Dexterity: A Low-cost, Remotely Controlled, Humanoid Robotic Arm

(Technical Project)

Access to Higher Education in U.S. Rural Communities with High Minority Rates

(STS Project)

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Technical Project Team Members:

Alex Schaefer, Bhargav Moosani, Jackson Lamb, Max Titov

On my honor as a University of Virginia student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor guidelines for Thesis-Related assignments.

ADVISORS

STS Advisor: Dr. Coleen Carrigan, Department of Engineering and Society

Technical Advisor: Adam Barnes, Department of Electrical & Computer Engineering

INTRODUCTION

The intersection of robotics education accessibility and barriers to higher education for rural minority students presents a significant sociotechnical challenge. While robotics is an increasingly relevant and dynamic field, educational institutions in rural and underserved areas often lack the resources to provide hands-on robotics learning experiences. Advanced robotics systems, like humanoid robotic arms, are often too costly and complex for many schools to implement. Without exposure to these interdisciplinary skills in fields such as robotics, engineering, and computer science, students in under-resourced areas face limited opportunities for engagement with high-demand STEM fields, exacerbating existing educational disparities.

This project seeks to address this gap by designing a low-cost, accessible humanoid robotic arm tailored for high school and early college students. The objective is to create a model that is feasible to construct within a single semester, using affordable, readily available components, while still fostering robust interdisciplinary learning. By making advanced robotics education more attainable, this project aims to promote STEM engagement and provide a pathway for students to gain valuable technical skills.

However, access to such educational tools in robotics is part of a larger issue of educational inequities faced by rural minority students. These communities often grapple with structural barriers, such as limited college-preparatory resources, teacher shortages, and economic constraints, that restrict higher education access (Grant et al. 2022). The STS research explores how these systemic inequities and power structures affect educational outcomes for rural, high-minority populations. Using a post-positivist approach, the study examines the influence of socioeconomic factors and institutional policies that often overlook rural minority students' unique needs, affecting their college readiness and STEM opportunities.

Together, the technical project and STS research aim to support more inclusive educational pathways by addressing both practical and systemic barriers in STEM and higher education for underserved rural communities.

TECHNICAL PROJECT

The growth of the U.S. robotics market underscores the increasing importance of robotics across consumer, industrial, and educational fields. Despite this expansion, robotics remains financially and technically out of reach for many educational institutions, especially at the high school and early college levels. Advanced robotic systems, such as humanoid robotic arms, are deeply motivational by are both expensive and complex, limiting their practical use as learning tools. This restricts students' access to hands-on STEM education and hinders the development of interdisciplinary skills in robotics, engineering, and computer science. Even in schools with robotics programs, many students find the resources inadequate for developing the skills needed for advanced engineering or fostering meaningful engagement with robotics.

This project aims to create an affordable, accessible, and educationally rigorous model of a humanoid robotic arm for high school and college education. The core objectives are to reduce monetary costs, ensure project feasibility, and foster interdisciplinary skill development in students.

The first objective is to explore cost reduction. We will identify materials, components, and design methods that reduce the robotic arm's cost without compromising its educational impact. By comparing commercially available robotic arms with open-source components and 3D-printed parts, we can explore the balance between affordability and functionality. Our design will focus on the usage of hobby-grade motors, microcontrollers, and sensors, balancing cost and performance to provide insight into educational value of a minimally priced humanoid robotic arm.

The second objective is to determine project feasibility and accessibility, aiming to ensure that students can design, build, and test the robotic arm within a single semester or school year. To assess this, we will attempt to create a prototype of the robotic armature in a single semester. Milestones will guide each phase, from design and assembly to testing, and feedback will be gathered to evaluate difficulty and engagement. For high school implementations, the level of technical complexity can be reduced to ensure project completion.

The third objective is to assess educational impact. We'll provide a qualitative assessment of the usage of various engineering sub-disciplines, such as electrical engineering, computer science, and mechanical engineering. After the project is completed, insights into each group members contribution to the project will be gathered and compared with initial learning objectives. In addition, the overall depth of study required to implement the complete armature design will be analyzed to identify any prerequisite knowledge required prior to a engineering design course in which the students design and build the robotic arm.

The research integrates three theoretical perspectives. Constructivist learning theory suggests that students learn best when actively constructing knowledge through practical tasks (Chand 2023). Building a robotic arm aligns well with constructivist principles, offering students a hands-on approach to problem-solving and engineering principles. This project situates students in authentic learning experiences, demonstrating real-world applications of their classroom knowledge.

Social cognitive theory highlights the role of motivation, self-efficacy, and peer observation in learning (Schunk 2020). Collaborative tasks in the project allow students to learn from one another, increasing both self-confidence and collective problem-solving skills. As students work through challenges together and observe each other's progress, they gain resilience and motivation to overcome complex problems.

Interdisciplinary learning theory posits that combining different domains enhances understanding and problem-solving capabilities. By integrating electrical, mechanical, and computer engineering, the project helps students draw connections between fields, which is essential for real-world engineering tasks. This interdisciplinary approach offers a holistic understanding of robotics and prepares students for the interconnected nature of engineering disciplines.

This project offers a replicable, cost-effective model for robotics education, demonstrating that high-quality robotics learning can be both accessible and affordable. The outcomes are intended to provide a framework that other institutions can adopt to enhance their STEM curricula. Additionally, this project contributes to STEM education research by documenting the impact of hands-on, interdisciplinary learning on technical skills and student engagement in STEM fields. Ultimately, we aim to dismantle barriers in robotics education, fostering the next generation of engineers and technologists through accessible, practical learning experiences.

This research investigates access to higher education in rural U.S. communities with high minority populations, focusing on how structural barriers—including socioeconomic status, language barriers, and educational quality—affect college access for these students. By using a post-positivist framework and analyzing structures of power, this study will examine how systemic inequities and the unique dynamics of rural life influence educational outcomes for minority youth. This research addresses a gap in the literature by highlighting the distinct cultural, economic, and structural factors shaping college access in rural, high-minority areas.

As rural U.S. areas face rapid demographic changes and persistent socioeconomic inequalities, this research is crucial to understanding and addressing the unique challenges minority students encounter in accessing higher education. Despite the fact that rural regions account for a large portion of the U.S. population, higher education policies often prioritize urban challenges, overlooking the specific needs of rural, minority students. Overlooking these students in policymaking can reinforce system inequities, further widening the access gap to college. This study will provide insights for educational policymakers, rural school leaders, and community advocates to support equitable pathways for rural students, especially those who are first-generation students, English learners, or from low-income backgrounds.

Students in rural areas often lack financial resources and family guidance in navigating college pathways. Studies by McGrath et al. (2001) and Grant & Roberts (2022) reveal that rural students, particularly those from low-income or first-generation backgrounds, are at a disadvantage in accessing college. Whiteside (2021) underscores how these students leverage community-based strategies to overcome barriers but still struggle with limited college access, emphasizing the role of merit-based scholarships as essential financial resources.

As rural communities diversify, minority students—many of whom are English learners—face distinct challenges that demand responsive education policies. Johnson et al. (2018) highlight the importance of culturally sensitive support in improving college readiness for minority students in rural areas, while Coady (2020) calls for a national agenda to address the educational needs of English learners in rural schools. This demographic shift underscores the need for educational systems to adapt and address the unique needs of an increasingly diverse student population.

Teacher shortages and limited access to college-preparatory resources constrain rural students' college readiness. Biddle & Azano (2016) discuss long-standing educational gaps in rural communities, with recent studies by Ingersoll & Tran (2023) and Sindelar et al. (2018) identifying high turnover rates among rural teachers as a barrier to sustained educational quality. This lack of consistent, high-quality education limits rural students' opportunities, making it difficult for them to prepare for post-secondary education.

Rural life presents a mix of supportive community ties and challenging economic conditions, creating a complex environment for students. Clark et al. (2022) describes how strong community networks provide support but can also reinforce local family obligations, complicating students' aspirations to leave for college. This duality often requires students to choose between pursuing higher education and fulfilling familial expectations, affecting their college access and choices.

Using a qualitative, post-positivist approach, this study will examine the structures of power influencing rural minority students' access to higher education. A post-positivist framework allows for a nuanced analysis of how social structures and systemic inequalities affect students' educational opportunities in specific geographic locations and population densities.

Research methods will include in-depth interviews with students, educators, and policymakers, as well as a review of regional education policies and support initiatives. This study will explore the intersection of race, class, and geography in shaping educational access (Margolis et al. 2017).

This analysis will also address the policies and systems that maintain educational inequities, such as scholarship requirements, under-resourced schools, and limited language support services. By examining power structures within the educational landscape, the research will provide a comprehensive understanding of the challenges facing rural, minority students and identify potential pathways for improving college access.

This study aims to illuminate the unique barriers and supports that shape higher education access in rural, high-minority communities. By applying a post-positivist methodology and focusing on structures of power, this research will offer insights into the complex issues impacting rural, minority students' college access. The findings will be valuable for policymakers, educators, and community advocates working to create equitable educational pathways for rural populations, ultimately supporting culturally responsive policies that ensure educational access for all students, regardless of geographic location or background.

CONCLUSION

The technical project will deliver an affordable, accessible humanoid robotic arm prototype tailored for high school and college education, fostering interdisciplinary STEM skills through hands-on engagement. This design aims to serve as a replicable model that can bridge existing gaps in robotics education for under-resourced schools. Meanwhile, the STS research will provide a critical analysis of the structural barriers affecting higher education access for minority students in rural communities, offering insights into the socioeconomic and institutional factors that shape educational inequality.

Together, these projects address the sociotechnical problem of limited STEM access in rural areas by both providing a tangible educational tool and a deeper understanding of systemic barriers. Insights from the STS research will inform the technical design to ensure it aligns with the needs of underserved communities. By advancing accessible robotics education and highlighting rural students' unique challenges, this work supports more equitable STEM opportunities.

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