still indicating slight heterophily.

For interactions between students of different majors, the mean EI index was .200, indicating that students interacted with other majors more than their own. When the frequency of interaction was taken into account, the valued EI index decreased more than it had for race/ethnicity (difference of .110), showing more frequent interactions within majors. Again, the valued EI index still stayed above zero, with a mean of .090, again maintaining heterophily.

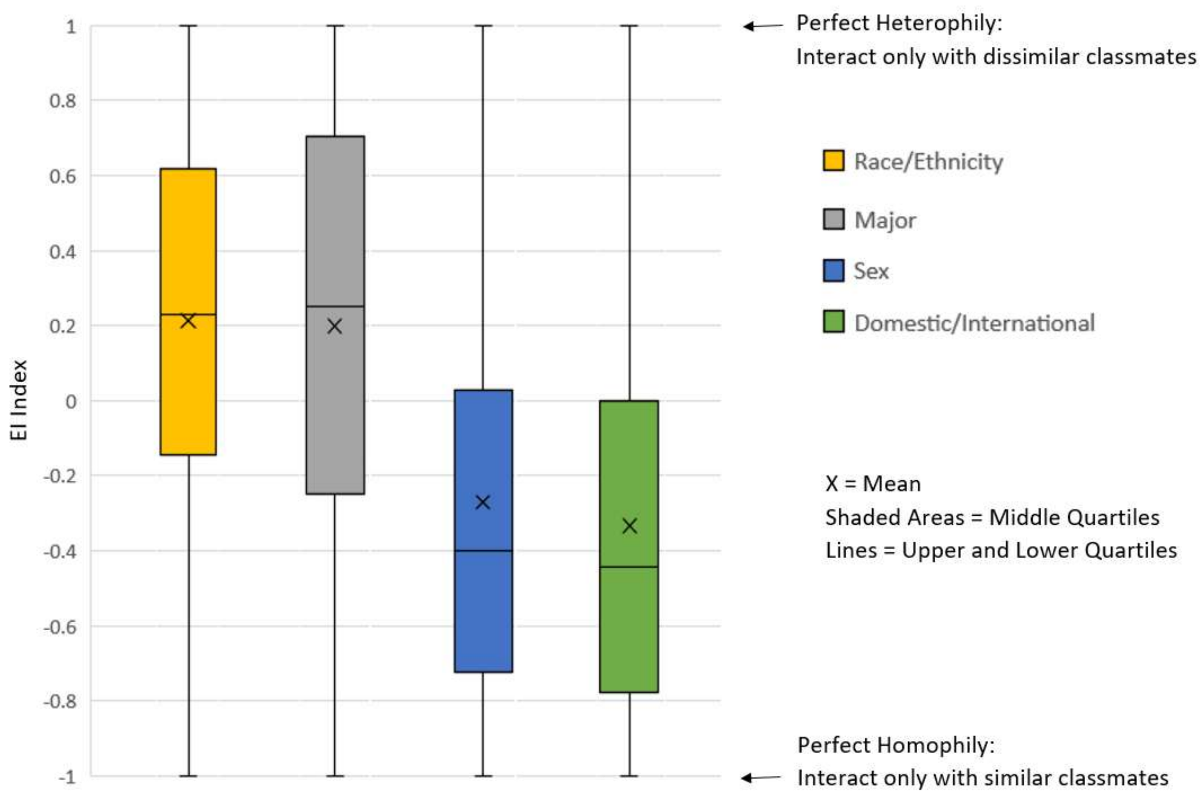

Figure 2: EI Indexes: A Measure of Student Interaction within and across Categorizations
EI Indexes are based on non-valued ties (i.e. whether interaction was reported or not)

Table 2: EI Indexes by Categorization

Attribute	N	EI Index Mean	EI Index SD	Valued EI Index Mean	Valued EI Index SD	Difference between Means
Race/Ethnicity	355	.215	.549	.169	.640	.046
Academic Major	355	.200	.607	.090	.674	.110
Sex	355	-.270	.643	-.292	.643	.022
Domestic/International	355	-0.323	.574	-.325	.626	.002

Table 3: QAP Correlations for each Categorization by Team▲

	Race/Ethn		Major		Gender		International	
Team	Coef	P	Coef	P	Coef	P	Coef	P
Team 1	-0.048	.364	0.073	.190	0.098	.167	-0.006	.572
Team 2	0.028	.404	0.314	.054	0.081	.288	-0.079	.458
Team 3	-0.268	.010	0.253	.031	0.020	.454	0.111	.108
Team 4	-0.044	.397	-0.169	.019	0.196	.048	-0.026	.426
Team 5	-0.075	.105	0.286	***	0.051	.336	0.011	.469
Team 6	0.111	.141	0.122	.107	0.124	.095	0.038	.209
Team 7	-0.087	.305	0.16	.151	0.039	.356	0.066	.425
Team 8	0.029	.425	0.171	.087	-0.071	.296	0.095	.243
Team 9	0.137	.108	0.042	.368	-0.041	.384	-0.054	.329
Team 10	-0.075	.594	0.766	.083	-0.075	.607	-0.201	.407
Team 11	0.016	.378	0.197	**	0.012	.396	0.156	.052
Team 12	0.096	.184	0.429	**	0.041	.372	0.017	.443
Team 13	-0.099	.098	-0.038	.361	0.066	.234	0.243	**
Team 14	0.041	.294	0.037	.315	-0.007	.502	0.055	.255
Team 15	0.037	.244	0.412	***	0.109	.109	0.029	.354
Team 16	0.049	.304	-0.106	.155	0.264	.013	-0.146	.057
Team 17	0.100	.227	1	1	0.127	.165	-0.032	.457
Team 18	-0.055	.345	-0.135	.089	-0.193	**	0.06	.253
Team 19	0.311	**	0.155	.031	-0.064	.175	-0.06	.210
Team 20	-0.084	.264	0.158	.090	0.101	.154	-0.056	.469
Team 21	0.214	.048	0.111	.262	-0.138	.108	0.176	.040
Team 22	-0.048	.330	0.366	**	0.262	.014	1	1
Team 23	0.206	.297	0.105	.486	0.171	.595	0.043	.594
Team 24	0.027	.324	0.396	***	0.100	.040	-0.073	.155

▲ Team sizes are not reported to maintain confidentiality

* $P < .05$

** $P < .01$

*** $P < .001$

The EI index for sex showed homophily, with a value of -.270. This indicates that students interacted more often with their own gender than with other genders. When frequency of interaction was taken into account, the index again decreased (valued EI index of -.292 and a decrease of .022), showing slightly more frequent interactions with students of the same gender.

The mean EI index for domestic versus international student status also showed homophily, with a value of -.323. When tie values were taken into account, the index showed a negligible difference, with a mean valued EI index of -.325 and a decrease of .002.

To determine whether student traits correlated with student interaction at the team level, QAP correlations were run on each of the four categorizations for each team. Correlations between interaction and attribute were significant in nine cases (Table 3). For race/ethnicity, there was statistical significance for team 19. For student status as domestic or international, there was statistical significance for team 18. For sex, there was statistical significance for team 13. Significance was most common by academic major, with a total of six teams: teams 5, 11, 12, 15, 22 and 24.

Discussion

In the semester studied, students interacted more with students from other majors than their own major. These results held true both when interactions were treated as present or not present, as well as when the frequency of interaction was taken into account. The difference between the mean EI index and mean valued EI index indicates that of the students interacted with, there were more frequent interaction with students of the same major. With this difference taken into account, students still interacted more often with students from other majors. The difference between the EI indexes by major was the greatest difference across the four categories studied. The QAP analysis, which measured the correlation between student interactions and students' majors within teams, found statistically significant correlations between major and student interaction for a quarter of the teams. The correlations for these six teams ranged from a weak correlation of 0.197 for team 11, to a moderate correlation of 0.429 for team 12. Differences in interaction by major were not unexpected, as students from the same major may work more closely within a given team. The EI indexes indicate substantial interaction between students of different majors across the program, but the QAP analysis indicates than on a quarter of VIP teams, major has statistically significant correlations with student interaction.

In considering race and ethnicity, students interacted more with students of other races/ethnicities than of their own. These results held true both when interactions were counted as present or not-present, as well as when the frequency of interaction was taken into account. The difference between the EI index and valued EI index indicate slightly more frequent interactions between students of the same ethnicity, but even with this difference, students still interacted more often with other races/ethnicities. The QAP correlation found significance between race/ethnicity and student interactions for one team (team 13). Together, the EI index and QAP correlations across the twenty-four teams indicate substantial interaction between students of different races/ethnicities, with an exception of one team. The results for this team will be further examined, with assistance and interventions offered as appropriate.

In the case of sex and of domestic versus international status, students interacted more often with their own gender and with students who were similarly domestic/international. The difference between the means for EI index and valued EI index for sex was small, indicating that of the individuals students interacted with, they interacted slightly more frequently with their own gender. The difference on these measures for domestic versus international status was negligible. It is worth noting that unlike academic major and race/ethnicity, the categories of sex and domestic/international are dichotomous, with only two possible values for each. In this case, even with effective integration, small subgroups would yield negative EI indexes. QAP correlation showed significance for one team for interaction by sex, and for one team for interaction by domestic/international status. Together, the negative EI indexes paired with low significance across the program point toward unbalanced subgroups by gender and domestic/international status (yielding negative EI indexes), yet effective integration of smaller subgroups into their respective teams (yielding low significance).

This study was motivated by results from a previous analysis of exit surveys, in which VIP students reported higher abilities in working in multidisciplinary teams and working with individuals from diverse backgrounds. The analysis of peer evaluations above provides evidence of student experiences that would contribute to these findings.

Further Work

This paper reports on a retrospective analysis of student peer evaluations utilizing social network analysis, quantifying student interactions that may contribute to stronger skills in working with diverse individuals and in working on multidisciplinary teams. The next phase of research will be aimed at faculty professional development, with an eye toward equity. This will include visualizations of the results of this study, to aid in the interpretation of statistically significant and non-significant correlations. This is of particular interest for teams showing significance for correlations between student interaction and student demographics (race/ethnicity, sex, and domestic/international status). By pairing deeper analysis with discussions on team management methods across the program, we hope to identify effective VIP team management methods. Results will be used to provide additional faculty professional development and instructional support.

The current study focuses on a single question in the peer evaluation. Additional analysis will be conducted on other questions to examine mentoring within teams, as well as the ways in which team networks change over time. The overall goals will be to understand the dynamics across the program and to provide instructors with effective feedback and support.

On a larger scale, VIP programs are in place at 22 institutions of varying sizes and compositions in the U.S. and abroad, and the VIP Consortium continues to expand [8]. Social network analysis can serve as a useful metric for institutions seeking to similarly quantify student interactions within their VIP teams, and it can create a foundation for further dialog on effective instructional practices.

Conclusion

This study sought to quantify interactions within the VIP Program that would support students' ability to work in multidisciplinary teams and to work with individuals of diverse backgrounds. While the peer evaluations were designed to support instructor grading and feedback, the resulting data captures a snapshot of student interactions and team networks. Results of this study indicate that in the VIP Program, students interact with students of different majors and of different races/ethnicities more than their own major and race/ethnicity. These findings reinforce results of an analysis of GT exit surveys for VIP and non-VIP participants. In that analysis, VIP participants reported higher abilities in both areas, with meaningful effect sizes for both. The results of this study are compelling, because they confirm that the VIP implementation at GT is providing truly multidisciplinary experiences, while creating an environment that crosses racial and ethnic boundaries.

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