

## **Aerospace Lunar Lander System Design - A High School Student's Independent Design Project**

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## **Abstract:**

In this study, a high school student is involved in research in an engineering laboratory at a public university. The student started with limited research skills but was able to quickly learn some of the tools and techniques. She developed detailed computer models for lunar rover vehicle and performed various engineering analyses. This gave her an opportunity to learn well above and beyond what was expected from a typical high school student. The merits of involving grade school students in research are discussed. Some details of the student design work are presented. Challenges and advantages associated with working with minors are discussed. Student reflections are also highlighted.

## **Introduction:**

In this paper, a case study is presented where a high school student is engaged in independent research in an engineering laboratory at a comprehensive public university. The minority female high school student is the sole participant in this project and is advised by a senior faculty member in the college of engineering. The student's long-term career goal is to become an aerospace engineer and work for a major national organization. The student undertook this study during the summer between her junior and senior years of high school and continued into the following fall semester while attending school full-time. She initially reached out to the faculty member and inquired about the possibility of doing research at the professor's laboratory. Her motivation was to design an engineering product that would provide an alternative solution to the existing lunar rover design concepts. She also wanted to learn the research process so she could prepare herself for more advanced opportunities in the future. The student helped develop a research topic, performed literature review, gathered pertinent information, defined requirements, bench marked existing designs, selected off-the-shelf components, planned missions, created models, performed engineering analyses, wrote a paper, and presented her work at a local symposium. In a short amount of time, she learned new knowledge including the use of engineering software and performed valuable analyses. She worked on developing a conceptual design of a lunar rover. The objective of the rover is to collect rock samples from remote locations and bring them back to the base station. The rover is equipped with various sensors to collect data on temperature, radiation levels, soil composition, and moisture. She worked on various aspects of the design starting with requirements definition, creating mission profile, creating Computer Aided Design (CAD) models, and performing Finite Element Analyses (FEA).

The challenges and opportunities of involving high-school minority students are explored in this paper. Research in Engineering Education has demonstrated the value of intellectual development of students when they work with faculty advisors on engaging research projects. Developmental experiences of the student in terms of motivation, learning behaviors, and engineering knowledge are explored. These developments are expected to have a critical impact on higher education and the future career trajectory that the student pursues. This study provides an example of how an

independent study may provide opportunities for high school student development and the critical role a university professor and advisor may play in enabling this development.

### **Literature Review:**

Literature is rife with convincing arguments about the benefits of involving students in research early in their academic careers. Sandnes et. al. assert that advancing the research agenda of a department, while nurturing the academic skills of the student, is a win-win scenario [1]. Grade school students are often involved in summer camps, research student assistantships, and other short-term studies where they are only able to make limited contributions. However, talented students can be engaged in research while they are still in their high school. These students often learn the prerequisite knowledge quickly and can make valuable contributions in a relatively short amount of time if given the opportunity. Involvement of students in research can help prepare them for lifelong learning. Research can stimulate students' enthusiasm for a subject [2]. Sandes discusses the value of including students as co-authors in publications [1]. Engineering in general is a discipline in which a lot of learning is done by hands-on, experimental, operational, observational, and exploratory techniques. These techniques can be taught and enjoyed by students of all ages including middle and high school students [3]. Schmitt et al argue that for years, grade school students experience instruction that is slow-paced, one-size-fits-all, and inadequate in meeting their unique needs [4]. The needs of high achieving students are often not met which results in them getting bored, apathetic, and disappointed in school because it fails to challenge them. This situation can be improved through involving these students in research at the university level. Christenson asserts that affective engagement of students is associated with positive learning outcomes [5].

### **Anecdotal Success Story:**

There are numerous examples of students who performed well, not only in the research lab, but also academically and professionally because of their early involvement in research. One such example is that of a middle school student [6, 7] who approached a research active professor and showed interest in getting involved in research with the lifelong goal of working at NASA. With some apprehension, the professor accepted the student in their lab. This student was self-motivated and driven to do well academically and had unwavering support from his parents. He indicated that he did not have access to a wind tunnel in his school and wanted to perform some studies involving wind tunnel experimentations. The professor worked with the student and created a structured approach for conducting research. The student performed literature review and learned the basic theory needed for fundamental aerodynamic analysis. The student would be driven to the research lab at the university by his parents every week, a parent would wait while the student had meetings with the professor or performed experiments and analyses. In a short period of time, the student learned the procedure for performing wind tunnel testing. By working with other undergraduate and graduate students in the laboratory, the student gained experience on using Computer Aided Design (CAD) and Finite Element Analysis (FEA). Within a year, the student completed two studies related to blended wing-body propulsion design and box wing design optimization. He conducted computer simulations, built 3D printed models and compared results obtained from the wind tunnel analyses. He presented his work at a professional aerospace

conference and won a special award for being the best and youngest student presenter. The student continued to engage in research through his high school years while taking advanced college level courses through dual enrollment. He then went on to publish his research work in two separate journal papers. By the time he went to college he had enough advance placement, college credits, and accolades to be able to finish his undergraduate degree in two years. He got admitted to a leading research university with a full scholarship and grants that not only paid for his college tuition but also gave him additional funds to pay for housing, books, meals, and other expenses – essentially making college completely free of cost. He then went on to complete his Master and Ph.D. degrees in less than 4 years. During the college years, he interned at the top aerospace organizations in the country. After his graduation, he got a job as an aerospace scientist at NASA Jet Propulsion Laboratory – i.e. his dream job when he was an 8th grader. The author believes that the students' involvement in research at a very early age had a positive impact in paving his way to success. The author often relates this success story to students and continues to engage not only graduate students, but also undergraduate, and younger students in his lab. The current study is an example of another high school student engaged in the author's research laboratory.

### **Design of Lunar Rover:**

In this study, the high school student helped design an autonomous lunar rover for soil sampling and testing applications. A systems engineering approach was used to design the rover referred to as Autonomous Lunar Investigation and Communications Explorer (ALICE). An essential component is the development and progress of autonomous rovers, which are capable of navigating and exploring the lunar surface without constant human interference. The student started the design process by defining the functional and physical requirements. Based on those requirements, the student came up with the mission profile. Following the design process, a weight breakdown structure was created, and an estimated weight was calculated. The vehicle structural elements were later modified to optimize the weight. A detailed literature search was performed to determine the Commercial Off the Shelf (COTS) Components including but not limited to Microscopic Imager (MI), navigation camera, descent camera, hazard avoidance camera, environmental monitoring system (REMS), Radiation Assessment Detector (RAD), Alpha Particle X-Ray Spectrometer (APXS), Mossbauer Spectrometer (MS), Rock Abrasion Tool, Neutron Spectrometer System (NSS) etc. The student generated scaled Compute Aided Design (CAD) models of all these components. Iterative sizing of the rover was performed to optimally house COTS components, batteries, motors, and solar panels. Detailed CAD models of the rover were generated using SolidWorks as shown in Figure 1. Detailed models of pole and robotic arm were created by the student to be able to carry the instruments and tools. The solar panels consisting of Spectrolab solar voltaic cells, and the Radiation Assessment Detector were integrated into the system. Rotation capability was added to the robotic arm for the four instruments. The rocker-bogie suspension system was used for the rover. The rocker-bogie system has two parts (rocker and bogie) which allows the wheels to climb over larger objects without compromising stability.

To perform this study, the student learned how to use SolidWorks – the main CAD package used at the university. She also learned how to perform Finite Element Analysis (FEA) using FlowSim.

Additionally, she created physical models using 3D printing. These tools were essential to complete her study.

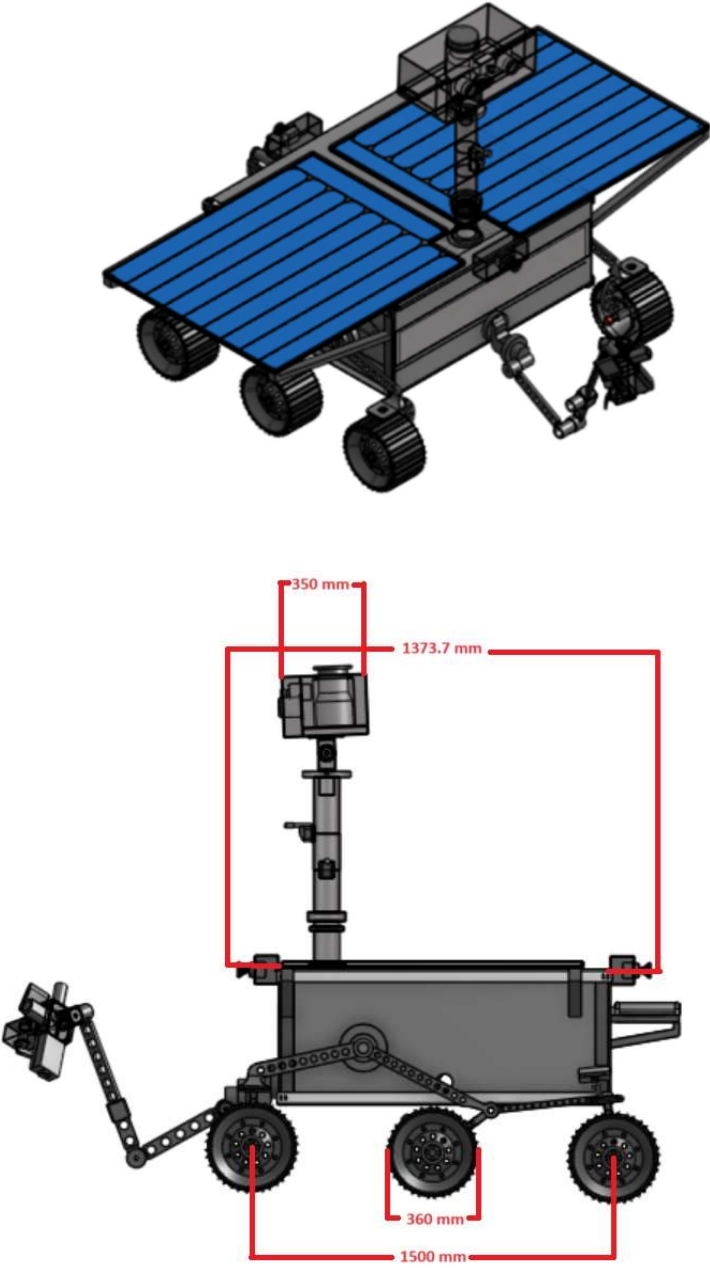


Figure 1: Parametric CAD Models of ALICE

The student performed Finite Element Analysis (FEA) on the robotic arm to ensure that the structure was strong enough to sustain the full load of the instruments and tools while fully loaded with oil sample in all configurations and orientations. She applied a Factor of Safety to ensure adequate strength. Applied distributed forces, Von Mises stress and displacements were calculated. The displacement results of the analysis are shown in Figure 2.

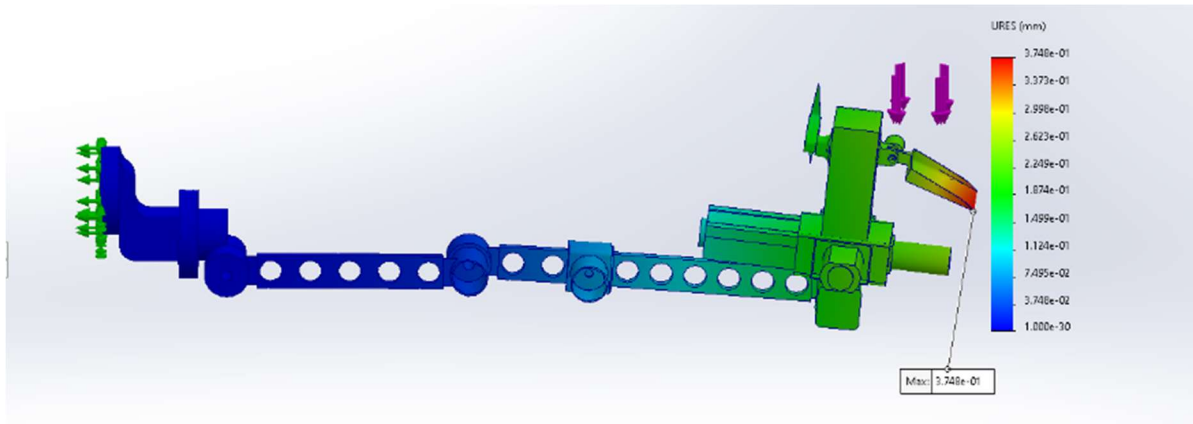


Figure 2: Finite Element Analysis Results of Displacement Analysis of the Robotic Arm

The next step for the student is to create a functioning robot arm attached to the rover.

### Challenges:

There were several challenges associated with involving grade school students in an engineering research lab at a public university. Since she was a full-time student at a local high school, she could only meet at certain times of the day and certain days of the week. The professor had to accommodate the schedules. Also, being a minor, she was not able to drive to the university. Her parents brought her to the lab once a week throughout the semester and waited while she met with the professor and worked on the project. The professor had to get approvals from the university including getting background checks done to be able to work with a minor. When the student started, she was not familiar with the research process. A few initial weeks were spent going over the methodology of conducting research. The student also learned how to use the engineering software. Since her school did not have the license for the software, she had to perform all the modeling and analyses at the university research lab. Also, since she was not officially enrolled at the university, she had to be given special access to the engineering lab and university computers. All these accommodations were made to give this student an opportunity to learn well beyond what her peers learned at her school.

### Advantages:

Despite all the challenges, the student performed well. She was able to complete the design and analysis of ALICE over the span of two semesters. As a result of getting involved in research and working on this project, she learned how to perform research starting with literature review. She

learned how to review and critique other research papers. She learned how to look up, review and analyze the COTS components, perform benchmarking and other engineering techniques to select the most appropriate components based on their specifications. She learned the meaning and need of tradeoffs while selecting components. She learned how to perform engineering calculations including but not limited to weight estimation; force, moment, energy, and momentum balance; creating CAD models; performing FEA analyses; comparing and analyzing results and drawing conclusions. She learned how to optimize the vehicle performance under the given constraints. She performed weight analysis and carefully selected and reduced weight of the vehicle where possible. She also learned how to write technical research papers using a template from a professional organization. She presented her work at the symposium of student scholars in the form of a poster – through this process, she learned public speaking skills and the ability to answer technical questions. She created 3D printed models of ALICE and performed additional tests.

### **Student Reflections:**

The high school student was asked about her experience of working on a research project at an engineering university. The questions and the corresponding responses are given as follows:

What were some of the challenges you faced during this study (include any challenges with scheduling, commute, balancing schoolwork, technical difficulties etc.)?

The student reported:

*“One of the biggest challenges during this study was balancing school and extracurricular activities. Taking five AP classes this year, being Outreach Director for my robotics team as well as being part of the design team, and running my club called Students in Space made it difficult to accommodate space in the day for everything, so extreme organization and time-efficiency was important. Additionally, I am in the stage in high school to be preparing for standardized tests such as SAT and ACT, which needs attention as well. Keeping a calendar and a detailed plan made time management easier, but not completely perfect. By being on a robotics team and taking engineering classes, I was able to acquire basic information on the design process and CAD skills, however, I did not have much experience with research nor with extensive systems design. Throughout this process, I was able to expand my knowledge on various types of mechanisms as well as proper research techniques. One other difficulty I faced was not having access to a software that was crucial for the analysis portion: neither did my school nor did I have an account for the most current version of Solidworks, where I would be doing FEA for the system. The solution for this was commuting to the lab once a week. I would have a limited amount of time since I could not work on the analysis portion from home, and therefore required a different approach to project planning when figuring out what the next steps were.”*

As evident from the student’s response, there were numerous challenges but because of her determination and willingness to learn, she was able to conduct an independent research study in a relatively short period of time.

What are the advantages of your involvement in this research study as a high school student (for example what have you learned and how do you think this will help you in the future)?

The student responded: “

*As a high school student being involved in a research project, one of the biggest advantages was the ability to develop a variety of skills including critical thinking, problem solving, and communication. I am able to delve deeper into a subject area that I want my career to be in, in ways that I would otherwise not be able to do in a normal classroom setting. Through presentations and networking, I was able to develop effective communication skills as well as confidence in articulating my ideas with my own words. As a high schooler, there isn't much emphasis on presentations or discussions, rather more note-taking with a set type of problems. This created a void in being able to express my thoughts clearly "on the spot", a skill which is vital in a professional setting. The study also presented an opportunity to provide a contribution to knowledge. During the literature review phase, I was able to learn how to assess the validity of certain sources and papers. Later, this extended into assessing the validity of software settings, such as in Solidworks FEA. More specific to the subject area, I was able to discover how interconnected different concepts were which allowed me to create the actual design of the system. Engineering and physics were just a couple parts in the entirety of the big picture. Not only was I able to gain more knowledge in Aerospace or Systems Engineering, I was also able to develop soft skills such as networking and critical evaluation.”*

As noted by the student, the advantages of student involvement in research go far beyond gaining technical skills. Students can gain soft skills that are not typically taught in a school curriculum. These soft skills include interpersonal skills, communication skills, listening skills, time management, problem-solving, leadership, and empathy, among others. These are some of the top skills that employers seek in the candidates they hire because soft skills are important for just about every job [8].

What could be done to make this research experience better?

The student suggested:

*“Because this is my first research experience, I do not have much to compare it to. With that said, I feel that I would benefit from meeting twice a week rather than once so that I have more set times each week to work on the project. This was a scheduling issue and continues to be one due to school, so it would be difficult to actually implement this. Another part that would make things much more convenient would be if I had access to the most current version of Solidworks, but once again, this is not something that can be fixed easily. One thing that I believe could be implemented in the future once the project is somewhat “whole” is interdisciplinary research. If I could explore the connections between different subject areas which present themselves in a research project, I would really be able to see the amount of effort a team puts in into a groundbreaking opportunity and what it produces. It would also be interesting to see if what I produce is in any shape or form actually used for its purpose and would definitely provide another level of accomplishment. As for the present, this research has been truly amazing so far, and there isn't much I would change; I feel motivated with each new question and obstacle.”*

The key element of working with a high school student is to provide an opportunity for them to explore engineering well beyond what they would ordinarily do in their school. As a result of the



current students' involvement in this research, the author believes that the goal has been accomplished.

### **Conclusion:**

Often, researchers are hesitant to involve minors or junior students with limited knowledge or skills in research studies. This paper presented a case study in which a high school student got involved with research, learned new skills, and was able to make independent contributions. Anecdotal evidence of the success of involving a high-achieving student in research, early in their academic career, is presented. From the author's perspective, there is a time commitment required from the professor to engage high school or junior students in research, but the broader advantages often outweigh the challenges. As evident from the students' comments, the experience was worthwhile. It intrigued her interest in engineering and put her on the path to lifelong learning and a successful engineering career.

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