# INTRODUCTION

Education has always been important to me from a young age. It was my educational experiences that influenced me to pursue the path of an engineer and inspired me to work hard and be ambitious. Thanks to my positive educational experiences from my physics teacher and robotics club in high school, I am now a senior studying Robotics Engineering and conducting research in Dr. Dan Aukes’ robotics lab at Arizona State University. This experience of conducting research as an undergraduate has, in turn, inspired me to pursue a graduate level degree in computer science and continue conducting research in robotics. I would like to continue this cycle by contributing to the field of educational robotics so that I may impact the next generation.

I first became interested in engineering when I was in high school and I realized that I particularly enjoyed my physics classes. This was in-part due to our excellent AP Physics teacher Mr. Middleton who challenged us to break down problems analytically and reason out information for ourselves both through physical experiments and Gedanken experiments. While this approach to learning mechanics and electromagnetism was difficult, it taught me what could be accomplished using scientific investigation. My passion for investigation has carried me through the engineering program and led me to academic research where a curiosity motivates our questions and hypotheses and we carry out investigations to find the answers.

Without my inspirational educational experiences, I would not have found my way into academia and research, and I would like to help make sure that other students have the same opportunities as I did to discover a passion for scientific inquiry for themselves. One way that I believe we can do this is through the tool of robotics. My second impactful experience in high school came from joining my school’s robotics team. Here I discovered a practical application for my skills and passions as well as—equally importantly—a community of peers to work alongside and collaborate with. This community, I believe, is one of the essential aspects of research because it serves as a motivator and a guide of our inquiries.

My goal is to advance our robotics capabilities so that robots may be used in more areas than they are currently, effectively bringing robotics to the masses. To do this I would like to continue researching in the area of robotics as I get my doctoral degree in computer science. Whereas my undergraduate research has focused on the mechanical design of robots, I would like to move into the software controlling robots. I feel the two main factors preventing the wider proliferation of robotics is their cost and the difficulties involved in programming them to accomplish desired tasks. My undergraduate research has been in the new field of foldable robotics, which is one potential solution to the problem of cost. I would now like to work on what I see as the other main issue, intelligent control software.

After being the first in my family to receive a PhD, I would like to become a professor and lead a research team in the area of autonomous robotics, so that I may continue to advance the country’s robotics capabilities and one day become a leader in this field. In order to do this I need to build my credentials and connections in this field, which is why I want to go to graduate school. As a PhD candidate I will learn more about autonomous systems, machine learning, and artificial intelligence both through my coursework and through my research. The opportunity to apply my knowledge was what got me interested in robotics in the first place back in high school, and now getting to learn on my own through research has been one of my favorite and most inspiring experiences as an undergraduate. I am excited to continue the same type of experience to a greater extent throughout my doctoral degree. ~~The result of this research will be multiple publications which are important for sharing knowledge with the community as well as for building my own credentials as an author of scientific articles.~~

The community in graduate school is also important to me. In high school, I learned the power that comes from collaborating with the like-minded individuals on my robotics team as we critiqued, challenged, and encouraged each other. The lab community that I have now has been crucial for inspiring my work. My mentor has served as someone to teach me the skills I need, push me to work harder and go outside my comfort zone, and help me to reconcile issues when I have gotten stuck. I believe that this mentor relationship is necessary to build up new experts in a field, and I am thankful to have already gotten some taste of it as an undergraduate. As a PhD student seeking to become a professor, I will be even more challenged by my mentor, but will have the opportunities to learn how to be an effective professor from their teaching and leadership styles. ~~I also am excited to continue working in a close community of fellow scholars who are all mutually interested in robotics. After graduate school, these connections will continue to be important. The professors that I knew while in school will be important resources and references as I attempt to establish my own career. The students that I work with will be important peers who will also be trying to establish their own labs and will be facing the same challenges as me. This academic community will live on past school and continue throughout my professional career.~~

# BROADER IMPACTS

In college, I have helped students in elementary through high school discover the same transformative joys I experienced. I have mentored my old high school’s robotics team for these past three years and volunteered at all of their competitions where someone with experience is needed to help organize and officiate the events. While my inspiration came in high school, many students now are being exposed to engineering as early as elementary school. One effective tool that many educators are using to do this is robotics because it makes engineering concepts fun and practical for students since they can build mechanisms and see these principles in action. I have seen this first-hand as I taught several robotics workshops with elementary-age students. For many students, what they previously considered to be boring or too abstract becomes hands-on and enjoyable through the tool of robotics.

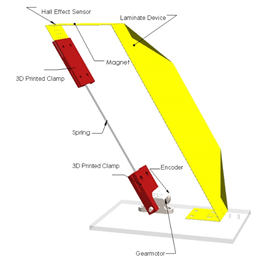
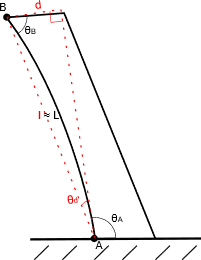
The research in Dr. Dan Aukes’ lab centers around developing robots using unconventional materials and methods. One of our primary areas of work is foldable, origami-inspired robotics. This field has the potential to lower the cost and increase the accessibility of robots by using cheaper materials, more available manufacturing processes, and simpler design methodologies. By developing this field, I hope to allow more students to have the kind of positive educational experiences that I had.

Traditional robots are precision machined from metal, which requires significant investment in the materials and machines, as well as advanced expertise. Several commercially available robotics kits attempt to solve this issue, however the limitation of using prefabricated parts inhibits students’ creativity and restricts the designs that can be explored. My research in robots made from informal materials and rapid prototyping seeks to lower the cost, time, and technical skill required to make robots, while still allowing construction from scratch. This makes the process more accessible and opens the doors for more students to experience robotics in their pre-college education. Students don’t need to attend a school with a machine shop or be limited by what can be made with kits. They can rapidly make foldable mechanisms from cardboard, test them to discover the motion they produce, and iterate on their design to learn how to produce the desired effect. The goal is to show students that engineering is not beyond them and to inspire these students as I was inspired.

# INTELLECTUAL MERIT

My research has focused on improving the quality and ease of building foldable robots without increasing the complexity or costs. The first project that I worked on to this end when I joined Dr. Aukes’ lab after receiving an undergraduate research fellowship, was an individual assignment to develop a force sensing device that could easily be integrated into an existing foldable robot design. This device takes advantage of the inherent flexibility of foldable laminate materials and uses it to the designer’s advantage. By having a single soft member that deforms under a load, this deformation can be measured and the force acting on the device extracted. What is unique about this design is that it integrates the soft member into the structure of a mechanism in parallel with more rigid members. This reduces complexity compared with the traditional method of building a completely rigid structure and then going back and adding a soft layer on the exterior. By building the flexibility into the design, there is no need to make a structure completely rigid only to then make it soft again.

~~The force control solution is built around the cantilevered beam model. The device is a parallelogram, with 3 sides consisting of rigid laminate structure and the fourth a spring in series with the rigid structure. Whereas, with a completely rigid structure, knowing only one of the angles of the parallelogram (along with its dimensions) would suffice to fully define the state of the device, with the flexible element, two of the angles are required to fully define the state of the system. As shown in Figure 1, measuring the angle on either side of the spring (θA and θB) allows the deflection of the spring and the position of the device to be determined. This method allows for a variety of spring designs to be easily inserted provided the geometry and material is known as the angle sensing is independent of the spring choice.~~

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~~Figure 1: Parallelogram Beam Deflection~~

~~The force applied to the end of the device is calculated from the spring deflection angle using the cantilevered beam model. The deflection angle (θd) is calculated as the supplement to the sum of angles A and B as shown in Equation I, assuming the deflection is small and the linkage remains a parallelogram.~~

~~In order to measure angles A and B in Figure 1, a motor encoder and linear hall effect sensor are used. Point A is fixed and the rotation of the joint is driven by a DC motor, while an encoder measures its position. The setup is shown in Figure 2.~~

I made a prototype device and tested its measured force verified against known applied forces. After the accuracy of the force measurement was confirmed, I demonstrated an application of this system by utilizing the data in a force feedback control loop. By taking into account the force measured by the device, the movement of the motor can be adjusted so as to maintain a constant force or to prevent the exceeding of a certain specified force. One example of an application of force feedback is human-robot interactions. In these situations, robots need to take into account the force they are exerting so as not to cause injury. Another example is when a robot is operating in an unstructured environment and may damage itself if it attempts to exert too great of a force on its surroundings. Although I conducted this research independently, I am currently writing a collaborative paper with another undergraduate student titled *Using Informal Materials to make Formal Robots*, in which we present how to leverage the deficiencies of soft, low-cost, informal systems to our advantage to sense contacts that more rigid systems might not be able to. In this paper, my early work on a laminate force sensing device will serve as one example of our methodology.

Following my completion of this force sensing device, I was awarded another fellowship by the Fulton Undergraduate Research Initiative to work on a larger project to construct a bio-inspired laminate robot based on terrestrial birds. My role has been to develop simulations to optimize the design of the robot’s legs for jumping. The goal of this work is to understand the limitations and important factors of a traditional modeling effort in capturing the nonideal behaviors of laminate systems. I am investigating a more generally available gaming engine that features a physics engine as well as a purpose-built symbolic equation builder based on Kane’s method. This expands our knowledge of how to make high-performance systems with informal materials. ~~By developing these tools, a better understanding of how simulations can easily be made to represent robot performance is advanced. Furthermore, it is easier for others to utilize these same methods and take the same aspects of the design into consideration in their models and develop an optimized design that fits their own parameters.~~

While other members of the team have been tackling separate challenges the robot will face, such as gliding and balancing, I have been investigating jumping. To answer the question of which factors were important and needed to be considered in the model, I began with a simple representation and added components as necessary. In order to determine which aspects of the leg needed to be included in the model, I built several leg prototypes, and compared their jumping performance with those of the models at each step. This work is being presented in a second paper about using open simulators to design a high-performance foldable robot.

Through this investigation, it became apparent that the flexibility of the laminate materials in the leg was affecting the jumping results and needed to be modeled. To do this, I experimentally examined the force-deflection relationship of the material and found it could be reasonably approximated by a rotational joint with a linear spring. This resulted in a closer fit between the trends of the simulated and the experimental results. To further close the gap, I examined another unmodeled aspect of the leg: the motor dynamics. After collecting data on the motor’s electrical and mechanical characteristics, I replaced the linear motor model I had been using with a more complete dynamic model. This contributed some to resolving differences in the magnitude of the simulated and experimental performances but did not have as significant an impact of reconciling the differences as I had hoped.

This work seeks to show how high-performance robots can be made from informal methods. A free and easy to use game engine is the logical simulator to pair with foldable robotics which also seeks to be more affordable and accessible to novices. There has been little investigation into the usefulness of free physics programs such as game engines and Python libraries as means of modeling complex dynamic systems in engineering. However, they are effective means of representing a dynamic system and provide useful insights on the design choices. Knowledge about the design can be gained quickly through the model and then applied to the rapid prototyping of the foldable robot. This allows as much performance as possible to be squeezed out of a cheap laminate mechanism, so that a high-performance device can be made and tested quickly.