Team-based Software/System Development in a Vertically-Integrated Project-Based Course

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Abstract - **We use per-student virtual machines to allow new students to configure servers, thus enabling them to develop an understanding of the complex eStadium system. The outcomes include: student learning as the per-student virtual machines progress into software development and production machines supporting the eStadium game-day environment; the teamwork and leadership skills that evolve as students progress from initial learning to leadership roles in the creation of sophisticated applications; guidelines for instructors mentoring students through the process of building and maintaining a working production system; and, parallels with best-practice software and system development in industry. The use of peer-evaluations and social-network studies enable us to determine how the students interact with and learn from each other across years (sophomores through seniors). This cross year, cross experience-level learning process is essential for maintaining the technical and team continuity of the project. It also prepares students in a very realistic way for the software-development process in industry.**

Index Terms – software development, virtual machines, peer-based learning, project-based learning

INTRODUCTION

The Vertically-Integrated Projects (VIP) Program [1-2] is an undergraduate education program that operates in a research and development context. Undergraduate students that join VIP teams earn academic credit for their long-term participation in design efforts that assist faculty and 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 studies.

The VIP Program is based on the idea that the learning success of engineering students is based on the broad spectrum of positive **active learning** experiences that involve peer to peer interactions and real life problem solving [3] that are not only important for development of professional capabilities [4], but also for the retention of students in the engineering programs [5]. The core of cooperative learning is the promotion of learning through providing cooperative incentives rather than competition. 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 [3]. Through joint work, new students are able to access the tacit knowledge accumulated in the team, and more experienced students acquire leadership skills necessary for management of the teams [6,7]. More specifically, the continuity, technical depth, and disciplinary breadth of these 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.

eStadium [8-10] is a Vertically-Integrated Project (VIP) team at Georgia Tech that currently consists of 20 undergraduates, four graduate students, and three faculty. The team creates systems that gather multimedia content from the stadium, process it and deliver it to the smart-phones of fans in the stadium. This content includes video-clips of plays, real-time stats, drive-visualizations, etc. The technology areas covered by the project include video capture/processing, wireless networks, and sensor networks.

Faculty involvement is generally limited to oversight and high-level advisement coupled with limited technical assistance. Students enroll in VIP for up to six semesters, so each semester involves new students and experienced students working side-by-side. Bringing new students up to speed on the many skills required, while also channeling them into technology areas that align with their interests and need additional effort, requires a different approach than traditional coursework. This is particularly true for the areas of system architecture and administration because they are rarely taught in depth in the undergraduate curriculum. They require a complex set of skills that can only be honed via hands-on experiences that involve a certain amount of trial and error. Such trial and error is typically not acceptable in a production environment, yet supporting live users brings many challenges that are otherwise difficult for learning suitable skills in designing, configuring and supporting operational systems. In this paper, we present how students work together to achieve complex goals that exceed the scope of material directly presented to them, specifically in the areas of software development, computer systems management, and operational support. While the following model has been applied to several VIP teams, this paper focuses on the eStadium team as an in-depth example.

eStadium uses a Linux/Apache/MySQL/PHP (LAMP) server architecture to disseminate the material of interest to the spectators. While such an endeavor would usually include a staff computer administrator to maintain the server, undergraduates are expected to provide complete operation support for the system as well as maintain and develop new applications for this platform. This has involved three main challenges:

- Teaching the students good development strategies; including documentation, revision control, and resisting the urge to adopt every new programming language.
- Providing the students the resources to learn, test, and develop code without interfering with their own operational goals and counterparts.
- Creating a network and server infrastructure that co-exists with campus network security policies.

For the first two bullets, the faculty have an oversight role but our experiences along with evaluation studies discussed later suggest that the collaboration between established team-members and new team-members provides the best learning and working environment for the student teams.

DEVELOPMENT STRATEGIES EVOLUTION

The eStadium application was initially developed and deployed at Purdue. The initial installation at Georgia Tech was accomplished by a new VIP team when Dr. Coyle transferred from Purdue to Georgia Tech. The students were given access to a dedicated e-stadium Linux server, the uninstalled software, and a technical contact from Purdue. The new team faced considerable challenges, including: minimal documentation; learning Linux, MySQL and PHP; and customizing the code to produce a Georgia Tech oriented display rather than Purdue. These challenges were addressed while the team was also learning basic teamwork.

For consistency with the Purdue team, a subversion (svn) [11] repository was used for version control. The basic server configuration was done by the team’s advisors, and the application was installed by remote access from the Purdue lead developer. The installation included source code and licensing agreements.

The first semester (Spr 09)of eStadium, the initial team of students worked with the Purdue developer to understand the code and customize it to GT’s configuration. Player biographies and statistics, along with team colors and logos, required the majority of the students’ efforts. Minor configurations associated with the configuration of the network and associated machines were required. Students were able to successfully test the entire capture, transcode, and web-server process during the Fall 2009 football season. Game-day operations utilized the system shown in Figure 1.

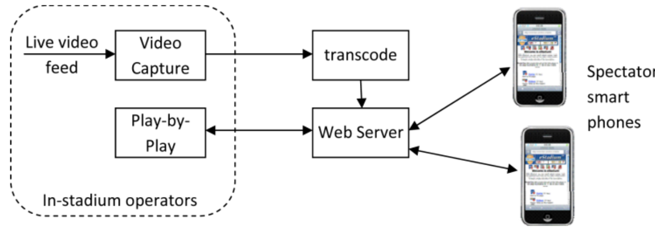


FIGURE 1: BASIC SYSTEM CONFIGURATION

During a captured football game, two student operators are required to run the system. Typically 3-4 students are present to allow students to take shifts. One student runs the video capture machine. This involves starting and stopping the recording on a computer equipped for video capture. Each video clip is saved and automatically sent to the transcode system, which converts the video to the multiple formats needed by different smart-phones. The transcode process then passes the video to the web server. A second student runs the play-by-play association system to correlate video clips with textual play descriptions.

A student "Game-Day Manager" was appointed as a first-level manager to coordinate both the game day events, and the configuration, development, and testing of the system beforehand. Identifying the appropriate student to fill this task, and helping them succeed as part of the overall team, is a key component of the faculty adviser's responsibility. A returning student, experienced with the team, is necessary. Recognizing the team leader's efforts to manage and coordinate the team is a necessary part of creating the right working environment for the team.

Two critical issues that require advisor monitoring arise in team-based student development: 1) students will adopt new programming mechanisms, languages and toolkits without regard to maintenance issues; 2) technical solutions are sometimes pursued in place of good communications amongst team members.

New programming mechanisms increase long-term maintenance complexity and therefore the learning curve, yet students have a tendency to want to completely rewrite each piece of code using a programming mechanism that is familiar to their individual experience. This is often done under the pretense of “cleaning up the code.” Therefore new programming mechanisms, especially in the operational code, are subject to team and advisor reviews of the long-term tradeoffs. Experienced team members appreciate the utility of such a process.

The issue of technical solutions to communications problems arises as the typical student mindset favors finding a tool or mechanism to solve the problem. For example, the version control software used does not easily restrict who can edit what code. Such edits are tracked and reversible so an unrecoverable situation does not result. A diversion of exploring permissions, new version tools, and other solutions was avoided by requiring the students to discuss the real issues as a group. Peer pressure during a group discussion resolved the issues by conveying the appropriate communication/coordination practices to all team-members.

RESOURCES AND PRACTICES

While the Fall 2009 team was able to successfully operate the system, training new students to understand the internal workings of the code requires giving them access to a working system to test their understanding. Several coding enhancements were also underway to improve the appearance and features of the web-pages. It became apparent that new students were not actively participating due to concerns about damaging a working system. Nor were the existing students clearly documenting the procedures and methods of managing the system. Since each semester replaces up to ½ of the team members, the knowledge to run the system would quickly decay unless a mechanism was found to facilitate intra-team learning.

Tutorials in MySQL, PHP, and Linux [12] provide basic skills to help students begin contributing to the team. Beyond these tutorials a new student is paired with an experienced student and told to review the pertinent documentation and revise it where it is unclear. This ensures that useable documentation is maintained via a VIP-housed wiki [13]. Wiki logs also provide a mechanism for reviewing individual contributions. Maintaining a good high-level overview and removing outdated documentation are ongoing challenges.

One of the requests that arose in many forms from the students was a desire for separate development servers. Established students suggested that a new student could better review server configuration documentation, and learn the installation process if a development server was available. Established students also wanted development servers to test significant system changes. The managing team leader wanted a prototype deployment server to freeze development and test the complete system before updating the production game-day server. While costs and information technology (IT) support prohibited the creation multiple physical servers to meet this need, a virtual server mechanism allowed the creation of multiple servers. Since those servers only needed to be operational in a test and development capacity, and are not used for the high volume game day traffic, sharing one physical machine across many virtual servers was technically feasible. This lead to a significant effort to create a VIP server infrastructure that is now used by several Georgia Tech VIP teams.

SERVER AND NETWORK INFRASTRUCTURE

Several options exist for publishing web content on campus without the need for setting up a new web server, but the required software, scalability and load dictate the use of a dedicated server. Since the eStadium application suite does not conform to a simple web content model but involves complex database and application programming support, staff administrators are not able to support a dedicated eStadium server. Therefore the eStadium team and VIP program at Georgia Tech moved to a model that has successfully built, maintained, and provided production level service on web servers, in conjunction with a development, test, and quality assurance plan for new software development.

Security policies in the department and campus generally require that production systems with external visibility, such as a publicly accessible web server, not allow students to have privileged access as this increases the security risk of other systems on the same local area network IP subnet. To address this issue, a VIP subnet was established with separately configured firewall policies. This required an initial effort in the form of configuring a separate IP subnet, allocating a VLAN on the campus network to support that subnet, propagating that subnet to the effected campus network Ethernet switches, and creating a new policy configuration in the firewall associated with that subnet. While this took some time and effort (approximately 4 months from a consensus to proceed to final implementation), this investment currently benefits 10 VIP teams. Detailed accounting of those efforts has not been maintained but the resulting ability to shift workload from support personnel to students provides long-term cost benefit.

Georgia Tech's VIP Cloud utilizes 4 physical servers to create virtual machines called guest machines. Each guest acts as an independent server, with a separate network identity, operating system installation, software installation, and configuration. The guest configurations includes team-specific guest servers for 5 teams and 3 general purpose guest server supporting the common website, shared file service, and account administration. To simplify creating new guests, a template guest configuration is maintained.

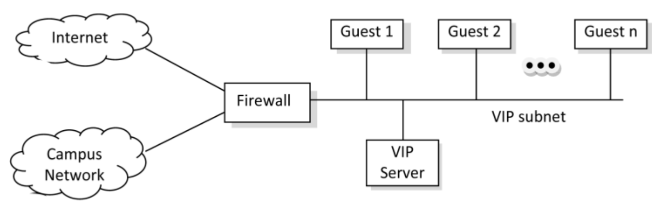


FIGURE 2. NETWORK SECURITY ARCHITECTURE

Each guest machine is allocated to a responsible administrator: a student, staff, or faculty member. Team-specific guest servers are typically administered by a graduate student but ultimately that decision resides with the VIP team's faculty advisor. The designated administrator must sign a form [14] indicating that:

- They are responsible for all system maintenance and operation, including backups
- They are responsible for assuring proper use of the guest in compliance with all applicable policies.

When the administrator is not a faculty member, the team's faculty advisor also signs the form.

To allow students to get experience with such a challenge, each student involved in the web project was assigned a specific guest server. Each guest server was configured with the operating system (RedHat Linux 5.4) preinstalled and a unique network identity preconfigured.

This methodology, developed for team-based guest servers, applies equally well to individual students' guest servers.

ACADEMIC EVALUATIONS

Since students are functioning as a team with individual members working on different goals, the evaluations of student accomplishments is not a curve-based numerical assessment of identical assignments. Students may be sophomores through graduate students, enrolled for 1, 2 or 3 credits, and vary from new first semester team members to well established team members. Therefore it is critical that students understand what is expected of them and how they are assessed.

As part of the VIP program, the students are expected to maintain design notebooks. In addition to meeting notes, these notebooks are expected to maintain a record of student efforts and accomplishments as well as tasks and current issues. With a primarily software focused development effort the design notebook does not provide a good mechanism for tracking code written. Since subversion was being used to track code changes, the subversion logs can be reviewed for student accomplishments. This in turn provides incentive for the students to make proper and frequent use of the version control software.

While each student's individual accomplishments are unique, each student is evaluated across these three equally weighted areas:

- Documentation: Design Notebook, Version Control, Wiki
- Technical Accomplishment: Tutorials, Papers, Motivation
- Teamwork: Participation, Cooperation, Peer Evaluations

This provides clear objectives within the context of team-based projects. Established team members generally have practices that align with these objectives, which helps new team members adopt good techniques for succeeding on the project. All team members are given mid-semester advisory assessment results. These results are reviewed individually with new team members and with any student wishing to discuss his progress. In addition to factoring directly into the grade, peer evaluations form an important cross-check for the faculty advisor's assessment. The general VIP syllabus, and evaluation form, is available on the Georgia Tech VIP wiki [15].

TRACKING COLLABORATION AND RELATED OUTCOMES

The eStadium team reflects the overall goals and structure of the VIP program as a multi-institutional and vertically-integrated engineering design/research project. Conceptually the eStadium students have the opportunity to interact with various ranks of students and faculty, in order to not only gain technical expertise, but also broader collaborative and related research skills. *How well is this working in reality?*

In order to track the expected results in a meaningful way, the VIP Program also includes an evaluative function where student-level survey data are collected annually. The evaluation, designed and conducted by social scientists at one of the VIP institutions, is structured along the two years of the VIP Program grant. While this evaluation can provide data on VIP processes and outcomes for the program overall [1,2], given the VIP structure and the scope of the evaluation study, the data are rich enough to provide insights to the dynamics and collaborative developments at the project level. Specifically, issues of student learning and socialization in the research environment, mentoring, knowledge-based interactions and collaboration, and use of technology, are expected to develop through each of the team experiences, and reflect important capacity development by student participants and are expected to be observable among VIP students [1,2,16,17] in earlier work, we have addressed these broad goals and findings of the VIP Program, without specific attention to any of the individual teams [2], while in this paper we report only on one team: the eStadium Project (eStadium) [8-10]. Here we ask the question, what benefits and outcomes have students accrued through their eStadium team experience?

<u>Data Collection and Scope:</u>
A common evaluative approach to student learning experiences involves student surveys that not only address satisfaction, but also some self assessment of learning [18]. Other techniques involve ethnographic observation of student behavior and interaction in ways that may reveal learning over time [19]. 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. The evaluation is 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.) An important aspect of this survey is that it includes a series of detailed social network questions that allow for the quantification of relationships among VIP students, across all teams, but also 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 know, 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 capturing using this survey structure typical for social network analysis to assess ties, linkages, and the strength of those linkages within an organizational environment [20,21].

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 [21,22]. 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. Importantly, their meaning must be then interpreted in light of organizational goals and objectives.

In the spring semester of 2010, 98 students from the Georgia Institute of Technology (Georgia Tech) and Purdue University were surveyed, of which 71 responded for an overall response rate of 72%. Of these, 76% are undergraduates, 6% masters students and 18% doctoral students. Purdue students responded at slightly higher rate (77%) than Georgia Tech students (67%). Specific to the eStadium team, 24 were surveyed and 15 responded for an eStadium response rate of 62.5 %. Overall, of the Georgia Tech eStadium group, 9 respondents had also participated in the first baseline (2009) survey.

eStadium Student Outcomes: Evidence From the Evaluation

An essential aspect of the VIP Program is the vertical integration of students around engineering design issues, while at the same time learning about project and team management, and end user needs. What skills are eStadium students developing to reflect these goals, and to what extent are students actually integrating in meaningful ways? Is student learning and skill development reflected in their interaction?

Consistent with the expectations for the VIP Program, we address student skill and learning development specific to the technical aspects of the eStadium experience, as well as other knowledge that students gain from working on a vertically integrated team. These items represent knowledge resources, both technical and managerial, that students should obtain from VIP faculty, but also from other students via their VIP Project interaction. Specifically, the survey instrumentation for the evaluation activities differentiated technical learning from managerial learning:

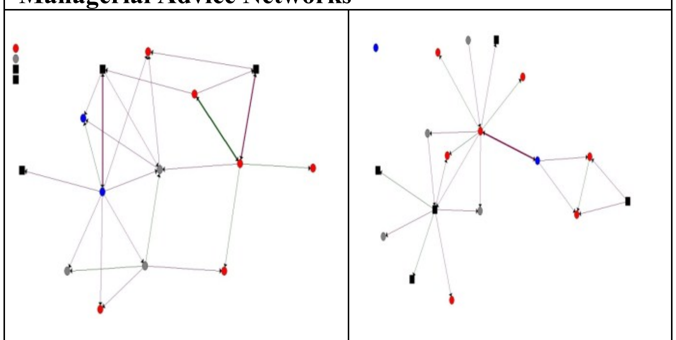
Technical:
- Technical advice (computer programming, hardware details, etc);
- Advice about engineering concepts (algorithm design for software, hardware infrastructure understanding);
- Advice about technical applications;

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

Our results show that eStadium students report developing a range of both technical and managerial skills through their VIP team experience. How do students develop these skills? To some extent, VIP faculty provide important knowledge and guidance in the development of both technical and managerial skills. Yet, VIP is specifically structured to create communities of students who may learn from one another. In fact, an important expectation within the VIP experience is that students benefit from one another – within but also across the vertically integrated structure of the program. To understand how this expectation has played out, we asked students to indicate who among their VIP student colleagues they seek out for technical and other project advice/information within the VIP teams (as well as across teams). The results provide insight to the knowledge resources that are exchanged within and across teams. These data were collected using social network question structure to also allow us to track the development of knowledge and learning networks within VIP.

Among eStadium students, the results show that students in both campuses actively interact in substantive ways consistent with VIP goals, providing both technical and management-related advice among student team members. Results show that all of the Georgia Tech eStadium students are engaged in the exchange of advice, interacting on average with 8 other students (mean centrality) in VIP-related matters. Furthermore, results also show that advice regarding technical and project management information and assistance is exchanged not only between the undergraduate and graduate students, but also between undergraduate students of different ranks. This finding is consistent with VIP goals for integration across student ranks. It is a particularly noteworthy finding given that the expectation may be that only the graduate students play a role in this type of interaction. Instead, the data show that undergraduate students interact and exchange technical, team management and project goal related advice across their ranks as well. When the technical and managerial advice interactions are broken out separately (Figure 3) , we see activity in both realms, although slightly more (27 ties as compared to 22) for technical advice. Further, the technical advice has a slightly higher mean centrality, while the managerial advice is centralized around two individuals in particular. Results show that technical advice is exchanged between the undergraduate and graduate students, as well as across the undergraduate student ranks.

Figure 3. Georgia Tech eStadium Technical and Managerial Advice Networks



	All technical advice	All managerial advice
# Ties	22	27
Density	0.07	0.09
Mean centrality	1.22	1.5
EI-Index (UG-G)	-0.18	0.26
EI-Index (UG rank)	0.46	0.48

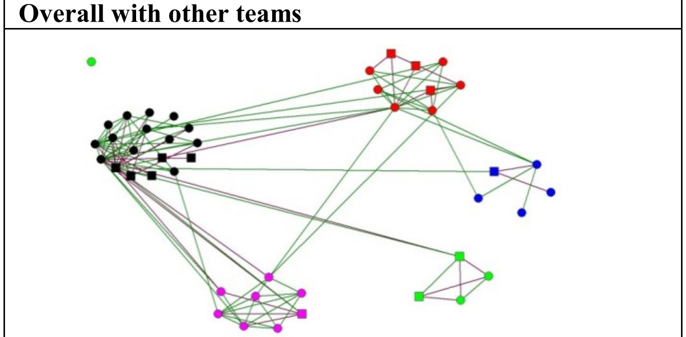
Thicker lines in this figure show reciprocal advice exchange – students consult each other about various technical issues, engineering concepts and technical applications. It is also interesting to observe, that many of these individuals at Georgia Tech are undergraduates. With respect to advice about team management issues, as well as the goals of the project our data show that all but one of the Georgia Tech eStadium students are engaged in the exchange of the this kind of advice, again reflecting important advice and knowledge sharing activities within the team.

While the overall expectation is that information flows within each VIP team, including eStadium, the results show that advice ties also cross team boundaries, and that this is true for both Purdue and Georgia Tech. To illustrate, Figure 4 shows the Georgia Tech and Purdue eStadium teams within the context of other VIP teams (the Georgia Tech eStadium team is colored in black and the Purdue eStadium team is in grey). This figure shows the network sociograph for all five categories of advice combined (computer programming, engineering concepts, technical applications, VIP team management issues, and VIP project goals and purposes), organized by team in order to show how the teams interact within and across team structures. While much of the interaction is within teams, as would be expected, there is some advice related exchange across teams. The E-I indices of values near -.6 suggest a consistent level of across-team interaction at both institutions.

VIP Student Feedback

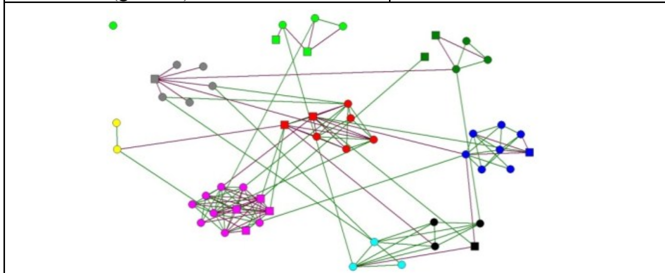
Finally, to understand the extent to which students see their VIP experience as beneficial we asked VIP students to identify the single most important skill they gained in the project and to assess the applicability of what they have learned in the project. The results show that students highly value the managerial aspects of the project and the opportunity to engage in "real world research." More specifically, results show that eStadium students point primarily to skills and knowledge related to team management and research processes as outcomes of their VIP experience. They mention such skills as the ability to organize teamwork and to planning and time management in a long-term project. Our data show that students also learn not only about practical aspects of solving technological problems, but also such issues as communication of technical ideas with industry partners and

Figure 4. Student VIP Networks: Advice Exchange, Overall with other teams



Georgia Tech: All Students, By Team

Number of Ties	124
Density	0.36
Mean centrality	8.29
EI-Index (team)	-.66
EI-Index (UG-G)	-.35
EI-Index (year)	.032
EI-Index (gender)	-.47



Purdue: All Students, By Team

Number of Ties	148
Density	0.39
Mean centrality	8.36
EI-Index (team)	-.58
EI-Index (UG-G)	-.23
EI-Index (year)	NA
EI-Index (gender)	-.67

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

patenting activity. Students report that participation in the eStadium team allowed them to get feel for how engineering teams work and to understand how engineering concepts that they have learned in their classes apply to real engineering problems. They also highly value (mean values 3-3.4 in 4-point scale) the contribution of their VIP experience to their project management skills, such as sharing responsibilities with other engineers and managers within and outside of their primary fields, as well as the time management.

CONCLUSION

In conclusion, the VIP Program at Georgia Tech has improved its peer-based learning by developing the infrastructure to support extensive student responsibilities in software development and system administration, thereby adding an important active learning element to an already robust curriculum. The evaluation results are important in underscoring the critical value of VIP in building research knowledge that goes well beyond technical skills and is integrated in the broader context of application. Importantly, the VIP Program adds the real life context of multi-rank, multidisciplinary teams, with an applied interest and application. The evaluation results show that the VIP Program is accomplishing what it set out to do. Furthermore, it shows the exchange of tangible knowledge resources between students, including among students at the undergraduate level.

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