Challenge-Based Learning at Scale: Effects of NASA Artemis ROADS on STEM Career Interest in a Rural 7–12 District

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Abstract — This paper examines the potential effects of implementing a large-scale, challenge-based learning (CBL) initiative, specifically the NASA Artemis ROADS program, on the science, technology, engineering, and mathematics (STEM) career interests of students in a rural 7–12 school district. Rural districts often face unique educational challenges, including resource and funding disparities, yet possess untapped potential. The objective of this analysis is to synthesize existing literature to build a conceptual framework for understanding how such an intervention might perform, paying close attention to critical moderating variables such as local school context, student grade level, and gender. This study utilizes a qualitative literature synthesis, drawing from meta-analyses, quasi-experimental studies, and programmatic reports. The findings indicate that while CBL is a potent pedagogical tool, its effectiveness is highly context-dependent. High school students typically derive the most significant benefits from STEM interventions. Furthermore, gender-differentiated factors, such as the influence of media, social support, and the presence of female role models, critically shape STEM interest. The analysis concludes that the success of programs like NASA Artemis ROADS in rural settings hinges on careful adaptation to local conditions and the deployment of demographically-informed engagement strategies to effectively foster STEM career aspirations.

Keywords — *Challenge-Based Learning, Stem Education, Rural Schools, Career Interest, Nasa, Educational Intervention, Gender Differences*

I. Introduction

The imperative to provide equitable and engaging science, technology, engineering, and mathematics (STEM) education is a key part of modern educational policy. However, significant disparities still exist, especially for students in rural school districts who often face fewer resources and less government and private funding compared to their suburban peers.[1] Despite these obstacles, rural schools demonstrate a remarkable ability to succeed, achieving national test scores that are not statistically different from those in large urban districts.[1] This resilience indicates a large, untapped potential that can be developed through innovative teaching methods and strategic partnerships. Technology-based interventions have shown promise in closing geographical and resource gaps, with one large-scale program connecting rural Chinese students with urban teachers leading to significant long-term improvements in both educational achievement and future earnings.[2]

Among promising pedagogical models, Challenge-Based Learning (CBL) has become a strong framework. CBL is an active learning approach where students work together to identify, analyze, and develop solutions to complex, real-world sociotechnical problems.[3] As a progression from problem-based learning, it often incorporates an Engineering Design Process (EDP) to enhance 21st-century skills and motivate students.[4] Large-scale, prominent initiatives like the NASA Artemis ROADS (Rover Observation and Drone Survey) challenge serve as an excellent platform for applying CBL on a broad scale. However, adapting such a program to the specific context of a rural 7–12 district presents a complex research challenge. Although the benefits of CBL are well documented, there is a significant gap in understanding how its impact on student STEM career interest is influenced by environmental factors unique to rural communities and critical student demographics such as grade level and gender.

This paper aims to fill this gap by synthesizing a body of empirical research to develop a conceptual framework for assessing the potential impact of the NASA Artemis ROADS program. The objectives are to: 1) review the evidence on the effectiveness of CBL and similar STEM interventions; 2) explore the specific challenges and opportunities in rural STEM education; 3) analyze how student grade level and gender can lead to different impacts on career interest; and 4) discuss the practical implications for designing and implementing large-scale CBL initiatives to enhance their effectiveness and equity in rural areas.

Literature Review

The conceptual foundation for this analysis is based on three pillars of research: the nature and effectiveness of challenge-based learning, the unique context of rural STEM education, and the role of demographic variables in moderating student outcomes. Challenge-Based Learning is defined as a multidisciplinary experience where learning is driven by designing a sustainable solution to a real-world problem.[3] It is an extension of problem-based learning that often includes an EDP to structure student work, improve critical thinking, and boost motivation.[4] The effectiveness of these active learning strategies is well-documented. A meta-analysis of 40 studies showed that the type of learning activity significantly influences academic achievement in STEM, with inquiry-based learning (a core part of CBL) showing the largest effect size.[5] However, the impact of STEM interventions is not consistent. A quasi-experimental study revealed that an intervention's success highly depends on the context, resulting in notable academic and engagement increases in one school, no significant change in another, and negative outcomes in a third.[6] Nevertheless, well-designed STEM Intervention Programs (SIPs) can have a substantial impact, with one study indicating that participating students had 3.0 times higher odds of continuing in a STEM major.

The rural educational landscape presents unique variables. Rural schools often have less funding than suburban and small urban schools, yet their students' performance on national tests is similar to that of students in large urban districts.[1] This shows resilience and potential that targeted interventions can harness. Technology has proven to be a strong equalizer; a program that

used satellite technology to connect over 100 million rural students in China with highly qualified urban teachers resulted in students completing more schooling and earning significantly higher wages nearly a decade later.[2] Recognizing this potential, NASA has a strategic history of focusing on rural districts for educational outreach, aiming to boost participation among educationally and economically disadvantaged youth and diversify its future workforce.[8,9]

Student demographics are key moderators of an intervention's impact. A meta-analysis of 66 studies found that academic level significantly influences outcomes, with the strongest effects of STEM education seen in high school students.[10] Gender is another important factor. Having more female students in a STEM course tends to lead to higher academic achievement for all students, particularly benefiting female students themselves.[11] Similarly, female students gain more from having a female STEM instructor.[11] The factors that foster STEM career interest also vary by gender; a survey of high school students revealed that social support was the most influential for males, while media had the greatest impact on females.[12] At the university level, research opportunities and course resources were more advantageous for women's career commitment, while peer interactions played a larger role for men.[13] These findings emphasize the need for tailored engagement strategies, while also warning against deficit-based mentoring models that have proven ineffective for women of color in STEM.[14]

II. Methodology

This study uses a qualitative literature review and conceptual analysis to examine the potential impact of the NASA Artemis ROADS program on STEM career interest in a rural 7–12 district. The approach involves a systematic review of a compilation of research including peer-reviewed meta-analyses, quasi-experimental studies, program evaluations, and strategic plans from educational and government organizations. No primary data were gathered; instead, the study synthesizes existing empirical evidence to develop a predictive and analytical framework.

The analysis is organized to address the main questions of the combined query, focusing on the intersection of three key areas: the pedagogical model (Challenge-Based Learning), the implementation setting (a rural school district), and the target population (students in grades 7–12 with diverse demographic backgrounds). By identifying similarities and differences across the literature, this paper creates a clear narrative that highlights the important factors likely to impact the program's success. This approach helps develop a detailed understanding of potential outcomes and provides a foundation for future research and program evaluation.

III. Results and Discussion

The synthesis of the literature uncovers a complex interaction of factors that influence the impact of a program like NASA Artemis ROADS. The findings are arranged into three main themes: the variability of CBL implementation, the unique dynamics of the rural educational setting, and the differing effects across student demographics.

The promise and peril of challenge-based learning implementation

The evidence strongly supports the potential of CBL and related inquiry-based methods to produce significant academic gains.[5] However, the promise of the pedagogical model is tempered by the risk of implementation variability. The success of a STEM intervention relies heavily on local context, as shown by a study where identical interventions yielded positive, null, and even negative results in three different high schools.[6] Practical barriers, such as limited infrastructure and inflexible school schedules, can hinder implementation, especially in under-resourced districts.[15] Therefore, the success of the Artemis ROADS challenge depends not only on its design quality but also on how faithfully it is implemented at the school level. Program evaluations from other NASA informal education projects emphasize the importance of using tools like a "Fidelity and Adaptation Survey" to assess how closely a program is implemented as planned and to record local modifications.[16]

The unique rural environment

The rural context is not just a variable but a key aspect of the implementation landscape. Although often marked by funding gaps, rural schools have hidden potential for high achievement.[1] NASA's strategic focus on rural outreach, going back to the 1990s, recognizes this potential and seeks to nurture talent outside traditional urban and suburban areas.[8,9] The proven success of large-scale technology programs connecting rural students with quality educational resources offers a strong example, indicating that well-crafted initiatives can overcome geographic barriers and produce lasting, transformative benefits.[2] The Artemis ROADS challenge, with its mix of hands-on engineering and digital teamwork, is well-placed to tap into this potential, but its success depends on understanding and adapting to the specific resources and culture of rural districts.

Differential impact across student demographics

A one-size-fits-all approach to the Artemis ROADS challenge would probably lead to unequal results. Research shows that students' experiences with STEM interventions vary depending on their grade level and gender.

- A comprehensive meta-analysis revealed that the impact of STEM education is strongest for high school students (grades 9–12), who showed the largest effect sizes for both overall learning outcomes and specific cognitive gains.[10] This indicates that while middle school students (grades 7–8) can also benefit, the program may need to be adapted differently for each group. For younger students, the focus might be on building foundational skills and fostering a positive STEM identity, while for older students, the emphasis could be on tackling complex problem-solving and exploring career pathways.

- Gender: The findings on gender are especially nuanced. Establishing an environment with strong female representation in teams and leadership roles is vital, as it has been shown to

improve academic achievement for all students, especially females.[11] The presence of female instructors or mentors is also a key positive factor.[11] Engagement strategies should also be gender-conscious. Program outreach and content that utilize media may be more effective at igniting interest among female students, while highlighting teamwork and social support may resonate more with male students.[12] Additionally, ensuring that female students have clear access to program resources and research opportunities could be more crucial for their long-term career commitment compared to their male peers.[13]

Discussion

The synthesized findings indicate that implementing the NASA Artemis ROADS program in a rural 7–12 district is a high-potential yet high-variance effort. The main implication is that success does not stem solely from the CBL model itself but depends on a deliberate and informed process of adapting to the local context and student population. This aligns with research showing the significant context-dependency of STEM interventions, where local school culture and implementation fidelity can be more predictive of outcomes than the pedagogical design alone.[6]

From a practical standpoint, this analysis emphasizes the need for a tailored implementation strategy. For students in grades 9–12, the program can be ambitious, utilizing the finding that this age group gains the greatest cognitive benefits from STEM education.[10] For grades 7–8, the focus should be on engagement and developing a strong science identity, which is a key step toward career interest. The gender-related findings highlight the importance of proactive program design. This includes intentionally showcasing female role models within NASA and the wider STEM community through media, ensuring female students are not isolated in project teams, and offering explicit mentoring opportunities. These approaches go beyond simply providing access and actively foster an inclusive environment tailored to the different factors that influence career interest for male and female students.[11,12]

This study has some limitations. As a literature review, it does not include primary data from the Artemis ROADS program and depends on combining findings from various contexts, some of which may not be directly comparable to a U.S. rural district. For example, insights on the impact of media and social support were taken from a study in China and may have cultural differences.[12] Additionally, while one meta-analysis on Design-Based Learning found that the specific STEM discipline was not a significant factor influencing outcomes,[17] the unique, multidisciplinary nature of an aerospace-engineering challenge like Artemis ROADS could lead to different results. These limitations emphasize the importance of conducting direct, empirical research on the program itself.

Despite these limitations, this paper successfully meets its objectives by providing a conceptual framework grounded in empirical evidence. It synthesizes the literature on CBL, contextualizes it within the rural educational environment, and analyzes the critical moderating

roles of grade level and gender, offering a clear roadmap for both implementation and future evaluation.

IV. Conclusion

Implementing a large-scale, challenge-based learning program like NASA Artemis ROADS presents a valuable opportunity to boost STEM education and interest in careers among students in rural districts. While the potential impact is considerable, the path to success is complex. The existing literature review suggests that effectiveness depends not just on the pedagogical model but also on careful, context-aware adaptations to each school's environment and the diverse needs of its students.

Future research must shift from the conceptual to the empirical. Quasi-experimental studies are necessary to directly assess the impact of the Artemis ROADS program in rural areas, with a focus on collecting and analyzing data broken down by grade level, gender, prior academic performance, and other important demographic factors. To understand the reasons for success or failure, such research should include tools like a "Fidelity and Adaptation Survey" to document how the program is being implemented and changed in practice.[16] Ultimately, by combining innovative, evidence-based programs with rigorous, context-sensitive evaluation, we can better unlock the great and often underused potential of students in every school district, no matter where they are located.

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