Designing an Engineering Research Experience for High School Students

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Abstract

During the Fall 2014 semester, the Transportation Safety and Operations Laboratory (TSOL) in the School of Civil and Environmental Engineering at the Georgia Institute of Technology hosted a high school student as an engineering research intern. In a departure from traditional practice in which interns are provided with an individualized project, TSOL sought to pilot an immersion approach to engaging a high school student in an active engineering research project related to the complexity of roadway environments. In this approach, the student intern, from the Academy of Mathematics, Science, and Technology at Kennesaw Mountain High School (KMHS), participated in regular project meetings and was charged with assisting the research team in extending the data collection efforts to include high school students. This paper discusses the structure developed to meet this immersive approach and includes overviews of the research modules, as well as insights from the high school student, professors, and graduate student researchers who developed the research unit together. This model of student immersion in research may help to facilitate the efforts of schools and universities in providing robust research experiences to high school students.

Keywords

transportation engineering, high school, research internship

Introduction

Scientific research and progress are dependent upon a constant source of innovation and young talent in a profession that hinges on the seamless passing of intellectual and philosophical approaches from teacher to student over time.[1, 2] The researchers, therefore, inherit a duty that is implicit in their work: to train, mentor, and inspire those who have chosen to pursue educational advancement within their fields.[1] However, the skills needed to perform and execute original and independent research are dependent on methodologies and mindsets that are acquired through practice and commitment over time.[3] As a result, graduate students take extended periods of time to become fully integrated and contributing members of a research lab.[3] Undergraduate and high school students, on the other hand, have less of a commitment and even fewer hours to be fully integrated into the labs. Consequently, often they are relegated to tedious and uninteresting tasks because of the belief that their short-term presence cannot yield more than a cursory understanding of a limited skill set. Additionally, the time necessary to train these students

frequently serves as a disincentive in a field where deadlines are constantly looming and time is always short. Unfortunately, this approach to undergraduate and high school students as researchers can result in lack of interest from the student and loss of our most valuable future intellectual capital.

The Transportation Safety and Operations Laboratory (TSOL) at the Georgia Institute of Technology has been actively involved in the development and execution of K-12 outreach initiatives since its inception. Therefore, the opportunity to work with the Academy of Mathematics, Science, and Technology at Kennesaw Mountain High School (KMHS) to bring a high school research intern into the lab represents a continuation of the lab's expertise in research mentorship and outreach. The duration of the internship (12 weeks in the lab followed by 3 weeks of final deliverable preparation) allowed the lab's graduate student researchers and professors to develop an immersive and exhaustive research experience for the student, who worked within a National Center for Transportation Systems Productivity and Management (NCTSPM) funded research project, to develop her own corollary to the problem statement. The student was expected to work with the graduate student cohort to perform at the level of independence and self motivation similar to that of graduate student researchers. The high school student completed the research process: problem definition, experiment implementation, data collection, and analysis over the course of her internship. While working closely under the mentorship of graduate students and with periodic meetings with professors, the high school student developed both independent and collaborative research and analytical skills.

Internship Overview and Timeline

Planning and Logistics

Prior to the beginning of the internship, the supervising professors and several of the graduate students endeavored to scope a research problem with a reasonable prospect for the student to complete the research process over the course of the internship period. The student joined the research lab in mid-August and completed her internship in mid-November. During that period, the student was in the lab for approximately ten hours per week while spending an additional six hours per week in a supporting research and internship class at her high school. The research plan was designed to be flexible in accommodating the student's interests, while allowing the graduate students to guide the project in parallel with their research duties.

One of the most important lessons that emerged from this process was the significance of ensuring that the student's project was related to an ongoing research study in the TSOL. This kept the high school student on the TSOL research project's schedule, and made it easier for the graduate student mentors and professor to facilitate the process. It also allowed the student to attend valuable weekly research meetings during which multiple professors and researchers could give her additional feedback. During the logistics phase, one graduate student was designated as the primary graduate mentor for the intern. This ensured that there was always one graduate student who knew the intern's schedule and tasks for the week, and who could coordinate the availability of all involved. Enacting these basic structures for the internship prior to the student arriving, provided a foundation for the student's research experience.

Human Subjects Research Training

The high school student was first tasked with completing four hours of human subjects research training coordinated through the Office of Research Integrity and Assurance at the Georgia Institute of Technology. A significant portion of the research projects handled through the TSOL relate to the collection of data from human participants, and thus, it was important for the student to learn the privacy protocols and research ethics associated with research projects involving human participants. This was a particular concern because the student was working in a shared laboratory space. Additionally, because the research project in which the student would be involved required the collection of human performance data, it was an absolute necessity for the student to obtain the training as early as possible.

Research Process

At the beginning of her internship experience, the high school student met with the research team with whom she would be working. During these meetings the ongoing TSOL research project was introduced. The research team was working on an experiment to examine the effectiveness of a driving simulator for studying driver perception and behavior in varying roadway environments. The overall goal for this ongoing research is to inform traffic guidance and roadway design. In order to obtain the appropriate knowledge base, the student was asked to read a recently completed report on the research as well other literature reviews that had already been prepared. When the student joined the lab, the research team was in the first stages of implementing an experiment to test driver perception of simulator images alongside in-field roadway images.

At the inception of the internship process, the graduate students developed a research process outline in collaboration with the high school student that provided an overview of the process while corresponding with the timeline for the student's internship period. This is a vital step towards ensuring that the student understands from a broader perspective what is involved in the research process, prior to being involved in the finer details. It provides a roadmap for the high school student to follow as they navigate the research process in its entirety for the first time.

Defining Research Objectives

The first official step in the research process was for the high school student to develop objectives and goals for her research study. The student acquired background knowledge on roadway complexity, driving simulator effectiveness, and inexperienced drivers during this stage of the process. This background knowledge, along with an understanding of the ongoing TSOL research study allowed the student to develop research questions that would guide the research process. The graduate researchers and faculty then helped the student refine and develop the questions that would address the primary goals of the study. The student selected the following objectives to investigate: 1) Perceived roadway complexity for inexperienced drivers as compared to experienced drivers; and, 2) Perceived complexity of field images versus simulator images for inexperienced drivers. The research questions matched well with the ongoing TSOL research that was exploring similar questions for experienced drivers, while allowing the high school student to expand the study to her peer group.

Conducting a Literature Review

After developing her research objectives, the high school student was given a tutorial on the purpose and structure of background research in the form of annotated bibliographies and

literature reviews using scholarly databases. The student was given access to all research resources and databases available through the library at the Georgia Institute of Technology.

The primary databases that the high school student used for her literature review included: (1) Transportation Research International Database (TRID); (2) ASCE Civil Engineering Database; (3) Compendex; and (4) Web of Science. First, the student completed an annotated bibliography focusing on the sources related to the objectives developed in the previous step. The student focused particularly on inexperienced drivers as this group was outside of the ongoing TSOL research project. After completing the annotated bibliography, the graduate students guided the high school student to organize the sources into a coherent and targeted outline that she developed into her literature review. The graduate students reviewed the literature review, provided comments on the student's final write-up, and worked closely with her to ensure that the final product fulfilled the expectations for a research paper. The high school student presented an oral synopsis of her literature review at the lab's weekly research meeting.

Experimental Design

After completing the literature review, the student developed the experimental design for her research questions. The experiment involved asking subjects to rate the image complexity, on a scale from 1 to 5, of simulator and in-field roadway images. The ratings portion of the experiment was followed by a demographic survey. Sample images utilized in this research experiment are included below as Figure 1. This experiment was in the process of being implemented for experienced drivers at the Georgia Institute of Technology at the beginning of the student's internship experience, so at this stage the student was tasked with adapting the experiment to her intended audience. The student proposed changes to the original demographic survey questions to obtain more relevant information from her target demographic of inexperienced drivers. These changes were discussed at the weekly research meeting and the student was given feedback and guidance. A sampling of the changes made to the demographic survey by the student is included in Table 1.

Figure 1. Roadway images used in experiment

Table 1. Sample demographic survey updates

Original Demographic Question	High School Demographic Question
Q: Which best describes your age? A: 18-24, 25-34, 35-44, 45-54, 55-64, 65+, Choose not to answer	Q: Which best describes your grade level? A: 9,10, 11, 12, Faculty/Staff, Choose not to answer
Q: In which country did you learn to drive? A: List countries	Q: *Which of the following do you currently hold? A: Driver's License, Learner's Permit, None of the above, other
Q: How many years of driving experience do you have? A: < 5 years, 5-10 years, 11-15 years, >15 years, choose not to answer	Q: If you have a driving license, how long have you had it? A: 0 months (I do not have my license), Less than 1 month, 1-2 months, 3-4 months, 5-6 months, 7-8 months, 9-10 months, 11-12 months, 13-14 months, 15-16 months, 17-18 months, 19-20 months, 21-22 months, 23-24 months, 24+ months

* Note: The original experiment required that subjects hold a driver's license for at least 2 years; this was not required for the high school implementation.

The ongoing TSOL experiment was designed and run using Inquisit® 3 by Millisecond Software, a stimulus control and data acquisition platform. An Inquisit program for collecting both ratings and response latencies from the subjects was developed by the research team as part of the TSOL project. A tutorial on the Inquisit coding language, which requires basic html and Python type scripting to build the experiment, was provided to the high school student. After the tutorial by the graduate researcher, the student was asked to review the Inquisit® documentation. Independently the student then modified the experimental script to change the demographic survey questions. The goal was to ensure that the student understood the experimental script and was able to manipulate it independently. Future implementations of this research experience should strive to preserve the sharing of operational knowledge of the experimental platform/script with high school researchers as this fosters confidence and ownership of the experiment for the younger student.

Experiment Implementation

The experiment implementation was the most intensive step in the student's research process. This was because the intern intended to implement the experiment at her high school, and therefore the experiment had to be approved by the Cobb County School District (CCSD) Research and Evaluation Department, as well as by the Principal of KMHS. Additionally, because data from human participants would be collected and there was the expectation that the research would be published, the researchers at the Georgia Institute of Technology were required to submit the research protocol for approval by the Institutional Review Board (IRB). Both approval steps required a substantial amount of effort and time on the part of the graduate researchers, faculty, and high school student. However, an important part of this learning process was to ensure that the high school student became knowledgeable in and was responsible for this research approval process.

Additionally, because the data collected at the high school would involve students under the age of 18, the research approval processes had additional steps for the involvement of minors. The team began preparing the forms and protocols for data collection very early in the student's internship. The graduate researchers guided the high school student in developing parental permission forms, assent forms, and informed consent forms for the potential high school participants. To obtain IRB approval, the student was also responsible for adapting the experimental protocol for the ongoing TSOL project to the high school setting and detailing recruitment and compensation methods for the study. There were several unexpected obstacles that the team encountered while pursuing approval for this study, and thus, it is recommended to future researchers pursuing this process to begin the IRB process as early as possible in the internship experience. Despite the early submission of the experiment protocol for approval by Kennesaw Mountain High School, CCSD, and the Office of Research Integrity and Assurance at the Georgia Institute of Technology, final approval from all requisite offices occurred two weeks prior to the end of the student's internship time in the TSOL.

Once approval was obtained, the high school student began recruiting participants using the IRB approved recruitment procedures that had been submitted earlier. These included making announcements at her school, visiting classes to inform students of the study, advertising using flyers and word of mouth, and obtaining permission from teachers to excuse students from their classes for the study. The participants were given one hour of community service credit for their participation in the study. An image of a flyer developed by the student and posted at her school is shown in Figure 2. The student also went through a series of pilot runs in administering the experiment to ensure that she was prepared to implement the experiment following the IRB approved protocol and methodology. The high school intern reported this stage of the research process as the most demanding and challenging phase, especially given the shortened timeline caused by the late approval by all involved institutions.

This phase of the internship also proved to be the most challenging to the graduate researchers because it required the most time and coordination on their parts. It was very important for the team to ensure that the equipment used at KMHS was equivalent to the equipment used for the experiment conducted at the Georgia Institute of Technology in order to ensure data comparability between the two data collection sites. For the research study, computer monitors of the same resolution were purchased and the same keyboards used in the original experiment were used in the high school implementation to limit confounding variables. The experiment was conducted onsite at KMHS, and the graduate students transported and assembled the equipment for all data collection efforts. The high school student recruited 40 participants from the high school population, and administered the experiment independently, with the graduate students present to assist in managing the experiment participants and ensuring that the equipment was fully functional throughout the experiment. Data collection was successful with no complications, and all data were collected over the course of two days. The data and equipment were transported back to a secure location on the Georgia Institute of Technology campus at the end of the each day. Figures 3-6 show the experimental setup of the experiment at KMHS.

Figure 2. Recruitment efforts at Kennesaw Mountain High School

Figure 3. Experimental setup at Kennesaw Mountain High School

Figure 4. High School intern setting up experiment

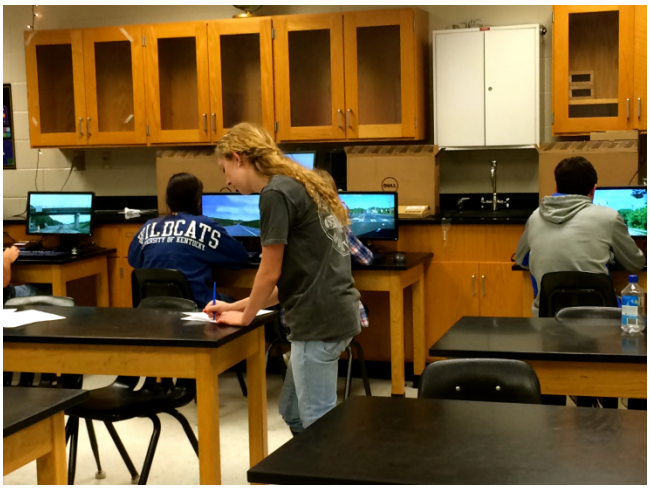

Figure 5. High School intern taking notes during experiment administration

Figure 6. Graduate students with high school student after data collection at KMHS

Data Analysis

This step of the research process occurred during the final week of the internship experience. The data from the high school experiments were transported back to the lab at the Georgia Institute of Technology where the high school student processed the data under guidance from her graduate student and faculty mentors. The data analysis was performed using both Microsoft Excel® and the "R" statistical language. The graduate students taught the high school intern the basics of data analysis using the aforementioned platforms. The student examined basic descriptive statistics regarding the ratings and latencies of her participants, and constructed histograms to observe and compare the rating trends between simulator and in-field images. The results from the inexperienced drivers were also compared with the data previously collected on the experienced drivers at the Georgia Institute of Technology. The high school student used the t-test and Wilcoxon Rank-Sum Test to check for statistical significance between population averages of image ratings. During the data analysis stage of the research structure, it was vital to teach the student the importance of thorough and ethical data analysis practices, as this is arguably the most important research skill needed to produce original and independent work.

Preliminary findings from the high school student's data collection efforts indicate no statistically significant differences between the inexperienced and experienced populations with regard to the average ratings. However, there are findings of differences in the average ratings between the in-field and simulator environments. The high school data also showed a positive correlation between the length of time that the inexperienced drivers held their licenses (measured in months) and the complexity ratings of the images. These findings must be explored in significantly greater detail by other researchers before definitive conclusions can be made; but, these conclusions do serve to indicate the level of data analysis that the high school student was able to perform on her data.

Research Deliverables

The high school student was given three weeks to prepare a presentation, research poster, and final report for the research team and for her high school teachers. During this month (mid-November to mid-December), the student continued to collaborate closely with her graduate student mentors who provided feedback and guidance on the deliverables. The research team also submitted an abstract titled *Perceived Complexity of Simulator Environments for Younger Drivers* to the Road Safety and Simulation (RSS) International Conference; the student is the second author on this accepted conference paper. Additionally, the student is second author on this ASEE SE paper titled *Designing an Engineering Research Experience for High School Students* which details her internship experience. The high school student has contributed substantially to these additional research deliverables under guidance from her graduate student mentors.

Integration of Student into Lab

The close guidance of the high school student through the research process is vital for the research internship experience to be successful, but it is not the only aspect that should be developed. If the student is interested in a research career, then the overall experience will be greatly enhanced if the student is exposed to other aspects of research life. In the case of the high school student who interned at the TSOL lab, her graduate student mentors sought out opportunities to involve the student in lab activities outside of research. These included a K-12 volunteer initiative at a local middle school, attendance at an urban transportation planning lecture, group lunches, and various excursions on campus designed to allow the student to experience the Georgia Institute of Technology outside of the lab. The high school student also attended weekly research meetings with the full research team, in addition to regular meetings with her graduate student mentors. Figures 7-8 show the high school student working in the TSOL lab. University research can be an exciting and collaborative process set within a dynamic learning environment, and every effort should be made to showcase and involve younger students in these aspects of research.

Figure 7. High School intern working in the lab

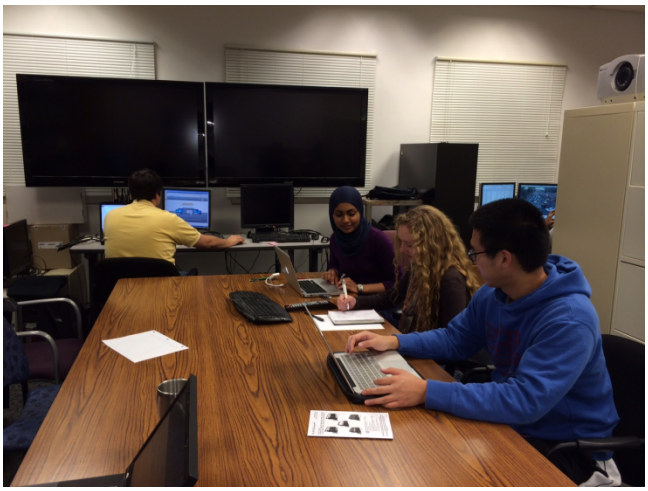

Figure 8. Graduate students meeting with student in lab

Evaluation Methods

While the research team, including the faculty, graduate students, and high school student, strove for a strong and comprehensive research experience, the tendency to focus primarily on the research objectives from the inception lead to a limited ability to objectively measure the value of the experience outside of the success or failure of the research project objectives. To address this weakness prior to future internships, the researchers will explore additional means of evaluating the research experience. These may include surveys of the high school student, faculty, graduate students, and high school teacher expectations, development of clear learning metrics not associated with specific research outcomes, and involvement of research personnel who study K-12 outreach assessments and evaluation metrics.

Hence, an important lesson learned by the research team was that research internships should have performance objectives besides the completion of research tasks. These objectives need to be developed by the mentor and intern prior to the beginning of the internship, and ideally should

be assessed at the beginning, midpoint, and ending stages of the research experience. One possible format for this assessment is a student survey followed by feedback and discussion of the objectives. Such an assessment should be enacted for the entire research team: professors, students, high school teachers, etc. and as such all personnel would be involved in a continual improvement process over the course of the experience. The professors could be responsible for guiding the process for the graduate students, and the graduate students in turn could guide the process for the high school students.

While this assessment method was absent at the beginning of this particular internship experience, it was developed towards the conclusion to serve as a final metric. Presented below is the assessment survey that was developed by the graduate researchers and high school student. The survey includes the objectives that the high school student wanted to develop over the course of the internship. The rating scale utilized is taken from the skill proficiency scale developed by the research foundation at the University at Albany.[4] In the context of this research experience, the following two sections summarize the high school student's self-reported responses detailing the development of her target skill sets over the internship experience.

Sample Survey Format

> Rate your ability to apply the following skills using the scale provided:
> **(1) None** – "not able to apply this skill", needs strong guidance
> **(2) Basic** – "able to handle only the simplest assignments or tasks", needs moderate guidance
> **(3) Intermediate** – "able to handle independently many types of assignments or tasks", needs minimal guidance
> **(4) Advanced** – "able to handle independently nearly all types of assignments or tasks", does not need guidance
>
> 1. Technical Writing Skills
> 2. Research (Information gathering) Skills
> 3. Collaboration Skills
> 4. Communication Skills
> 5. Presentation Skills
> 6. Understanding of the Topic Area
> 7. Data Analysis Skills
> 8. Programming/Coding Skills
> 9. Research Ethics Knowledge
> 10. Research Paper Formatting Knowledge

Student Evaluation

The high school student completed the sample survey presented above; the results of which are summarized in Figure 9. The student indicated an improvement in each of the target research skills that were chosen as being paramount learning indicators in this initiative. At the conclusion of the internship, the student also engaged in a reflective discussion with her graduate student mentors, and provided written feedback regarding the experience. The high school student indicated that she believed that the setting of a large research university was an invaluable experience with numerous educational learning outcomes that could have not been facilitated in a classroom or alternative setting. It was indicated that the many imperfections and obstacles

faced throughout the project resulted in the most substantial gains in understanding how the research process works. Ultimately, the student expressed the belief that the most important aspect of the program was the close contact and collaboration with her graduate student mentors throughout the internship. The high school student expressed comfort in testing her newly developed skills in a supervised environment monitored by the graduate students, and highly recommends this experience to her peers and other high schools students seeking such opportunities.

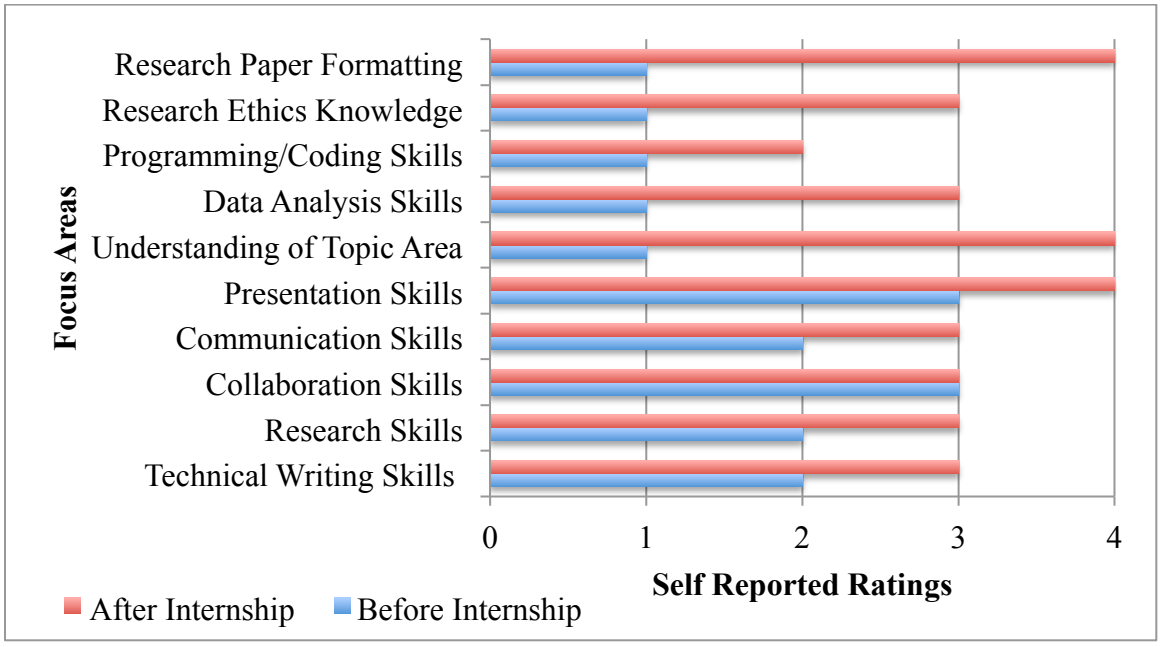

Figure 9. High school student survey results

Insights from the Research Team

As with the survey developed for the student, evaluation measures should be developed to allow for feedback from faculty, teachers, and graduate student mentors regarding the younger researcher's experience. In the absence of a formal evaluation method, insights and input regarding the high school student's experience are presented in this section to allow for the sharing of lessons learned from this pilot study.

The graduate students who worked together to implement this three-month research internship emphasize the commitment and time challenges involved in the initiative. However, overall they felt that the experience enabled them to develop and practice the research, leadership, and mentoring skills that are highly valued in their field. Almost all of the graduate researchers expressed an interest in facilitating the continuation of this level of research immersion in the TSOL lab. Additionally, they highly recommend such experiences to other graduate students, professors, and research labs with the cautionary note that a supportive research team will enable the successful implementation of the project with minimal increased burdens on all involved.

The high school teacher who served as the student's research teacher at KMHS also provided a written evaluation of the student's internship experience to the research team. The research teacher indicated that she believed this research experience at the collegiate level provided an invaluable experience for the high school student, while allowing for her to obtain a significant

understanding of the true research process. The high school student's teacher was complimentary in noting the supportiveness that the graduate student mentors provided in guiding and assisting the student throughout the process.

The professors involved in this research initiative were instrumental in guiding the internship experience for both the graduate student mentors and the high school student. By implementing a well-designed structure they ensured that the experience did not present excessive demands on the limited time of any one person, while allowing their graduate students to develop important mentorship and teaching skills. Overall, the professors believe that the experience provided significant developmental and intellectual benefits to all parties involved, and are interested in facilitating this experience in future semesters.

Conclusion

The goal of this research initiative was to develop a streamlined, immersive, and engaging high school engineering research experience that could serve as a model for other researchers and labs. By implementing a three month research unit that covered all steps in the research process for a relevant and publishable research topic, the team has successfully executed a pilot study of immersing a high school student within a university research lab. The intent of this exercise is to encourage and foster research opportunities for high school students through internships or other such experiences within research environments and universities. Based on previous research studies, it is believed that more initiatives like these will ensure that a greater proportion of future scientists will be inspired to enter Science, Technology, Engineering, and Mathematics (STEM) careers as a result of excellent high school research experiences.[5]

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Atiyya Shaw

Atiyya Shaw is a graduate student studying Transportation Engineering at the Georgia Institute of Technology. She received her B.S. in Civil Engineering from the Georgia Institute of Technology in May 2014. Atiyya's research interests are currently focused on transportation safety and human factors engineering, transportation systems planning and design, and computational modeling for transportation applications. She is committed to K-12 outreach initiatives where she seeks to connect real world applications with the math and science skills taught in classrooms.

Kathrine Udell

Kathrine Udell is a high school senior currently attending the Kennesaw Mountain High School Academy of Mathematics, Science, and Technology. She plans to enroll in college next fall and intends to major in engineering. Kathrine hopes to continue research as an undergraduate and graduate student. She would like to encourage young students to become involved in math and science.

Aaron Greenwood

Aaron Greenwood is pursuing a Ph.D. in Civil and Environmental Engineering at the Georgia Institute of Technology. His research focuses on transportation safety and human factors in road systems. Mr. Greenwood earned both his B.S. and M.S. in Civil Engineering from the Georgia Institute of Technology in 2010 and 2012 respectively.

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