# REU Site on UAV Technologies: Effectiveness of the Program on Student Success

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# REU Site on UAV Technologies: Effectiveness of the Program on Student Success


## Abstract

This paper discusses the effectiveness of the REU Program at California State Polytechnic University, Pomona (Cal Poly Pomona) on the student success. The REU Program titled "Research Experience for Undergraduates in UAV Technologies" was funded by the NSF's EEC Program. The main goal of the Program was to increase undergraduate students' participation and interest in research on unmanned aerial vehicles (UAV) technologies. Undergraduate students from 2- and 4-year institutions were involved in a multidisciplinary research projects at Cal Poly Pomona. The REU site has so far hosted a total of 31 diverse group of students for 8-10 weeks of summer search during the three year period, with the projects focusing on research on the Dynamics and Control of UAVs, Collision Detection and Avoidance System for UAVs, Artificial Intelligence, Computer Vision, Navigation in GPS-Denied Environments, and Flight Test experience. Another goal is to attract students from community colleges to STEM programs at 4-year institutions and encourage the participants to pursue their studies for graduate degrees.

The paper discusses the effectiveness of the Program in meeting its goals and objectives and on student success. The Program has been tracking the participants. Most of the participants are now pursuing their educational or professional career in the area of UAVs and other related areas. The program has also been successful in motivating the participants to graduate degrees in STEM disciplines. Some of the participants are already pursuing their studies for a Master's degree or are planning to apply to Master's/PhD programs. Most of the community college students have transferred to 4-year institutions for degrees in engineering. Also, all the participants have presented their work at student and/or professional conferences. This has helped the participants improve their written and oral communication skills. The paper discusses how the Program influenced in motivating them to graduate studies and/or for R&D career in industry in the areas of UAV technologies. The paper also discusses lessons learned, student feedback, and their suggestion for improvements. Students reported statistically significant changes in skills related to UAVs from pre-participation to post-participation. In addition, improvements in "soft skills", particularly with regard to working in teams, were found in qualitative/quantitative results.


## I. Introduction

The goal of this REU Site is to provide research experience to undergraduates and expose them to state-of-the-art in the area of UAV technologies in a multidisciplinary environment. The research focus of the Site is UAV dynamics & control, increased autonomy of UAVs, and their applications. UAVs have been used for remote sensing, precision agriculture, package delivery, traffic monitoring, search & rescue, traffic monitoring, and surveillance of fire-, earthquake-, flood-, and hurricane-affected areas. Lack of desired level of autonomy and safety concerns have prevented the mass adoption of UAVs for these applications. The research focus of the REU Site is the

increased autonomy and safety of UAVs for accelerated integration into the National Airspace System (NAS) for mass adoption. Despite being the fastest growing sector of aerospace industries, there is a lack of professionals entering the workforce for UAV related jobs and lack of interest among undergraduates to pursue their studies for advanced degrees in this area. The REU Site's objectives are to prepare a strong workforce for the needs of industry and academia in this area.

This paper presents the assessment of the effectiveness of the Program on student success. The Program so far has hosted 31 participants in three years from summer of 2017 to summer of 2019. They were selected from an applicant pool of 313 students. The following paragraphs discuss the research projects that the participants are involved in, professional development opportunities for the participants, and assessment of the effectiveness of the program on student success.

## II. Research Projects

The projects are being designed to increase students' interest in UAV technologies, engineering, and computer science to develop their research skills in a multidisciplinary environment. The goal of the Program is to involve the REU participants in the UAV related cutting-edge research projects. The UAV Lab at Cal Poly Pomona provides a suitable research environment for the participants [1]. References 1 and 2 provide the details on some of the projects that the participants were involved in. The participants are provided with an opportunity to gain knowledge on the application of engineering and computer science to UAV technologies, acquire skills necessary to conduct meaningful research, understand research process, and learn laboratory techniques. In most cases, the participants tested the algorithms they developed in simulation and flight tests. For example, Figure 1 shows the concept of operation for the obstacle detection and avoidance using optical flow for a multicopter UAV [3].

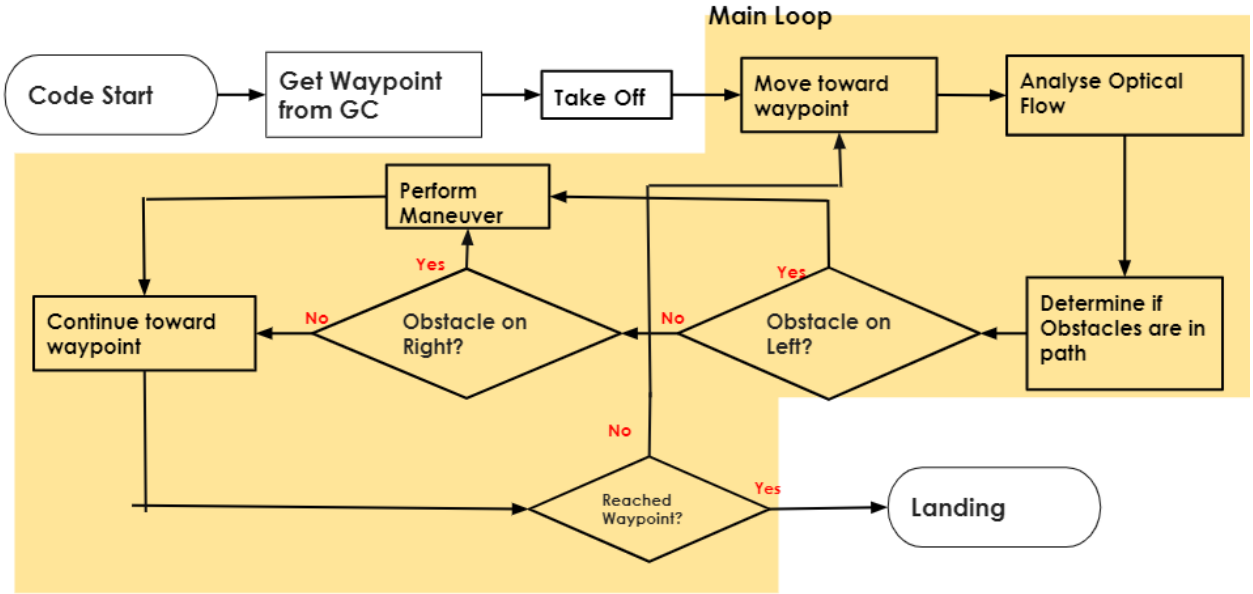


**Figure 1. Concept of operation: Obstacle avoidance system for a multicopter using optical flow.**

Figure 2 shows the test plan and vehicle trajectory during the flight test of the participants-developed obstacle avoidance algorithm on the multicopter shown in Figure 3.

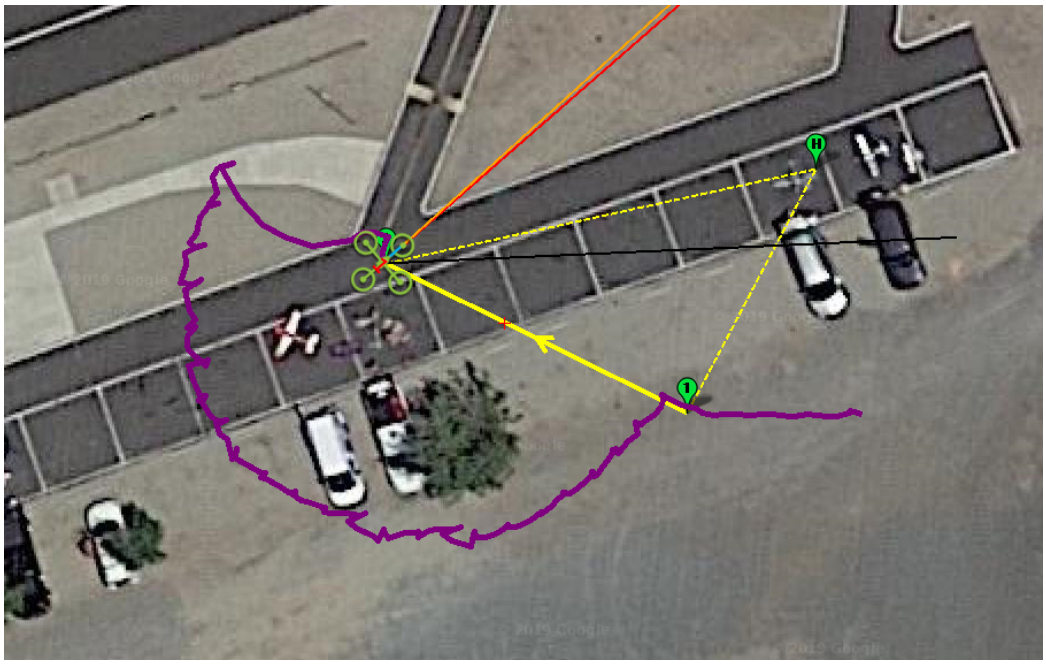

**Figure 2. UAV trajectory during flight tests.**

In the figure above, purple line shows the actual vehicle trajectory. The green circles with numbers indicate the waypoints that the vehicle was commanded to fly to. After detecting the obstacles, the vehicle moved to the left or right and after completing the avoidance maneuver, the vehicle attempted to continue to the mission waypoint. When another obstacle was on the flight path of the vehicle during that attempt, the avoidance maneuver was repeated.

**Figure 3. DJI S1000 multicopter.**

## III. Professional Development of Participants

For the professional development, several workshops were conducted during the course of the summer programs that included Ethics in Engineering and Science, Graduate School Application Process and Financial Support, Resume Building, Improving Oral and Written Presentation Skills, and Industry Careers [1, 2]. Students also participated in outreach activities and field trips to research labs or industry. These workshops had direct impact on the success of the participants. Figure 4 shows some of the summer 2019 participants engaged in outreach to local High School students.

**Figure 4. DJI S1000 multicopter.**

## IV. Effectiveness of the Program on Student Success

Effectiveness of the Program on student success was assessed using the qualitative and quantitative data collected through pre- and post-participation surveys, faculty mentor evaluations of the participants, and direct communication with the participants. The pre-/post-participation surveys and faculty mentor evaluations of the participants were conducted by an external evaluator. The PI has been in touch with the participants via email or texts to learn about their current status and future career plans. Effectiveness of the Program on student success were assessed using the following metrics and criteria: 1) Pursuance of career in the area of UAV technologies or related areas; 2) Pursuance of graduate degrees or plan to join graduate schools; 3) Transfer to 4-year institutions from 2-year institutions; 4) Improvement in written and oral

communication skills; 5) Recognition of the need for, and an ability to engage in lifelong learning; and 6) Knowledge of other disciplines.

Post-participation surveys showed that the participants generally expressed satisfaction with and enjoyment of the program. In addition, participants identified the acquisition of new skills and technical expertise as a valuable aspect of the program. Interestingly, participants of all three years also identified improvement in interpersonal and teamwork skills as an important aspect of the program.

**1. Pursuance of Career in the Area of UAV Technologies or Related Areas**

A total of 15 participants from all three years continued their involvement in the UAV research projects. The REU site has been able to motivate the students for career in UAV Technologies, which is one of the main objectives of the Site. This is also echoed in the students' written comments collected by the external evaluator from the participants at the end of the summer Programs. Some of the comments are: a) "I would highly recommend this program to everyone interested in UAVs," b)"Learning how to code for UAVs and working with an awesome team," c) "This program greatly increased my knowledge in computer science and UAV technologies. I now feel much more confident in my ability to perform in these categories," d) "The best aspect of the program would be the amount of knowledge obtained after 10 weeks. Also, I loved learning more about UAV dynamics & aerospace engineering in general," e) "They [my plans] did change. I want to go to grad school in a field related to UAVs," and f) "The tours of Lockheed, which gave an amazing opportunity to talk to the managers and workers, to get advice from them and provide resumes."

Of the 11 participants who have so far graduated with a BS degree in Engineering or Computer Science, five students have joined aerospace industry involved in UAV technologies. One student joined US Navy and is currently working in the related areas. The Participants of 2017 and 2018 REU Programs who have not yet graduated were accepted for summer internship positions at companies such as Northrop Grumman Corporation and Aerovironment. Both of these companies are heavily involved in UAV research and development. One student was accepted for another summer research Program. Some of this year's participants are already being considered by Lockheed Martin Corporation for Summer 2020 internship positions and employment after graduation. Several other students are applying for summer internships to NASA and aerospace companies that are involved in UAV technologies.

Figure 5 shows the mentor evaluations of the participants at the start and end of the Program. Faculty mentors provided feedback regarding the students' capacity for self-directed learning and original investigation as well as the participants' skills for communicating scientific and engineering, and UAV systems knowledge.

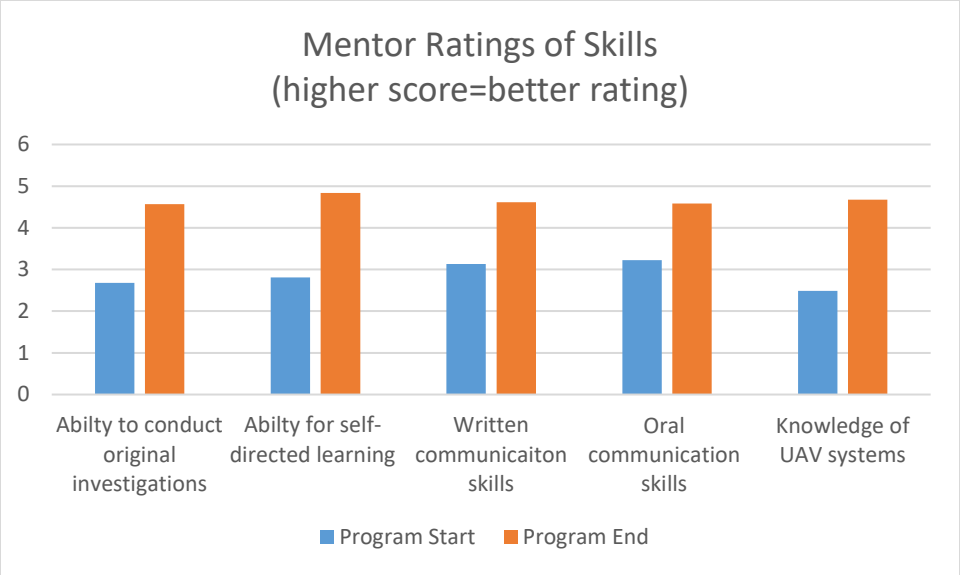


**Figure 5. Mentor evaluation of the REU participants (average of 3 years).**

Comparing the mean ratings of the student skills at the start and end of the program (collected retrospectively at the end of the program), mentor evaluations indicated statistically significant changes in the average skills ratings for the participants in the course of the Program.

## 2. Pursuance of Graduate Degrees/Plan to Pursue Graduate Degrees

Two of the 11 participants who have so far graduated with a BS degree in Engineering or Computer Science are pursuing full-time studies for graduate degrees in the area of UAVs or Computer Science. One student who will graduate in May 2020 is in the process of applying to graduate Programs in Engineering. Two students have received DOD's *Science, Mathematics, and Research Transformation* (SMART) scholarships, and will pursue graduate degrees upon completion of their BS degrees. All of the graduated and not-graduated participants are planning to pursue their studies for graduate degrees, either full-time or part-time. Updated statistics will be reported in future. The Program had direct impact on the participant's plan for graduate degrees as is evident from their written comments on the post-participation survey. Here are some comments: a) "They [my plans] did change. I want to go to grad school in a field related to UAVs," b) "I have become a bit more interested and open to attending graduate school," c) "I planned to go to graduate school before, but this time I may seek out a fellowship instead of doing it through my employment, " and d) "Yes, while I had not made up my mind on going to graduate school before, I now am certain that I want to get a masters." Increased interest in Graduate schools is also seen in Figure 6, which shows the participant responses to survey questionnaire before and after participation.

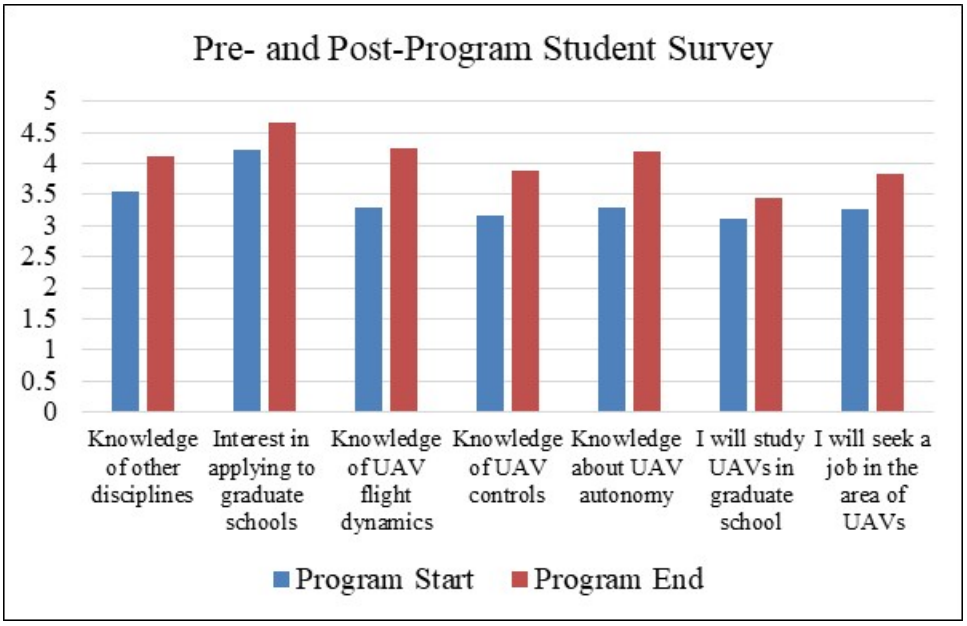


**Figure 6. Student responses to pre- and post-participation survey questions (average of 2017, 2018, and 2019 ratings).**

### 3. Lifelong Learning Skills and Acquisition of Interdisciplinary Knowledge

Figures 5 and 6 also show that the program has been able to instill lifelong learning skills in the participants and increase their knowledge of other disciplines. Mentor and participant qualitative feedback reflected the value of participant exposure to the full process of research. In addition, participant qualitative responses indicated an ongoing commitment to the field and to the research process. For example, some of the participants have been continuing working on the project even after the end of summer programs to learn more about and expand their knowledge in UAV technologies. Also, the participants from aerospace engineering discipline are independently able to work on projects that require significant knowledge of Computer Science and Electrical & Electronics Engineering. Here are some comments from the participants related to lifelong learning and knowledge of other disciplines: a) "I am more open about the possibilities of working with autonomous aircraft and spacecraft," b) "The UAV program taught me a lot of practical skills that I will carry on to other projects, like working in a multidisciplinary environment and furthering my coding, 3D modeling, and presentation skills," c) "My favorite aspect of the UAV program is the confidence it gave me to take a very complex problem and still succeed in the end. I knew very little about UAVs, but my technical knowledge helped me understand what I needed to learn to solve these complex problems," d) I will definitely be bringing these experiences with me in my future career," e) "I massively improved my coding knowledge, as well as learned the ability to solve problems without relying on any advisor help," f) "This UAV Program not only influenced my knowledge on UAVs, but it also introduced me to learning new skills, artificial intelligence, and team building," and g) "I feel inclined to study UAVs further. I enjoyed learning about this and would like to know more."

Studies have shown that knowledge of other disciplines increases the students' success at getting employment and advancing their career [4, 5].

### 4. Transfer to 4-Year Institutions from 2-Year Institutions

Five of the six participants from Community Colleges have already transferred to 4-year institutions including to Cal Poly Pomona for BS degrees in Engineering. The sixth student also plans to transfer to a 4-year institution for BS degree in Engineering. Some of the transferred students have been working on the projects related to UAVs.

### 5. Improvement in Written and Oral Communication Skills

All the participants presented and/or have been presenting their work at the student conferences. Also, 9 participants so far are main authors or co-authors of papers presented at and published in the proceedings of professional conferences including AIAA SciTech Forum and International Conference on Unmanned Aerial System (ICUAS) [6-10]. Out of these, four participants were the presenters at these conferences. Three participants presented their work at the REU Symposium organized by Council on Undergraduate Research. This shows improved written and oral communication skills of the participants. Studies have shown that writing professional papers and presenting at conferences/seminars/meetings helps undergraduates improve their written and oral communication skills significantly [11, 12]. Studies have also shown that improved communication skills are important for students' future success in the industry [13]. Some other participants are continuing their work and have already obtained publishable results. Several papers are under preparation for submission to professional conferences and/or journals.

## V. Lessons Learned

The experiences from hosting REU programs for three years have taught us several important lessons. Most of the projects require more than one participants due to their interdisciplinary nature. Since the participants may be from different backgrounds and institutions, there is a potential for interpersonal tensions that may negatively impact participants' experiences. We will organize a teambuilding workshop to address any interpersonal conflicts that may arise among participants. We have also learned that the first week is crucial to get the participants up to speed. The participants need more interaction with the faculty mentors and program coordinators during the first and second week. Field trips to industry and research labs seem to have great impact on motivating students to pursue a particular line of industry career and research. As suggested by participants, we try to organize more field trips to local aerospace industries and research labs involved in UAV research and development such as Northrop Grumman Corporation, Lockheed Martin Corporation, and NASA Armstrong Flight Research Center.

## VI. Conclusion

A total of 31 participants were hosted by the REU Site during the course of three years. Six of the participants were from 2-year institutions. Each summer Program included development of technical expertise and professional development of participants.

The REU Program had a great positive impact on the success of the participants. Effectiveness of the Program on student success was assessed using the qualitative and quantitative data collected through pre- and post-participation surveys, faculty mentor evaluations of the participants, and direct communication with the participants. The Program has been successful in preparing the participants for career in industry that are involved in advancing UAV technologies or related areas, motivating them for graduate studies, and motivating them to choose a career path in the area of UAV technologies.

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## References

[1] S. Bhandari, Z. Aliyazicioglu, F. Tang, and A. Raheja, "Research Experience for Undergraduates in UAV Technologies," *Proceedings of American Society of Engineering Education Annual Conference*, Salt Lake City, UT, 25-28 June 2018.

[2] S. Bhandari, Z. Aliyazicioglu, F. Tang, A. Raheja, and E. DeJonghe, "REU Site in UAV Technologies: Assessment of the Program after the Second Year," *Proceedings of American Society of Engineering Education Annual Conference*, Tampa, FL, 16-19 June 2019.

[3] B. Richards, M. Gan, S. Bhandari, et al., "Collision Avoidance System for UAVs using Computer Vision,"*Proceedings of AIAA Infotech@Aerospace Conference*, FL, 5-9 January 2015.

[4] S. Bhandari, Z. Aliyazicioglu, D. Tang, and S. Boskovich, "Engaging Students in Multidisciplinary Projects in Unmanned Vehicles Technologies for Enhanced Learning Experience," *Proceedings of American Society of Engineering Education* (ASEE) *Conference*, Seattle, WA, 13-17 June 2015.

[5] S. Bhandari, "Preparing Aerospace Engineering Students for Career in UAV Technologies," *Proceedings of American Society of Engineering Education Annual Conference*, New Orleans, LA, 26-29 June 2016.

[6] S. H. Cho, V. Gonzalez, S. Bhandari, M. Tischler, et al., "Flight Dynamics Model Identification of a Coaxial Tricopter in Hover using Frequency Domain Technique," *Proceedings of Vertical Flight Society's 75th Annual Forum,* Philadelphia, PA, 13-16 May 2019.

[7] T. Sherman, J. Tellez, H. Haideri, J. Lopez, S. Bhandari, et al., "Cooperative Search and Rescue using Autonomous Unmanned Aerial Vehicles," *Proceedings of Infotech@Aerospace Conference*, *AIAA SciTech Forum*, Kissimmee, FL, 8-12 January 2018.

[8] C. Carreon-Limones, M. Asher, V. Ruiz, R. Lauf, and S. Bhandari, "Increasing the Accuracy of 3-D Maps Created using a UAV-Based LIDAR," *Proceedings of Infotech@Aerospace Conference*, *AIAA SciTech Forum*, Kissimmee, FL, 8-12 January 2018.

[9] E. Perez, A. Winger, S. Bhandari, et al., "Autonomous Collision Avoidance System for a Multicopter using Stereoscopic Vision," *Proceedings of International Conference on Unmanned Aerial Systems*, Dallas, TX, 12-15 June 2018.

[10] T. Sherman, T. Elemy, M. Retherford, T. Cady, and S. Bhandari, "Collision Avoidance System for Fixed-Wing UAVs using Ping-2020 ADS-B Transceivers," *Proceedings of AIAA 2019 SciTech Forum*, San Diego, CA, 7-11 January 2019.

[11] J. Tapper and P. Gruba, "Using a 'Conference Model' to Teach Communication Skills in a Communication Across the Curriculum Program," *Language and Learning Across Disciplines*, Vol. 4, No. 1, May 2000.

[12] J. Borstler and O. Johansson, "The Student Conference - a Tool for the Teaching of Research, Writing, and Presentation Skills, *SIGCSE Bulletin*, Vol 30, No. 3, pp. 28-31, 1998.

[13] M. J. Riemer, "Communication Skills for the 21st Century Engineer," *Global Journal of Engineering Education*, Vol. 11, No. 1, 2007.