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ADAPTING VERTICALLY INTEGRATED PROJECTS TO UNIVERSITY TEAM COMPETITIONS

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ABSTRACT

Beginning in 2009 Vertically Integrated Projects (VIP) courses have been implemented at Georgia Tech. These VIP classes allow undergraduate students to receive academic credit for participating on teams that further faculty research efforts. The teams are: multidisciplinary, vertically-integrated, and long-term. Participation on these teams has been shown to help students gain understanding of project timelines, effective project communication, and other applicable real-world experience.

EcoCAR 3 is the latest in a series of Advanced Vehicle Technology Competitions (AVTCs) sponsored by the Department of Energy since 1988. At Georgia Tech, the EcoCAR 3 team has been structured using the VIP program to improve the all-around experience of faculty members and the graduate and undergraduate students. Based on Georgia Tech's experience in the first three years in EcoCAR 3, we have learned lessons that we are implementing on our team to improve the educational experience of the students working on the project. One of these lessons is the value of strong undergraduate leadership on competition teams and in project based learning. The benefits have included a more evenly distributed workload, increased mentorship of new undergraduate students, and improved team capability to successfully meet deadlines while still educating undergraduate team members.

INTRODUCTION

Vertically Integrated Projects (VIP) [1] is a program at Georgia Tech that allows undergraduate students to receive academic course credit for participating on teams that contribute to faculty research. VIP is now instituted at twenty four universities (nineteen in the U.S. and five internationally). VIP is the only program that runs long-term, large-scale teams that are embedded in the research activities of faculty and their graduate students. These VIP teams are multidisciplinary—drawing students from around the university, 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 seven semesters. The structure of these VIPs is illustrated in Figure 1. Undergraduate students are integrated with graduate students and faculty members working on long-term research projects. The longevity, up to seven semesters, is a benefit to undergraduate students as it gives them the opportunity to learn and grow over time, in contrast with conventional classes and typical undergraduate research experiences. The continuity of VIP courses also offers the student the necessary time to meaningfully contribute to a significant endeavor in their respective technical area. The VIP course offers students the opportunity to have a unique experience that cannot be obtained in conventional classroom settings. These experiences prepare students to better integrate themselves into future industrial projects as they join the workforce.



Figure 1. STRUCTURE GOALS OF VIP PROGRAM

Georgia Tech was selected to participate in EcoCAR 3; a four year advanced vehicle technological competition (AVTC) sponsored by the Department of Energy and General Motors (GM). As part of this competition, a team comprised of undergraduate and graduate students at Georgia Tech was given a stock Chevrolet Camaro to modify into a hybrid-electric vehicle. In addition to improving the fuel efficiency and reducing emissions of criteria pollutants, the design must maintain the performance of this iconic American muscle car. In addition to GT there are fifteen other university teams from North America competing in EcoCAR 3.

As part of the competition, teams are asked to follow a similar design process as that used at GM. This vehicle development process and the nature of the student competition have been described for previous versions of AVTCs [2]. The process is detailed and over the years has become more comprehensive in scope. As a result, the size of the teams are large, and a broad range of skills needed. The competition aspect of the GT EcoCAR 3 team also creates a stark contrast with other VIP programs because of the additional presence of external sponsors that stipulate deadlines and other rules and regulations on the GT EcoCAR 3 team. Other VIP teams often have the liberty to follow their own academic schedule and are largely regulated by the faculty adviser without outside stipulations.

Georgia Tech participated in earlier AVTC competitions: Future Truck (1999-2004), and EcoCAR 1 (2008-2011). Based on the team's previous experience in AVTCs, the GT EcoCAR 3 team elected to structure the competition team using the VIP program. The leadership on the team has seen that the VIP program has helped us to improve in several key areas that had been seen as challenges based on previous AVTCs. The areas that have seen improvement included:

- 1) Increased and more evenly distributed participation of students.
- 2) Improved communication within the team.
- 3) Raised retention of team members.

While structuring the Georgia Tech EcoCAR 3 team through VIP led to the desired improvements, it also led to unforeseen challenges detailed in our previous paper and reiterated below [3]:

- 1) Equal motivation between technical and non-technical aspects of the project.
- 2) Communication between faculty and students and between different sub-teams.
- 3) Meeting deadlines set by project partners with students whose schedules are relatively inflexible.

- 4) Finding ways to help students succeed in a highly self-motivated environment.

This paper will review some of the findings made by the GT EcoCAR 3 team leadership as we have tried to mitigate the challenges experienced by our team throughout the last two years of the competition. During the last two years, additional schools participating in the EcoCAR 3 competition have begun using the VIP program to structure their teams as well. Our findings and experience should prove useful in their efforts to improve their teams. Additionally, the findings should prove useful to other student projects and project based learning groups on how to help improve the educational experience offered through these types of experiences.

VIP IMPROVEMENTS FOLLOW-UP

As detailed in the introduction, the VIP program led to several significant improvements during the first year of competition. Now that the team is finishing its third year in the competition, team leadership has found that many of the improvements have persisted and continued to be a source of strength to the team. Team leadership found that the VIP program was important to these improvements partially because it led to more students participating for a longer period of time on the project. The increased number of core participants has proven instrumental in increasing the ability of the team to foster a good learning environment for additional new team members. The benefits of having stronger undergraduate student leadership will be detailed throughout this paper.

Having strong undergraduate leaders has served to help more evenly distribute participation by allowing more of the workload to be delegated from graduate student team leadership to undergraduate team leaders. Due to their time on the team, they have progressed to a point on the team and in their schooling where they have the knowledge and skills to be able to contribute more fully to team deliverables. The addition of more skilled team members has significantly decreased the load on graduate student team leaders. Previously, graduate students would distribute work to undergraduate students and devote time to help them complete the delegated work only to have it returned in a state unfit for submission. Because of the deliverable not being successfully completed by the undergraduate, the graduate student would have to finish the deliverable themselves with a reduced amount of time. The reason for these failures was theorized to be caused by a lack of supervision, due to the great burden on team leaders, and a lack of willingness of undergraduate students. After three years, team leadership believes that these failures were caused more by team inexperience than team unwillingness. As the team's key undergraduates have gained experience, they have made important contributions to the team and made it so that the team workload is more evenly distributed. This is because the undergraduate team leaders are better equipped to finish assigned tasks and they provide more supervision for other undergraduate students.

Having undergraduate team leaders has increased the capacity of the team to better supervise and mentor additional undergraduate team members. The team previously had only one or two people who could answer many of the questions that would arise as students worked on assigned projects. This number has increased to approximately three to four students for each topic and there are more individual experts in each area of the team. This development has led to more resources for newer undergraduate team members to receive answers to their questions, help with their projects, and advice on best practices. Undergraduate team leaders also relate more readily to the new undergraduate students because they were in the same position in the past couple years and know how to achieve the greatest amount of success on the team. The increased depth and breadth of the team's leadership has led to a more evenly distributed workload due to the improved ability of the team to answer questions, supervise projects, and delegate tasks to capable team members.

The VIP program led to improved communication because it provided a class time for team meetings and a platform for team communication. Additionally, team leadership has found that team communication has been further improved over the past two years by three key changes:

- 1) Addition of a common work space
- 2) Use of a cloud-based team collaboration tool
- 3) Increased familiarity of team leadership

During the first year of the competition, the team was often spread out and only met once a week during class time. Now that the car has arrived, the team has a shop space where the team gathers at least two times per week to work on the car. The addition of having a common work area has led to improved communication between the different sub-teams as they meet together more regularly. The communication between the entire team has also been improved by beginning the use of a cloud-based team collaboration tool this past year. The team uses a Slack account to make general announcements for the whole team. It also allows for private messaging between each of the team members. This has led to better overall team and team leadership communication. The increased familiarity of the team leadership with one another has also led to improved communication as a natural development of increased knowledge of each person's tendencies. The separation of tasks between different team leaders has also been defined and reinforced as time has passed. Leading to a better understanding of who will complete each tasks and knowing who to turn to when assistance is needed on different aspects of the project.

The VIP program has also been seen to be beneficial in improving the retention rates of new students as compared to the EcoCAR 1 project. As students obtain credit for their participation on the team, this has allowed them to advance in their coursework while working on a project that they have

passion for. The ability to obtain school credit has been seen to not only attract students initially, but has also been helpful in getting them to stay for a longer period of time. Figure 2 shows the retention rate up to this point of the competition. The data shows that retention levels have been fairly consistent for the duration of the competition at a little over 50%. The initial goal set by team leadership for 70% retention may have been lofty considering the amount of team members that graduate or obtain coops each semester. The team experience each semester has been increasingly good as time has passed. However, it has highlighted the importance of recruiting. During the Fall 2015 semester, the team experienced some difficulties partially due to the high ratio of new to returning team members. Team leadership has found that having a 1:1 ratio of new and returning team members is effective in maintaining a good balance between up and coming team members and returning team members. The new team members train to become good mentors for the new students the following semesters and the returning team members mentor new students while making important contributions on team deliverables. Maintaining the proper balance on the team through ensuring retention of good team members and recruiting the right amount of new team members is vital to the future success of the team. Increased team familiarity has also helped with retention rates as team members are more likely to stay due to relationships formed during their time on the team [4].

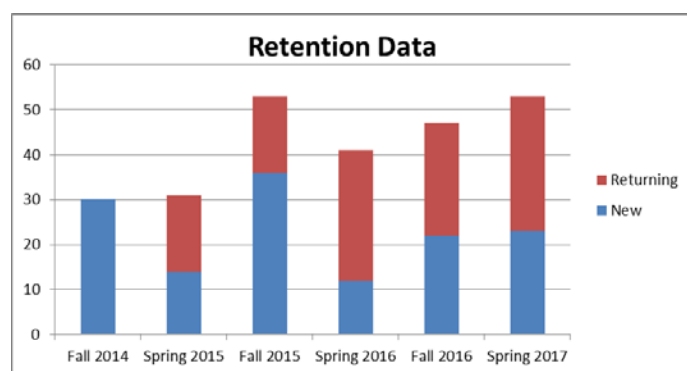


Figure 2 GT EcoCAR 3 Team Retention Data

One key development in the team, due to the retention of key team members, is that the team also is shifting towards a more experienced team than at the beginning of the competition. When the GT team first joined EcoCAR, not only were all of the students new, but most of them were also sophomores and juniors with very few seniors and graduate students. The GT EcoCAR team's ability to retain team members has led to having more experienced team members who can mentor newer team members. The retention of core undergraduate team members has led to a better leadership structure of the GT EcoCAR team that more ably sustains and supports the other undergraduate student's activities on the team. This has been important in addressing several of the challenges that were previously faced by the team and in improving the educational experience of all students.

One additional practice that has proven useful in improving the team leadership has been the addition of more graduate students. Team leadership advertised opportunities for Master's students to work on the project. In return, the students would be able to write their thesis primarily based upon their work on the project. These students have proven instrumental in improving the leadership of several sub teams as they have taken primary responsibility for supervising different aspects of the project. So far, four students have served in this role on the team. The team additionally has the option to give graduate students special problems credits for their participation on the team. Finding ways to strengthen team leadership by retaining strong undergraduate team members and eliciting the participation of graduate students has proven useful in increasing the strength of team leadership and its abilities to help mentor more undergraduate students.

VIP CHALLENGES FOLLOW-UP

After the first year of the competition, team leadership focused on further improving upon the VIP structure for the team. During the first year of the competition, each undergraduate team member was required to participate on a non-engineering team. These included activities such as project management, outreach, or fund raising. However, team members' contributions on these activities were often meager and served to detract from their technical tasks. After numerous attempts to find the correct balance for undergraduate students between technical and non-technical tasks, the team found that it was best both for the undergraduate students and team productivity to place more emphasis on the technical tasks than on the non-technical tasks which had previously been required of all students. Undergraduate team members were no longer required to be on a non-technical sub team. This entailed placing most of the responsibility for the non-technical tasks on the graduate student leadership. While this did lead to more responsibility for the graduate students, it also led to better performance because those best qualified to accomplish the tasks were completing them. The non-technical tasks on this project also proved to be able to be completed by the graduate student team leadership with help in only a few key areas from other team members.

Assistance from other team members included key undergraduate team members helping to manage the schedule, scope, and budget of each of the respective aspects of the project that they oversaw. Each semester, team leadership was able to create a team schedule and budget by combining contributions from team undergraduate leaders on each of the aspects of the project that they were responsible for overseeing. The graduate student leadership then combined the different sub team schedules while ensuring that the separate schedules melded in a way that allowed for team collaboration. This mostly entailed making sure that no one sub team schedule interfered with another sub team's schedule. This past semester also entailed a very clear declaration to students requiring them to help with team outreach efforts by attending one event over

the course of the semester. Team leadership saw an increase in undergraduate participation at outreach events when it was detailed that it was required for them to receive a good grade in the class. The team also found that detailing a more minor amount of help from undergraduate students on non-technical tasks, which was tied directly to their grade, allowed them to focus more on their technical tasks and for team leadership to function more smoothly. Initially placing the focus on the technical tasks that the students are more comfortable with will help them to adjust to the project based learning environment that is significantly different than the conventional classroom setting most students are more familiar with. While non-technical skills are very useful for students to learn as they will be utilized in their eventual careers, it was found that this was best introduced after team members already have some experience on the team.

Successful projects are dictated on effective team communication. Finding the best way to encourage team members to ask questions to better understand their projects, inform on the efforts that they are making from week to week, and to present challenges that they are facing is conducive to overall team success. A previous study showed that providing students with an opportunity to turn in questions on a regular basis led to a greater understanding between teachers and college students in large classrooms [5]. One way that the GT EcoCAR 3 team has attempted to provide avenues of communication for undergraduate students was to introduce a weekly report to be completed by every undergraduate student each week. These reports were limited to one slide and entailed their accomplishments from the past week, their plans for the next week, any questions they had, and anything that was preventing them from finishing their assigned tasks. After the reports are submitted, a team leader reads through each report and provides individual responses. Team leadership found that it was best to submit these reports the night before the team meeting, so that the team leader could read the reports in the morning before the general team meeting. This allowed the team leader to address any issues during the team meeting. Team leadership has seen that weekly reports have helped undergraduate students to feel more comfortable with communicating their questions and challenges. An example of a weekly report is shown in Figure 3. These weekly reports have served to improve undergraduates' contributions throughout the semester by forcing them to think each week about what they had accomplished and what they planned to accomplish the following week. The weekly reports also helped improve communication by giving team members the opportunity to ask questions and report anything that was preventing them from completing tasks in a timely manner. This helped team leadership to be able to answer these questions and to help team members overcome the obstacles they faced in a timely manner. The use of weekly reports gives each team member the opportunity to communicate progress, plans, questions, and obstacles each week to a team leader. This has helped to increase the productivity of each team member.

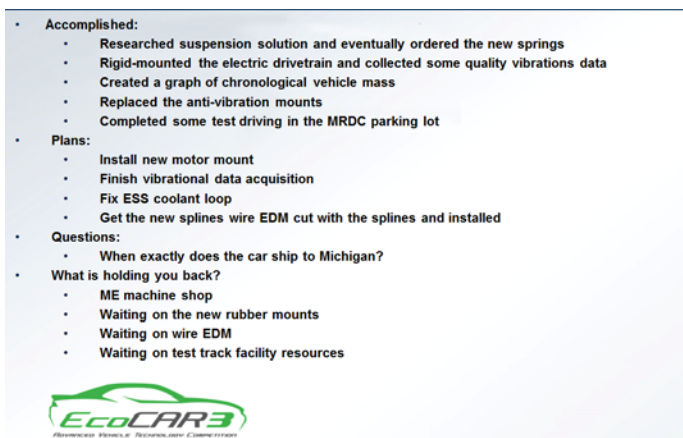


Figure 3 Example Weekly Report

To improve the GT EcoCAR team's ability to meet sponsor deadlines, team leadership introduced internal deadlines to provide additional slack for any unforeseen difficulties and also to allow time for the team to revise drafts of each deliverable. While this has been important to the improvement in the team's ability to meet deadlines, team leadership believes that a stronger undergraduate leadership structure has been instrumental. As the team's core leadership structure has expanded to include more students, the team has been able to delegate activities more effectively. The ability to spread the work required for each deadline more efficiently has increased team leader's abilities to act in more of a supervisory role. Also, increased undergraduate team leadership enables more undergraduate students to contribute. This is because there is an increased amount of mentorship from undergraduate team leaders over their fellow undergraduate students. The increased understanding of the competition schedule among a greater percentage of the team has also led to a better ability to complete team deliverables in a timely manner.

The last challenge was how to help students succeed in a highly self-motivated environment. In conventional classroom settings, assignments are more straightforward and cover material that was taught in class. Project based learning often presents tasks that requires a different application of knowledge and can be challenging for students to tackle effectively. While one key to student success is still the student's own passion, team leadership has seen that an effective bridge between faculty and graduate student expectations and undergraduate students needs for high levels of supervision is the improved undergraduate leadership structure. Strong undergraduate leaders serve as mentors to other undergraduate team members in helping them to achieve tasks that they are assigned. One significant determinant of undergraduate student success on the team depends on the strength of their assigned undergraduate leader. Undergraduate students assigned to strong undergraduate leaders are seen to perform significantly better on average than students with weak undergraduate leaders. Georgia Tech EcoCAR leadership has found that strong undergraduate leaders can act as a bridge between faculty expectations and students' needs in helping project based

learning to be effective. The VIP program contrasts with typical senior design or capstone experiences because the teams are formed of students that are all new to the project assigned. The VIP program students all have different amounts of experience on the project. This has proven to be helpful in increasing the education of newer team members.

An additional reason for the team's success this past year is that the new graduate student who led the team for year 3 had previously participated in the EcoCAR 3 competition at another university. His previous experience on the competition proved very useful in helping the overall team performance to improve. The graduate student's knowledge gained from his previous AVTC experience was not only limited to practical technical know-how, but also how to instill a successful culture and team dynamic. The leader's knowledge and experience had an effect on every team member as he passed on knowledge and advice based on his own experiences. Leadership experience on projects has previously been shown to be a key factor in determining team success [6].

ADDITIONAL AREAS OF FOCUS

While the performance of the team has drastically improved over the course of the past three years, areas of focus have been identified by team leadership for maintaining and further improving upon the team's success. Some of these areas are listed below:

- 1.) Maintaining strength of undergraduate student leadership.
- 2.) Retaining key undergraduate student team members.
- 3.) Improving the training of new undergraduate students.
- 4.) Ensuring critical team knowledge is maintained and transferred to new team members.

These four points have been identified as areas of focus in order to maintain the success of the team both in the competition and in mentoring and educating undergraduate students. Team leadership has recognized some of the challenges that will be faced in successfully achieving each of these objectives and presents the challenges, along with some proposed solutions, below.

Since the strength of the undergraduate student leadership has proven instrumental in increasing the success of the team in the competition and in improving the educational experience of undergraduate students, team leadership has begun planning how to best maintain this valuable asset to the team. Many of the key team members have been on the team for three-six semesters and are approaching their graduations. Due to the fact that their experience on the team is one of the key reasons for their contributions to the team, their replacements

will likely need to have at least two semesters of experience to replicate the leadership that the current undergraduate leaders are providing. This means that the replacements need to already be on the team or be recruited one year prior to the previous leader's graduation. These are the two possibilities that exist for finding replacements for key undergraduate team leaders.

The first step in replacing key undergraduate team leaders is to know when they plan on leaving the team. Team leadership has accomplished this by maintaining close communication with each team leader, and also getting a count at the end of each semester of team members that plan to return the following semester. This gives a deadline for when the replacement will be needed to step into the former leader's position. Ideally, the new undergraduate team leader will be able to shadow the old undergraduate team leader for at least one semester. Shadowing gives the opportunity for the student to take on responsibilities over time and to learn some best practices from the previous team leader [7]. This will allow the new team leader to learn on the job. As the shadowing process proceeds, the new team leader should take more and more responsibility from the old team leader until the new team leader has assumed all of the old team leader's responsibilities. This would indicate that the new team leader is now serving the same function that the previous team leader did. Identifying the replacement, however, is no easy task. Especially in cases where team leadership feels that the replacement is not currently on the team. Recruiting efforts need to be focused on finding individuals that would be capable of quickly assimilating to the required role. There is also more of an inherent risk that the newly recruited team member is not retained, as less is known about their intentions for how long they plan to be a member of the team. Ideally, team leadership plans to identify replacements for each key team leader one year before their graduation and to then have them shadow the team leader with the knowledge that this is the role they will play on the team after the previous team leader graduates. This will help in maintaining the strength of the current undergraduate student leadership.

Related to this effort, is the work required to retain undergraduate team members. While the most important part of retaining team members is ensuring that they have a positive experience, team leadership has found that those students that the team wants to be retained generally have a good experience on the team, while those that do not contribute as much to the team typically do not have as good of an experience. The issue that is often more difficult in the retention of team members is that a lot of work is required for little return. Additionally, many key team members have expressed misgivings about staying on the team after they have attained all the credits that they can obtain from our course that contribute towards their graduation. One way to overcome this challenge is to introduce a greater focus on senior design than the team has previously adopted. The team in the past two years has had two senior design team experiences. While one was fairly successful, the other proved to not be very effective in maintaining the contributions of many key team members. One

of the differences between the two senior design teams included the amount of stipulations. The senior design class that was more highly stipulated made it more difficult to adhere to the senior design class stipulations while maintaining the integrity of a project that would prove useful to the team. Adding senior design class rules to a project that already includes VIP and EcoCAR rules led to another layer that needed to be managed to allow senior students to receive senior design credits by contributing to the EcoCAR project. While having senior students signed up for more credits, in theory, would allow them to put even more time into the project at a time that they are most useful to the team. In practice, the additional stipulations led to them not really contributing to the team in the way that had been desired originally. While the senior design credits are available and a good motivation for team members to stay on the team, team leadership must find a way to better manage the conflicting requirements to be able to successfully leverage the resources that it has at its disposal.

While the addition of stronger undergraduate team leaders has led to a lot of improvements mentioned previously, it has also presented a challenge with training new team members. Because the team has more team members who are capable of completing the work, less of the work is delegated to new team members and they do not have the same opportunity to be trained on the job. This will necessitate a change in the training process to help new students be on-boarded to the team successfully. The team has found that new students are most successful when they are given well-defined tasks that stretch them, but are achievable. This is a challenge for team leadership as it requires knowing new team members capabilities as well as creating assignments from workloads that are not normally given as separate small assignments. Team leaders have set up a survey in the recruiting process to better understand team member's capabilities as they join the team. This has enabled us to better assign team member's tasks as they join the team. One additional area of focus is to make sure that our recruiting efforts match the work that is available. This past semester the team recruited quite a few new team members to sub teams that had very little work to accomplish this past semester. This led to the new students and team leadership being frustrated because the new students were not productive due to a combination of their lack of capabilities and the lack of tasks that they could be given. Using more foresight during recruiting should help in improving the training that new team members receive.

As key team members leave the team, the team does not only lose their leadership, but also the critical knowledge they have about the project. Some of the efforts that have been maintained in the past have included design notebooks, end of semester reports, and training documents. While training documents have proven fairly useful, the other techniques have largely been ineffective in promoting necessary knowledge transfer. The team needs to introduce an effective process for maintaining key knowledge in an easily accessible location in order to make sure that the knowledge is not lost as key team members graduate and leave the team. The team currently uses

a cloud storage system provided by the university where important information is maintained. Team leadership plans to assign key team members to write documents that details information that is critical to each team member's success. These documents will help in mitigating the amount of information that is lost when team members leave the team.

CONCLUSION

In conclusion, the VIP program has continued to contribute to the success of the Georgia Tech EcoCAR 3 team. It has led to a better distribution of the workload, improved team communication, and increased team retention from the team's previous AVTC experience. One major key in all areas of improvement has been the development of stronger undergraduate team leaders that has increased the team's capabilities to meet sponsor deadlines and better mentor new team members. Strong undergraduate leadership has also been instrumental in overcoming some of the initial challenges that the GT project team experienced during this first year of competition. Strong undergraduate leaders have proven more adept at helping with the important non-technical tasks required of the team than newer undergraduate students. These team leaders have also improved team communication based upon their familiarity with each other, and the graduate students and team faculty. Their experience has also helped the team to meet the deadlines set by sponsors. Undergraduate leadership mentoring new students has proven instrumental in bridging the gap between faculty and graduate student expectations and undergraduate students' needs for supervision. An additional item that has been useful has been introducing weekly reports for all students where they detail their accomplishments and plans each week. As well as being given the opportunity to ask questions and present challenges that they are facing. This has led to more questions and communication between new students and team leadership.

For the team to maintain its current success and improve in the future, it will need to maintain the strong undergraduate leadership it has developed by having plans in place to replace key leaders as they leave the team. The team also needs to increase the amount of credits available to team members by better integrating senior design courses with the VIP environment. This will help with the retention of key team members. Focusing on recruiting new team members based on the work available and with key tasks in mind will help improve the training and education of new team members. Lastly, documents need to be created by key team members to ensure that information critical to the team is not lost when they leave the team.

The Georgia Tech EcoCAR 3 Team's mission statement is as follows: "To develop a cutting edge hybrid vehicle that exceeds all technical requirements provided by our sponsors via ingenuity and pragmatism while cultivating the potential future leaders of the automotive industry." The education of undergraduate students is one of the primary goals of the GT team's participation in this AVTC and team

leadership believes that VIP has helped the GT team in improving the educational benefit for each undergraduate participant on the competition team and team leadership will continue to strive to enable each undergraduate participant to have the most positive and beneficial experience that they can have when they choose to participate on the GT competition team. This positive experience will enable them to prepare themselves to become meaningful contributors in the automotive industry of the future. The VIP program, along with the AVTC, provide experiences that are not conventionally available in typical university education, but that provide students with skills that will enable them to more quickly assimilate in industry.

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