AC 2012-5300: THE SOCIAL WEB OF ENGINEERING EDUCATION: KNOWLEDGE EXCHANGE IN INTEGRATED PROJECT TEAMS

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The Social Web of Engineering Education:
Knowledge Exchange in Integrated Project Teams

ABSTRACT

Engineering education is evolving to become an environment of project-based learning, research assistantships, and other mechanisms that approximate the research and collaborative aspects of true-to-life processes. From this diverse set of learning environments, students are expected to not only gain technical skills, but also social and group skills relevant to the realities of collaborative work in engineering. This expectation is in turn underscored by ABET accreditation standards, which extend beyond simply technical skills to include the development and learning of professional skills. In this paper, we ask: From an instructional perspective, how can learning outcomes be better observed so that faculty can provide appropriate guidance and occasional control? What are the sources of this diversity of learning within student groups? How do the ways that engineering students interact in team network environments matter for the skills that they develop through this experience? Scholars working in the science of learning argue that peer-relations form a social context of knowledge creation that constitutes a foundation for the development of team-skills. In this paper, we show how peer relations develop, and subsequently provide knowledge and learning resources within multi-ranked student teams over time. The data in this paper are based on a multi-year evaluation of the NSF-funded Vertically Integrated Projects (VIP) Program at two institutions. The VIP Program brings together graduate and undergraduate students to solve applied engineering problems. Results show different patterns of knowledge seeking and exchange behavior across student groups. These results show that technical knowledge sources are distinct from project management and related information needs. Most interestingly, results show that knowledge exchange does not maintain its hierarchy. Undergraduate students develop their own information communities within teams, including regarding technical information. These results have important implications for the management of teams that include a range of students and expertise.

INTRODUCTION

The days of the lone inventor have been eclipsed. Modern innovations – from space exploration to the Internet – are the result of collaborations of hundreds of organizations and many thousands of people. These collaborations generate the networks of knowledge and skills that foster the ideas, technologies, and products needed for global-scale innovation. In response, student learning in engineering is increasingly conceived as a process and experience that is situated in a "complex web of social organization," that is situated in the collaborative and social environment of applied engineering work [20]. In order to prepare for this this collaborative environment, students are expected to learn not only technical skills, but also managerial skills and related capacity [19]. Discussion in the profession is that students' ability to recognize the contextual nature of knowledge and use evidence with a level of sophistication characteristic to the engineering profession is critical to their success [15].

The community of engineering educators has recognized that these goals cannot be achieved with the traditional knowledge-transmission based instructional methods alone, and that the effective learning experiences are those that support the development of expert professional practice [27]. Modifications of engineering instruction settings include movement to project-based learning, research assistantships, and other mechanisms that approximate the research and collaborative aspects of true-to-life processes. These active learning experiences typically focus on applied problems, which are important for the development of professional capabilities. Some experiences may be more cooperative and team based, whereas others may involve one-on-one collaboration of a student and faculty member.

For team-based research and project experiences, skill development extends beyond technical skills to the social aspects of collaboration and team interaction. The core of cooperative learning is the promotion of learning through providing *cooperative incentives* rather than competition. In many ways, this emphasis on team work in engineering schools has evolved to embrace not only different approaches to formal learning through classroom and various applied experiences, but also the informal learning that takes places outside of structured activities. Students experience "social learning" [3, 4, 41] by watching and observing others. From this diverse set of learning environments, students are expected to not only gain technical skills, but also social and group skills relevant to the realities of collaborative work in engineering. This expectation is in turn underscored by accreditation standards of ABET, which include the development of professional skills.

The increased emphasis on the "complex web of social organization" in engineering education via project-based learning, rather than one that is limited to "shifts in the mental structures of a learner" [20], has led to the development of instructional methods that emphasize learning facilitation. These methods have become increasingly common and have replaced the traditional methods that were primarily focused on knowledge transmission [39]. These methods are intended to develop managerial, team, and life-long learning competences in engineering graduate education that approximate the research and collaborative aspects of true-to-life processes [34, 19].

These **active learning** experiences, such as project-based learning, research assistantships, and other mechanisms, typically involve peer interactions, and the creation of social communities that focus on applied problems, important for the development of professional capabilities [34]. Yet, evidence of the actual outcomes of these active learning experiences is limited. Engineering education research indicates that instructors who use these methods face several challenges related to monitoring the learning progress and assessing its outcomes [40]. The challenge is presented by the social environment in which this learning takes place – not all variables affecting learning outcomes can be easily observed and successfully controlled by instructor. Further, some aspects of these active learning outcomes are primarily linked to student attitudinal changes, behavioral changes in study habits and related interactions and other outcomes not measured through improved test scores [34].

An expectation of collaborative learning environments is that learning is based on knowledge and experience that emerges from participation and interaction in the group itself. Knowledge may be gained by interacting with different individuals, and be distributed across the group, rather than provided through a traditional instructor-student relationship. In this paper, we address the knowledge flows that exist in student collaborative learning networks. We ask, what are the sources of knowledge in these student collaborative environments? Are knowledge flows fairly hierarchical, moving from advanced students to those less experienced, or are they more distributed? How does the way in which students interact within the group matter for student learning? The results of this work have implications for engineering instruction, illustrating that learning outcomes can be better observed, possibly enabling faculty to provide appropriate guidance and occasional control in team environments. Scholars working in the science of learning argue that peer-relations form a social context of knowledge creation that constitutes a foundation for the development of team-skills. In this paper we show how peer relations develop, and subsequently provide knowledge and learning resources within multi-ranked student teams over time.

Student learning in collaborative environments

Learning outcomes in team-based engineering educational environments is based on the broad spectrum of positive **active learning** experiences that involve peer to peer interactions and real life problem solving [34], and that are important for both the development of professional capabilities [31] and for the retention of students in engineering programs [5]. In their studies of collaborative interaction, Katz and Martin [24] noted the "need to work in close physical proximity with others in order to benefit from their skills and tacit knowledge." In social network terms, this implies instruction within a defined and deliberately conceived network, or project team.

A "social network" refers to a set of individuals or entities that are connected by sets of ties, where the ties represent different types of relationships [41]. Within a network, individuals gain access to resources through those ties, some of which provide more access to resources than others [41]. In collaborative student teams, peer-relations and informal social structures that emerge from these relations, or network ties, is a source of student learning [18, 20]. The structured peer-relations support student learning by enabling exchange of knowledge and expertise between students, and by allowing for interactions between peers of different intellectual development. Within this context, individuals can freely seek advice, information, and assistance to help them in their work, where advice is a "subset of general knowledge generation in which individuals seek or give specific assistance" [30]. Individuals seek advice to fill gaps in their knowledge, to obtain information, and learn about opportunities in order to more quickly solve problems or take advantage of opportunities [30].

Thus, another expectation is that in the team environment, students will use one another as resources and, in this exchange, further their own learning. Peer-relations form a social context of knowledge creation that enables exchange of expertise [18] and constitute a foundation for the development of team-skills [21]. Problem-solving is used to provide the context and motivation for the learning, to develop skills of solving open-ended problems and to engage in continuous learning). Importantly, problem based-learning implies significant amounts of self-directed learning on the part of the students [31].

Through joint work, new students are able to access the tacit knowledge accumulated in the team, and more experienced students assist in guiding others, acquiring leadership skills necessary for team management [13, 16]. The value of "learning by teaching" is often discussed in the academic setting as a lifelong process in which faculty engage. Do students also learn by "teaching" or assisting others?

An assumption and expectation of the peer learning environment is that peer interaction is in fact beneficial to all involved. Peer advising or instructing refers to the concept of *learners advising other learners*. The goal of such learning process is to "require each student to apply core concepts being presented and then to explain those concepts to their fellow students" [12]. Such an approach to learning has shown substantial and significant positive effects [38, 39] on a range of learning outcomes, such as performance on quizzes [36],clinical practice [37], problem solving ability [10], increase of student grades as well as student retention [8, 33]. Therefore we hypothesize that:

H1: Students to whom other students turn for help in the student team environment will experience greater learning outcomes than students who do not serve as frequent resources for other students.

The pedagogical goal of collaborative interdisciplinary problem-based learning is to develop skills of solving complex real-life engineering problems [34, 27]. The real-life engineering problems typically are ill structured, knowledge solving knowledge is distributed between the team members and beyond the organization, and solution of these problems requires extensive collaboration [22, 23]. The process of solving such problems is iterative and can be conceived as a design process [22]. In this, problem-solving skills include communication and ability to locate and access necessary expertise [23]. These skills also include whole-brain iterative thinking skills (analytical, sequential, imaginative, and interpersonal) [28].The interpersonal thinking refers to the interactive processes in which problems or ideas are formulated and refined [28].

For example, in one study of mathematical learning, peer discussions of problems were found to enhance calculus instruction [29]. While the exchange of expertise between students is an important element of the collaborative, interdisciplinary problem based learning process ([18], the expectation is that it is a relationship where "everyone wins." In other words, not only do the students who "teach" or provide information to others gain, as discussed above, we also expect that those students who actively engage with their peers in the problem-solving process and seek for advice and help from their peers will report higher levels of learning outcomes. Therefore we hypothesize:

H2: Those students who actively seek out advice and problem-solving help from their peers will report higher learning on a range of learning outcomes than those who do not.

Yet, within a student group, there may be variations in confidence and intellectual maturity. For example, junior students are likely to believe in the certainty of knowledge and omniscience of authority, whereas more senior students have learned to recognize the contextual nature of knowledge and to gather and use appropriate evidence to support their judgments, as well to question their judgments in the light of the available evidence [15]. This variation reflects, for example, empirically observed differences in the breadth of problem scoping between junior and senior undergraduate students [2]. In more general terms, learning is also well recognized to be a cumulative process, where information, social learning, and other resources combine and accumulate over time [5, 32]. Therefore we hypothesize that:

H3: Students who are engaged in long-term projects will report high levels of learning than those who have been engaged for shorter periods of time.

Finally, in any educational environment, faculty can structure classroom setting, substantive projects, and other interactions to maximize learning and knowledge flows. Yet, at some level, the extent to which students engage in the work can also have a relationship to what they gain, and learn, from the experience. An important implication of the variation in intellectual maturity is that students vary in the terms of their enthusiasm in working with high-level open-ended problems, and, therefore, require different types of mentoring and support that peers can provide to each other [14]. Engineering education researchers point at the importance of the meaningfulness of the teamwork and students motivation for both enhanced learning outcomes and student retention [15, 7]. According to the theory of student involvement, the greater the student's involvement in college, the greater will be the student learning and personal development. Therefore, the effectiveness of any educational practice is directly related to the capacity of that practice to increase student involvement [1]. There is a broad consensus that student motivation is a perquisite of learning success [5], A high level of motivation is often a prerequisite for success. There is a thus high probability that learning will not be successful if there is a lack of motivation. Therefore we also hypothesize that:

H4: Students with higher levels of enthusiasm for the project will report higher learning outcomes.

Data and Analysis:

The data in this paper are based on a multi-year evaluation of the NSF-funded Vertically Integrated Projects (VIP) Program [11], which brings together graduate and undergraduate students to solve applied engineering problems. A common evaluative approach to student learning experiences involves student surveys that not only address satisfaction, but also some self-assessment of learning [9]. Other techniques involve ethnographic observation of student behavior and interaction in ways that may reveal learning over time [6]. This evaluation study is structured to collect student reported data regarding their self-assessment of skill development and its applicability overall as well as in their coursework.

In the VIP Program, student projects are designed so that graduate students can assume leadership roles, and, thus, gain experience in real-time project planning and implementation and management of multidisciplinary teams. The Vertically-Integrated Projects (VIP) Program [11] is an undergraduate education program that operates in a research and development context. Undergraduate students that join VIP teams earn academic credit for their participation in design efforts that assist faculty and graduate students with research and development issues in their areas of technical expertise. The teams are: multidisciplinary - drawing students from across engineering and around campus; vertically-integrated - maintaining a mix of sophomores through PhD students each semester; and long-term - each undergraduate student may participate in a project for up to three years and each graduate student may participate for the duration of their graduate career. As shown in Table 1, the VIP Program has grown over time, with year-end enrollment and composition data shown below. In 2010-11, Morehouse College, a Historically Black College/University also joined VIP.

Table 1:
VIP Program Enrollment and Size

	Georgia Institute of Technology				**Purdue University**				**Morehouse College**	
	S2010		**S2011**		**S2010**		**S2011**		**S2011**	
	N	%	N	%	N	%	N	%	N	%
Number of teams	5		10		10		11		1	
Number of faculty	9		13		15		17		1	
Number of students	45		109		53		71		8	
Graduate Students	13	29%	16	15%	13	25%	6	8%	-	0%
Undergraduates (UG)	32	71%	93		40	75%	65	92%	8	100%
UG Student : Faculty ratio	4:01		7:01		3:01		4:01		8:01	
Freshmen/ Sophomore	6	13%	15	14%	8	15%	5	7%	-	-
Junior	8	18%	34	31%	8	15%	21	30%	-	-
Senior	18	40%	44	40%	24	45%	39	55%	-	-
New to project	20	44%	96	88%	53	100%	63	89%	8	100%
Women	8	18%	33	30%	7	13%	14	20%	0	0

More specifically, the continuity, technical depth, and disciplinary breadth of the VIP teams are intended to:

- Provide the time and context necessary for students to learn and practice many different professional skills, make substantial technical contributions to the project, and experience many different roles on a large design team.
- Support long-term interaction between the graduate and undergraduate students on the team. The graduate students mentor the undergraduates as they work on the design projects embedded in the graduate students' research.
- Enable the completion of large-scale design projects that are of significant benefit to faculty research programs.

There are 12 VIP teams at Georgia Tech for the Spring 2012 semester. Their titles and goals are:

- *Collaborative Workforce Team*: Design and test multimedia systems, web-based applications, and human-computer interfaces to support the distributed design and research teams that are the future of the global engineering workforce.
- *eDemocracy Team*: Design and create devices, systems, processes and policies for both secure, authenticated voting procedures and citizen participation in government.
- *eStadium Team*: Design and deploy smartphone apps/games, websites, wireless networks, and sensor networks to gather and deliver game and venue information to football fans in the stadium on gameday.
- *Intelligent Tutoring System Team*: Design, test and use systems to enhance student learning in Tech courses by applying techniques that include video and data mining, artificial intelligence, machine learning, and human-computer interfaces.
- *Computational Structural Biology Team*: Develop software and web-based tutorials to facilitate the understanding of basic principles of macromolecular simulations and their application to research problems in structural biology.

- *eCampus Team*: Design, develop, and deploy mobile wireless applications for the use of visitors, students, faculty, staff and administrators on the Georgia Tech ATL campus.
- *Intelligent Transportation System*: Analyze the performance and energy efficiency of existing transportation scheduling algorithms, and then design and implement better ones, for the Tech Trolley and other systems at and around Georgia Tech.
- *Medical Devices for the Treatment of Diabetes*: This project combines materials processing, human factors design, biological activity, and chemistry to create a solution for the millions of people with diabetes.
- *I-Natural*: Design, build, and test interfaces that enable humans to naturally interact with robots (whether physical or virtual) in performing activities of daily living.
- *USLI Rocket Team*: Design, build and launch a reusable rocket with a scientific or engineering payload to one mile above ground level.
- *Brain Beats Team*: To understand the neural basis underlying the human ability (or lack thereof) to keep "rhythmic time," i.e., a constant cadence.
- *GTRI Robotics Team*: Development of critical technologies for prototype robotic/unmanned systems.

VIP Programs exist at Georgia Tech, Purdue University and Morehouse College and are the focus of the study reported in this paper. A new VIP program started this semester at the University of Strathclyde in Scotland: http://www.strath.ac.uk/viprojects. Full information on the teams listed above is available at: http://vip.gatech.edu.

The evaluation of VIP took place over two years and was primarily based on a longitudinal survey of VIP students, supplemented with student interviews/focus groups as well as interviews with VIP faculty (in the second year). The survey was conducted in the Spring of 2010 and then repeated in 2011. In the spring semester of 2011, 109 students from the Georgia Institute of Technology (Georgia Tech) and 71 from Purdue University were surveyed, of which 160 responded (96 for Georgia Tech and 64 for Purdue) responded, for an overall response rate of 89%. Of these, 89% are undergraduates, reflecting the overall composition of VIP. In this paper, most data analysis (with the exception of the social network data) are reported for undergraduates only. The small number of graduate students does not allow for statistical comparison. Additionally, although 8 students were surveyed (and 6 responded) at Morehouse College, those data are not included here due to our interest in addressing institutional effects. The small number of students from Morehouse College also does not allow for statistical comparison.

An important aspect of the survey is that it included a series of detailed social network questions that allow for the quantification of relationships among VIP students, both across all teams as well as within teams. Through the use of detailed survey questions, respondents indicate specific relationships and the nature of exchange with their VIP colleagues. For example, students were first asked who they knew from a roster of VIP students. Then for each of the students that they knew, they were asked about how frequently they communicate with each person, to whom they go to for technical and other advice, and other interactions. From these, a range of details about student relationships may be captured using a survey structure typical for social network analysis to assess ties, linkages, and the strength of those linkages within an organizational environment [6, 41].

While network graphics provided in this paper are visually interesting and informative, certain statistics allow for a meaningful comparison of network dynamics. In the networks displayed in this paper, we provide statistics for five standard network-level metrics: number of ties, average degree centrality, external-internal index for campus, and external-internal index for discipline, as well as other relationships [41,25]. More specifically:

- *Number of Ties* measures the number of linkages between VIP students. This measure reflects the size of the network.
- *Average Degree Centrality* measures the average number of immediate connections that each individual has in the network. This measure allows for some consideration of the level of participation in network activity by the 'average' person in the network.
- *External Ties*, which is measured using what is called the external-internal (E-I) Index [26] captures the extent to which the collaborative network is made up of individuals outside as compared to inside a particular environment or context. In this paper, we report the E-I index for a) cross VIP team interaction, b) cross (student) rank interactions (undergraduate-graduate), and c) gender in order to address integration of women in the network interactions. Further, because these are longitudinal data, we also calculate the E-I index for students who were engaged in VIP in the first year to address whether newer students are being actively integrated into the student networks. The EI index is calculated as: (external ties – internal ties) / (external ties + internal ties) and ranges from negative one to one, with a negative score indicating that collaborators within groups are more strongly represented, and vice versa.

To support the analysis, network visualizations were developed using *NetDraw* to accompany the networks statistics. Overall, the patterns of nodes and ties should be visually interpreted together with the network statistics in order to understand the dynamics of the individual networks. Together these measures provide a useful descriptive characterization of the nature of the network, and the relationships within that network. Over time, changes in these statistics may be observed and used to develop a better understanding of the ways in which individuals are linked within the VIP Program. In the two years of the evaluation, they provide an early indication of time within this framework, which provides the foundation for the analysis presented in this paper. Finally, their meaning must be then interpreted in light of organizational goals and objectives.

Finally, the variables used in the analysis in this paper are provided in Table 2. While not shown here, there are no significant differences in any of the key dependent variables by institution, suggesting that there is no inherent institutional bias in the analysis.

Table 2: VIP Student Survey Respondent Descriptive Data					
Variables	N	Mean	SD	Min	Max
<u>Technical Skills</u>					
experimentation and data analysis & interpretation	140	4.24	1.14	2	6
engineering design	137	4.45	1.11	2	6
programming and designing computing algorithms	140	4.05	1.38	2	6
understanding computer and communication hardware and systems	140	3.86	1.41	2	6
Applied problem solving	140	6.98	1.66	3	9
<u>Managerial & Other Skills</u>					
working on a multi-disciplinary team	138	2.22	0.66	1	3
working on a project team within my discipline	138	2.42	0.64	1	3
communicating technical concepts and designs to others	138	2.44	0.60	1	3
writing professionally	138	1.95	0.70	1	3
making professional presentations	138	2.20	0.66	1	3
planning a long term project	138	2.31	0.64	1	3
managing a project team	137	2.18	0.69	1	3
resolving team conflicts or disagreements	138	2.14	0.61	1	3
collaborating on project team solutions	137	2.39	0.57	1	3
coordinating activities with project members in remote locations	138	1.82	0.75	1	3
communicating and clarifying technical issues with team members in remote locations	138	1.88	0.77	1	3
giving an effective presentation to an audience with both remote and local participants	138	1.99	0.73	1	3
<u>Student Interaction & Enthusiasm</u>					
Number of VIP students sought for advice	142	1.59	1.83	0	10
Number of VIP students asking for advice	142	1.20	1.27	0	7
VIP Enthusiasm	133	6.71	1.58	2	8
Prior Experience					
Research assistant for a faculty member	140	0.26	0.44	0	1
Worked on a project team as part of your employment	140	0.36	0.48	0	1
Participated in project in 2009/2010	142	0.07	0.26	0	1
<u>Demographics & Other Characteristics</u>					
Georgia Tech	142	0.59	0.49	0	1
Team is new in 2011	142	0.38	0.49	0	1
Team Undergraduate Student: Faculty Ratio	142	7.65	3.11	1.5	14
Female	142	0.26	0.44	0	1
Junior	142	0.35	0.48	0	1
Senior	142	0.51	0.50	0	1

FINDINGS

VIP Student Learning Outcomes

An essential aspect of the VIP Program is the vertical integration of students. Through this innovative integration, students are expected to learn important technical skills and knowledge, but also learn about the "grey matter" of collaborative interactions and team management. This is consistent with ABET guidelines, which include "an ability to identify, analyze, and solve broadly-defined engineering technology problems" (ABET general criterion 3f) as well as other professional skills.

To address these learning outcomes, students were asked to indicate the extent to which their VIP team experience helped them to gain a set of specific technical skills, as well as other collaborative and managerial skills and knowledge. They were provided with a set of skills and asked the extent to which they agreed that participation in VIP had helped them to develop these skills. We provide a summary of these responses by showing the mean responses for this four point scale.

(Overall, students overwhelmingly agree, on both campuses and in both years of the VIP Program, that participating on their VIP team has yielded important practical and technical skills (Figure 1.) In this figure, the Georgia Tech teams (in blue) and the Purdue teams (in green) show slightly different behavior. Lighter colors reflect the first survey period, and the darker blue and green reflect the second survey period. This allows for the comparison of skill gains from student's VIP experience over the course of the funded period. Importantly, students seem quite enthusiastic about the applicability of those skills in real world settings.

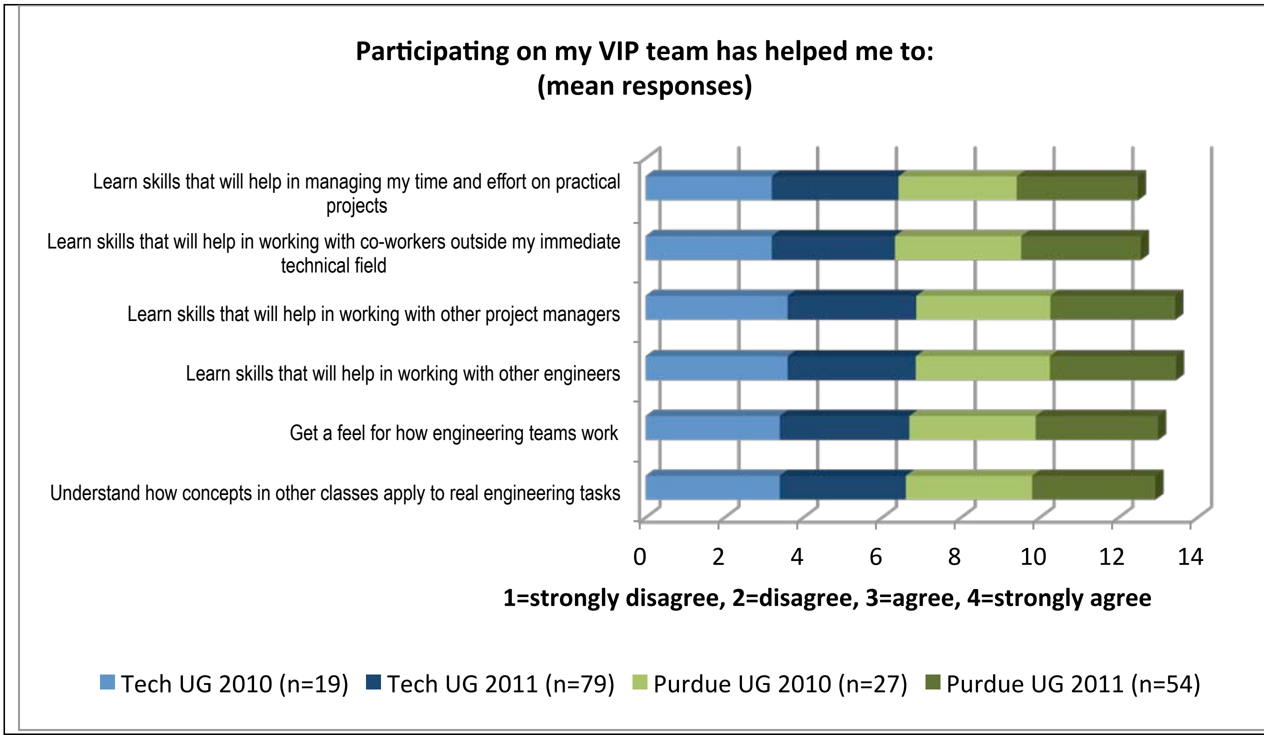
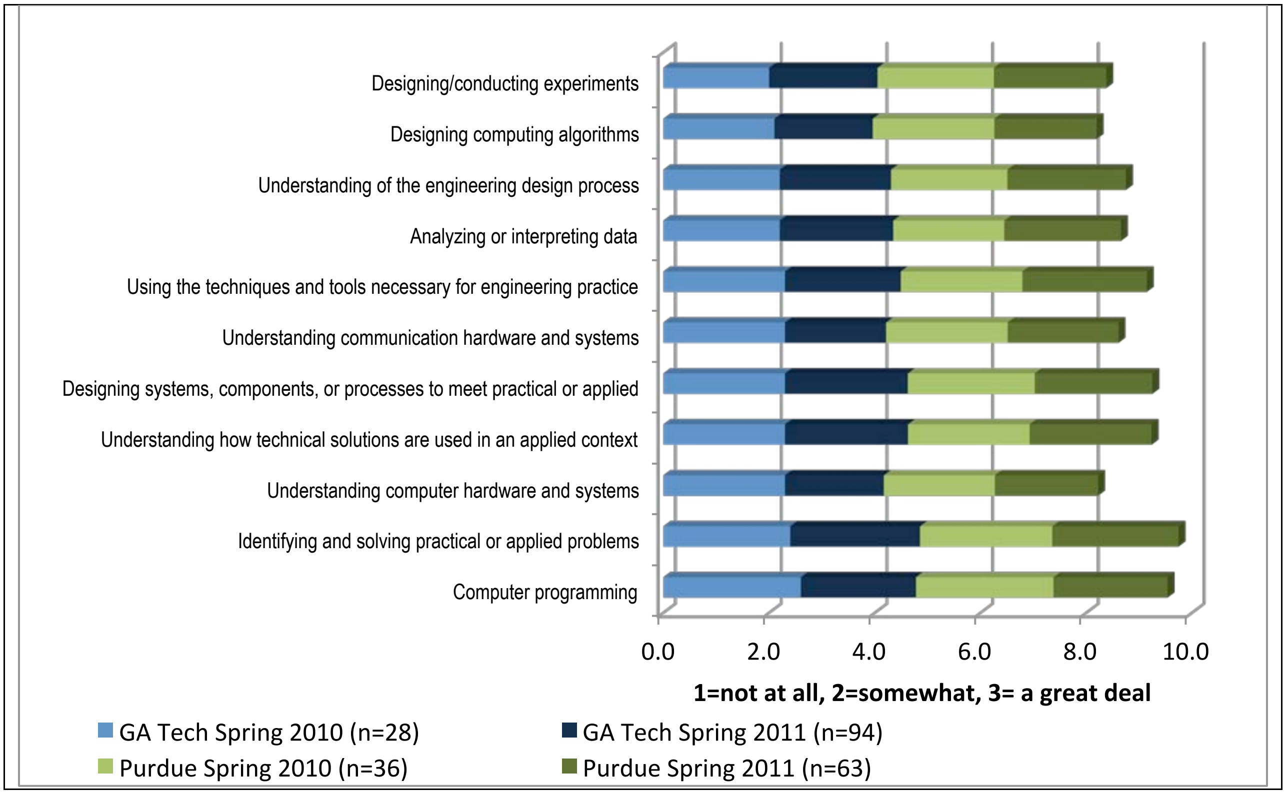


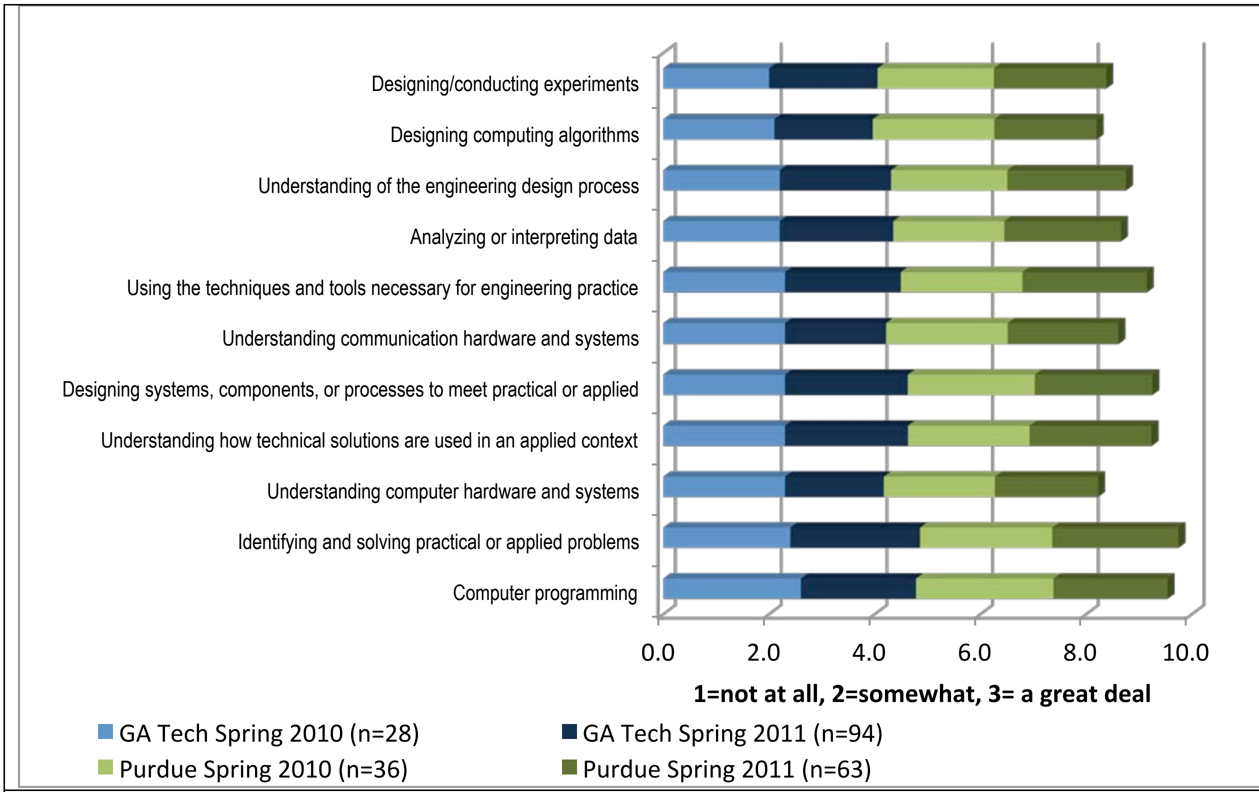
Figure 1: Respondent Self Report of Technical Skills

More specifically, as shown in Figures 1 & 2, students have consistently reported skill development attributable to their VIP team experience, both in terms of technical information, as well as other aspects of the collaborative experience. Students were asked "How much has your VIP experience helped in the development of these (technical and other) skills? Students were asked to indicate whether VIP contributed "not at all", "somewhat" or "a great deal." As shown in the mean responses shown in Figure 2, there is some variation across schools (GA Tech = blue and Purdue = green) as well as skills sets, but not dramatically so.

For example, the VIP teams at Purdue are closed disciplinarily and in terms of technical skills. Thus, fewer Purdue respondents indicate that they have gained skills in working on interdisciplinary teams. Team coordination and planning are noted in both years for both Purdue and Georgia Tech. Further, while these questions yielded relatively consistent and positive results, they may not portray the full range of outcomes that students have experienced.

In addition to close-ended data shown here, the surveys also included a series of open-ended questions that allowed students to indicate and elaborate on what they had learned and gained from their VIP experience. Those qualitative results were consistent with the quantitative data shown here.





How much has your VIP experience helped in the development of these (technical and other) skills?

Figure 2: Respondent Self Report of Other Skills

In addition to the self-assessment of their own skills, the baseline survey asked students to identify other VIP students who were "most important in providing advice or assistance" regarding a set of specific issues related to their VIP Project. These data were important in assessing the resources and learning environment of the VIP teams. It is based on the idea that if students are to learn from one another in an integrated environment, that they be aware of, and access those resources. Given the collaborative learning objectives of VIP, these resources are critical in fostering learning within the teams. Unlike the self-assessment of skills, this line of questioning addresses the behavioral aspects of their VIP experience specific to seeking knowledge resources critical to their learning experience. Using a common social network methodology, students were given a roster of VIP students and asked to indicate from whom they had sought assistance or advice regarding the following specific areas:

<u>Technical Information:</u>
- Technical advice (computer programming, hardware details, etc);
- Advice about engineering concepts (algorithm design for software, hardware infrastructure understanding);
- Advice about technical applications;

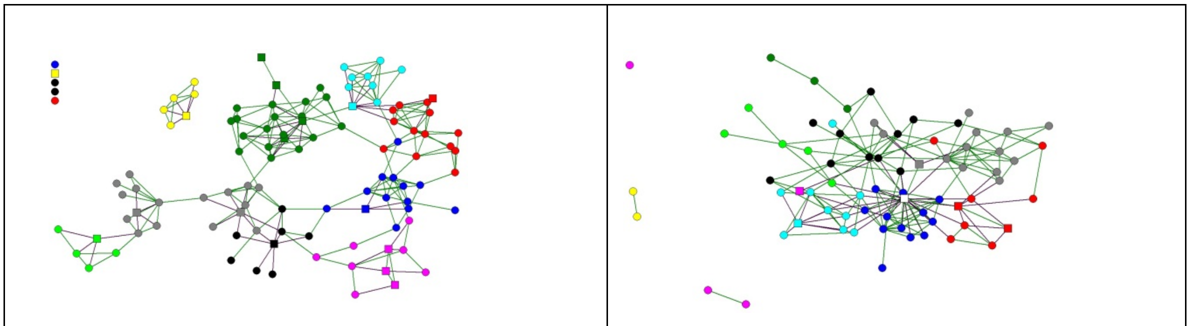
<u>Managerial Information:</u>
- VIP team management issues; and
- Advice about VIP project goals and purposes.

Here, our analysis showed some important findings. As shown in Figure 3, results show students actively interact on both campuses regarding both types of advice, technical as well as managerial. First, looking at all technical ties (the first 3 items above) shows that the number of individuals with whom students interact in this way has increased slightly as the program has grown. The E-I index for some items has become more positive, showing more integration across gender and teams. Students at Purdue are slightly more interactive across graduate and undergraduate student ranks.

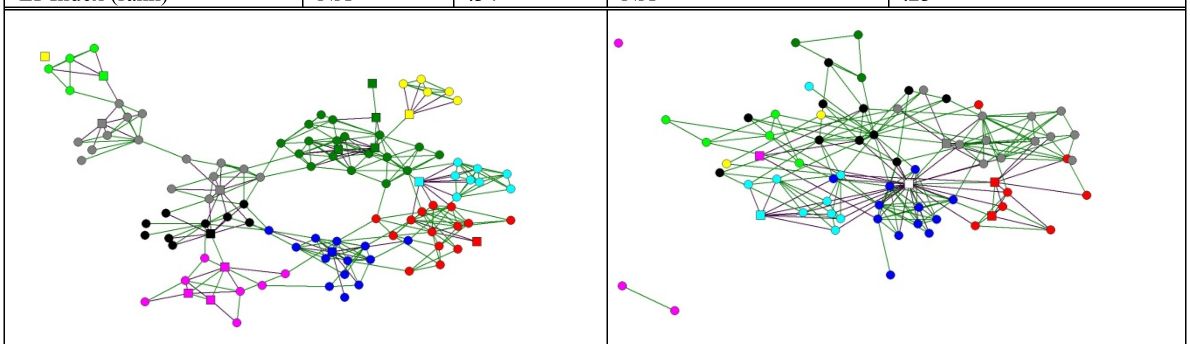
Combining these data with the managerial advice above shows that students tend to developed about 2-3 sources of advice on average. This suggests that students are interacting to address not only technical solutions but also other aspects related to the process of research and team management.

One expectation might be that graduate students are knowledge leaders in VIP, and serve as the primary resources for the range of advice and assistance noted above. Our findings support this in part, but highlight the important peer exchange that happens among undergraduate students. The data show (Figure 3) that advice-based ties flow not only between undergraduate and graduate students, but that the undergraduate students are also engaging across rank regarding technical and project management information and assistance. (Note that the statistics provided in these figures were defined earlier in this paper.)

Interestingly, while it is expected that information should flow within each VIP team, results show that ties also exist across teams at both institutions. Looking at undergraduate students only, reveals interaction across undergraduate sophomore, juniors and seniors. When categories of the individual interactions are examined (not shown here due to space limitations) results show that undergraduate interaction occurs across all categories of advice and assistance – both technical and managerial in nature. Overall these results show that the VIP Program is showing integrative activities, across undergraduate and graduate ranks, but also across undergraduate ranks as well.



All technical advice: **Georgia Tech**			**Purdue**	
	Spring'10	Spring'11	Spring'10	Spring'11
Number of Ties	69	263	77	193
Density	.03	.02	.03	.04
Mean centrality	1.51	2.41	1.45	2.72
N. centrality	15.1%	7.1%	8.9%	14.9%
EI-Index (team)	-.91	-.80	-.58	-.40
EI-Index (UG-G)	-.32	-.51	-.23	-.47
EI-Index (year/VIP1)	.09	-.67	NA	-.43
EI-Index (gender)	-.62	-.18	-.68	-.48
EI-Index (rank)	NA	.34	NA	.23



All advice: **Georgia Tech: All Students**			**Purdue: All Students**	
	Spring'10	Spring'11	Spring'10	Spring'11
Number of nodes	45	109	53	71
Number of ties	124	336	148	235
Mean centrality	2.75	3.83	2.79	3.31
EI-Index (team)	-.66	-.79	-.58	-.36
EI-Index (UG-G)	-.35	-.52	-.23	-.47
EI-Index (year)	.03	-.64	NA	-.44
EI-Index (gender)	-.47	-.19	-.67	-.47
Georgia Tech: Undergraduates Only			**Purdue: Undergraduates Only**	
	Spring'10	Spring'11	Spring'10	Spring '11
Number of nodes	33	93	40	65
Number of ties	77	245	72	167
Mean centrality	2.33	2.25	1.92	2.35
EI-Index (team)	-.66	-.80	-.69	-.59
EI-Index (year/VIP1)	.04	-.72	NA	-.65
EI-Index (gender)	-.38	-.20	-.72	-.45
Green line: within students year Purple line: across students year Node colors: VIP Teams			Diamond: Freshmen or sophomore Circle: Junior Square: Senior	

"Who among the following did you tend to turn to for advice on the following issues related to your VIP Project?"

Figure 3: Advice-Based Ties in VIP

Factors Affecting Student Learning in VIP

Finally, while descriptive results provide some important formative input regarding trends and changes over time in VIP, we were also able to develop a series of explanatory models to better understand the factors that matter in determining different levels of skill attribution. In order to address the relative effects of various factors on student learning, we developed a series of explanatory linear regression models. As a caveat, and reflective of the exploratory nature of this early evaluation, student learning is a self-assessment, and is also focused only on the VIP experience. Specifically, students were asked: "How much has your VIP experience helped in the development of your technical skills in the following areas?" and then provided with a set of items. These items were combined summatively in the categories in Table 3. A second set of questions addressed other skills, including managerial and team related skills, as noted in Tables 4 & 5. These variables served as the dependent variables for the following regression analysis. Results are presented in Tables 3-5.

The model for all dependent variables is as follows:

Skill = f(outdegree + indegree network variables + time on project + student rank + gender + institution + student enthusiasm + prior research/team experiences + student faculty team ratio.

A core network variable in this model was presented in the earlier network graphics in this paper. Using the social network methodology, students were given a roster of VIP students and asked to indicate from whom they had sought assistance or advice regarding the following specific areas:

<u>Technical Information:</u>

- Technical advice (computer programming, hardware details, etc);
- Advice about engineering concepts (algorithm design for software, hardware infrastructure understanding);
- Advice about technical applications;

<u>Managerial Information:</u>

- VIP team management issues; and
- Advice about VIP project goals and purposes.

From these data, the "number of other VIP students sought for advice" variable reflects the "outdegree" network ties of the respondents, reflecting the magnitude of ties identified by the respondent from whom they seek advice or assistance on the above items. Conversely, the "number of VIP students asking respondent for advice" reflects the "indegree" network relationship, or the magnitude of the times other respondents have identified an individual as someone from who they seek advice or assistance.

The regression analysis shows some interesting results. First, for the first hypothesis, we suggested that students who teach others learn. We expected that the students who serve as a resource for other students learn through the process of guiding them, addressing questions and challenges, and overall gain a range of skills through their experience. Our results show that this is not the case. Students identifying the respondent as a source for any of the technical or other information discussed in the prior section is not significant for any of the dependent variables. This is somewhat surprising, and may suggest that students who are more capable may need additional challenge in this setting.

Table 3: Regression Models: Respondent Self-Reported Technical Skills										
How much has your VIP experience helped in the development of these technical skills?										
	Experimentation and data analysis & interpretation		Engineering design		Programming and designing computing algorithms		Understanding computer and communication hardware and systems		Applied problem solving	
	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Number of other VIP students sought for advice	**0.09**	^	**0.06**		**0.06**		**0.23**	***	**0.18**	**
Number of VIP students asking respondent for advice	-0.11		-0.02		-0.09		0.10		-0.11	
Georgia Tech	-0.23		-0.06		0.10		-0.10		-0.10	
Participated in project in 2009/2010	**0.62**	^	**0.74**	*	**1.31**	**	**0.63**		**0.88**	^
Team is new in 2011	**0.17**		**0.04**		**-0.93**	***	**-0.69**	***	**-0.16**	
# of undergraduates per faculty	-0.04		-0.05		0.06		-0.03		-0.07	
Female	-0.04		0.22		-0.34		-0.25		-0.15	
Junior	0.02		0.18		0.22		0.19		0.22	
Senior	0.21		0.25		0.05		0.11		0.19	
Student Enthusiasm for VIP	**0.30**	***	**0.30**	***	**0.17**	**	**0.23**	***	**0.45**	***
Research assistant for a faculty member	0.20		-0.04		0.39		0.11		0.09	
Worked on a project team as part of your employment	**0.16**		**0.33**	^	**-0.09**		**-0.18**		**0.80**	***
Control: Freshman or Sophomore										
Adj R-squared	0.20		0.26		0.16		0.21		0.24	
N	133		130		133		133		133	
P<0.1=^ , P < 0.05= *, P < 0.01 = **, P<0.001=*										

Our second hypothesis was that students who seek advice from others learn more than others who do not seek the same degree of advice. Here, the results are quite different, showing important positive effects of this advice seeking behavior on self-assessment of both technical skills, as well as other team-work related skills.

Addressing the length of time that a student had been affiliated with VIP in our third hypothesis was significant and positive for technical skills, some communication skills, and also team skills. These preliminary results suggest that cumulative learning has occurred in VIP, which is consistent with the social learning literature.

Our final hypothesis addressed individual issues. Are students who are more “bought in” to the project more likely to get something out of it? Certainly more engaged students are open to knowledge, learning, and may be more motivated in general. The regression results show this to be consistently true across the various skills.

Finally, the regression results also provide some interesting insights based on the control variables. Most markedly, we do not observe that students with prior research experiences in the form of research assistantships (which are roughly one quarter of our respondents) have any significant effect on skill attainment, with the exception of project planning. For students who have worked on project teams in their jobs, there are some positive effects, although limited to applied problem solving. We see no institutional effects, nor student rank effects in the self-assessment of learning in any of the skill areas. Regarding team characteristics, we do observe lower reports of learning by members of VIP teams that were new in the second year of the grant. This also supports in part the cumulative learning aspect of this work. There are some moderate gender effects, with female students more likely to report increases in communication and planning skills.

Table 4: Regression Models: Respondent Self-Reported Technical Skills						
How much has your VIP experience helped in the development of these other skills?						
Other skills: communication-related						
	communicating technical concepts and designs to others		writing professionally		making professional presentations	
	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Number of VIP students sought for advice	0.04		0.05		0.04	
Number of VIP students asking for advice	0.04		0.00		0.05	
Georgia Tech	-0.05		-0.19		0.11	
Participated in project in 2009/2010	0.27		0.48	^	0.57	**
Team is new in 2011	-0.02		0.21		-0.02	
# of undergraduates per faculty	0.00		-0.02		-0.06	**
Female	0.28	**	0.24	^	0.21	^
Junior	0.07		0.32		0.15	
Senior	0.01		0.11		0.05	
Student Enthusiasm for VIP	0.17	***	0.09	**	0.10	**
Research assistant for a faculty member	0.00		0.25	^	0.02	
Worked on a project team as part of your employment	0.03		-0.19		-0.11	
Control: Freshman or Sophomore						
Adj R-squared	0.22		0.10		0.16	
N = 133 for all models						
P<0.1=^, P < 0.05= *, P < 0.01 = **, P<0.001=*						

Table 5: Regression Models: Respondent Self-Reported Technical Skills												
How much has your VIP experience helped in the development of these other skills?												
Other skills: teamwork-related												
Variable	working on a multi-disciplinary team		working on a project team in my discipline		planning a long term project		managing a project team		resolving team conflicts or disagreements		collaborating on project team solutions	
	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.	Coef.	Sig.
Number of VIP students sought for advice	**0.05**	^	**0.04**		**0.07**	*	**0.03**		**0.06**	*	**0.05**	^
Number of VIP students asking for advice	0.02		0.02		-0.02		0.10	*	0.06		0.03	
Georgia Tech	0.42	***	0.04		0.14		0.12		-0.04		0.02	
Participated in project in 2009/2010	0.38	^	0.48	*	0.20		0.35		0.19		-0.05	
Team is new in 2011	0.05		0.08		0.03		0.12		0.08		0.04	
# of undergraduates per faculty	-0.03		0.00		0.00		-0.02		-0.01		-0.03	
female	0.17		-0.05		0.23	*	0.14		0.14		0.16	
Junior	-0.10		0.36	*	0.09		0.13		-0.08		-0.04	
Senior	-0.04		0.18		0.08		0.01		-0.14		-0.13	
Student Enthusiasm for VIP	**0.09**	**	**0.12**	***	**0.15**	***	**0.12**	***	**0.09**	**	**0.10**	***
Research assistant for a faculty member	**0.06**		**0.03**		**-0.03**		**0.28**	*	**0.18**		**0.13**	
Worked on a project team as part of your employment	-0.01		0.06		0.02		0.15		0.01		0.09	
Control: Freshman or Sophomore												
Adj R-squared	0.14		0.10		0.17		0.17		0.08		0.10	
N = 133 for all models												
P<0.1=^, P < 0.05= *, P < 0.01 = **, P<0.001=*												

Conclusion

The purpose of the data analysis presented in this paper was to provide an example of an evaluative process, and preliminary findings, of an innovative engineering team learning program. Data were drawn from repeated surveys of student participants and included detailed social network items. The structure of the data collection process, and subsequent analysis, were designed to collect self-reported skill assessment data, but also data on the social structure and resource-based connections on the teams. The findings showed that on both the Georgia Tech and Purdue campuses, the VIP Program has been effective in recruiting new students and in meeting many of the student's expectations in terms of their learning and skill development. Overall, the evaluation of the Phase I VIP Program showed that undergraduates are gaining important technical, as well as management and collaborative skills through their experience.

These results provide evidence that the VIP program has been successful at fostering the creation of knowledge networks that include the students, graduate students, and faculty on each team. They also demonstrate that these networks extend across teams and across institutions, thus creating the type of "innovation network" that characterizes the current global economy [35].

Finally, our results have implications for the evaluation of team based student teams. Effective useful and meaningful evaluation of student-teams must address the social aspects of learning in addition to technical assessments. This acknowledges the social aspects of collaborative work, and the added benefits and skills that derive from team participation. Developing detailed survey instrumentation that includes some aspect of behavioral analysis in the form of student interaction can significantly extend our understanding of student effects. However, a weakness of the analysis presented here is that the skill assessment would be more robust and meaningful if additional information on other team experiences were integrated in the analysis. Additionally, as VIP expands and this exploratory evaluative process is refined, a control group will also be included in the overall design in order to control for various effects on the student experience. And, finally, because the relationships shown in this paper only reflect activities on two campuses, the specific results about student effects should be used cautiously and as a tool to inform future evaluative processes. These are exploratory findings that may not be generalizable to other institutions or other pedagogical approaches.

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