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Finding the Inner Researcher and Leader through an Engineering Mentored Research Program at an HSI

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Abstract

Through being involved in effective and well-planned research activities, undergraduate engineering students can feel as if they are involved and part of the research community. One way of engaging these students is through undergraduate research experiences (UREs) in which students engage in research activities. URE experiences have been associated with positive outcomes for historically underrepresented students. This study explored the high-impact research-oriented learning experiences (ROLE) program, in which minority undergraduate engineering students participated at a Hispanic-Serving Institution (HSI). In the ROLE program, participants built strong technical skills while sharing space and knowledge with their fellow peers and mentors. Crisp and colleagues' conceptual framework framed this study to understand the effectiveness of mentoring in educational contexts. This mixed-methods study included the participation of 19 students who completed surveys and participated in one-on-one interviews. On the one hand, the qualitative data revealed most participants' first research experience, and consequently, students were highly motivated and interested in their research activities and learning. In addition, this research experience also helped students further develop their personal, academic, and professional goals and aspirations. On the other hand, the quantitative results indicated that after completing the ROLE program, participants had significantly higher research understanding in the specific area than before taking part in the program. A better understanding of what research is and what researchers do contributed to expanding students' vision and opportunities in college and beyond. This study confirmed the great influence of URE on minority students to keep involved in other research programs on and off campus, and think about graduate school as a tangible opportunity for them and their peers.

Introduction

The sciences and engineering disciplines are often characterized by the lack of human interaction and a personalized relationship between students and professors [1], [2]. These practices result in students switching majors or dropping out of college. The aspect of student engagement through high-impact practices as an effective tool for retention calls for effective and well-planned research activities, where undergraduates feel involved and included as part of the research community [3], [4]. One common strategy is undergraduate research experiences (UREs), where undergraduate students engage in research activities [5]. URE programs provide students with a further understanding of how knowledge is generated in STEM fields and what it means to be a STEM professional, as well as the process of working as STEM researchers [5], [6]. In addition, for students in STEM, UREs provide them with access to further engagement and skills in their specific field [5].

For historically underrepresented students, experiences in UREs have been associated with positive outcomes, including persistence in STEM and degree completion [5]. This is important as women and underrepresented minority students are less likely to declare a STEM major and persist in a STEM field, with this being stronger in the field of engineering [7]. For Latinx students, involvement in undergraduate research experiences has been associated with an increase in the percentage of students who identify as scientists [8]. Involvement in UREs has also been associated with increased retention [9]. Therefore, UREs have become an important academic and professional development for students pursuing STEM degrees.

Mentored Research Program Overview

This study resulted from a project situated at New Mexico State University (NMSU) in the southwest borderland, a community with large Latinx and Indigenous populations. NMSU, as a Hispanic-Serving Institution (HSI), provides education to these communities, housing approximately 12,500 undergraduate students, of which 63% are Hispanic or Latinx [10]. The development of an engineering research-focused program, Research-Oriented Learning Experiences (ROLE) at NMSU, aims to contribute to the educational equity and research initiatives of Latinx college students. The ROLE program seeks to reduce such inequalities, providing Latinx students with the opportunity to excel in highly demanding programs and build their education and career path, acquiring the needed technical skills, as confident scientists and outstanding leaders in the engineering field. Students spend two semesters in the ROLE program. In the first semester, students learn about the Linux OS, Robot Operating System (ROS), and the Python programming language. In addition, students learn to operate a motion capture system, providing them with knowledge about indoor GPS capabilities. In the second semester, students work in teams to develop specific projects. In this phase, students apply the knowledge acquired in the first semester, for example, to replicate in a controlled laboratory environment, real-world missions like flight surveillance operations. Students' schedules in the laboratory overlap to increase peer interaction, collaboration, and mutual support.

This study's goals were to explore the high-impact research-oriented learning experiences for the Latinx undergraduate participants of the ROLE program and how they built strong technical skills while sharing space and knowledge with their fellow peers and mentors. Two research questions framed this study. The first research question addresses the qualitative data, and the second research question informs the quantitative section of the study:

1. How did Latinx undergraduate students change their perspective about being researchers in their field after participating in the ROLE program?
2. Does the Latinx undergraduate students' understanding of research in engineering improve after completing the ROLE program?

Literature Review

Access to STEM research

According to Kuh and colleagues [11], student engagement results from the time and energy invested in academic activities supported and developed by universities. Such activities include educational experiences, co-curricular activities, as well as faculty, staff, and peer interactions [12]. The long-term learning impact of minoritized students who participated in research experiences showed positive effects in aspects such as "academic performance, scientific baccalaureate attainment, acceptance into a scientific graduate program, and longer-term scientific workforce participation" [13]. However, according to Pierszalowski and colleagues [14], the obstacles to engaging in research as undergraduate students have to do with different aspects including *Institutional* issues linked to 1) physical resource issues and limitations, 2) lack of course-based research opportunities, 3) lack of institutional commitment to undergraduate research opportunities, and 4) lack of advertisement regarding the benefits of participating in research including networking, and skill development, and 5) lack of diversity within academic faculty. A second layer has to do with *Faculty* aspects related to 1) limitations on the time faculty had to dedicate to research projects, 2) faculty lacked incentives and compensation for the additional work related to undergraduate research, and 3) negative faculty perceptions regarding student competency. Lastly, *Students'* difficulties dealing with 1) perceptions of preparedness and readiness for research participation, 2) lack of interest and motivation to participate in research, 3) financial constraints preventing them from dedicating time to research projects outside course hours, and 4) other social deterrents, including social influences and obligations. Authors in [14] and [15] pointed out that institutional, group, and individual efforts are needed to make a difference in increasing underserved and marginalized research opportunities. In effect, Latinx students pursuing STEM-related disciplines, as a minority student population, still participate at lower rates in undergraduate research experiences (URE) and are not often mentored by faculty members, lacking Latinx students' involvement and research interest [16], [17].

Underrepresented Students in STEM

Overall, Latinx students continue to be underrepresented within STEM fields [9], [18]. For example, from 6-year data for all 4-year institutions from the National Center for Education Statistics, Hispanic students completed graduation at a 53.6% rate compared to the 63% rate of Caucasian students [18]. Oftentimes, students describe experiencing a variety of barriers in their pursuit of a STEM degree [19]. Some of these barriers were associated with specific cultural concerns, including language barriers, ethnic discrimination, and immigration status [19]. In particular, Latinx students enrolled in engineering, oftentimes, perceive hostile environments in and out of classrooms [20], and several female students face isolation and a lack of sense of

belonging in the engineering programs [21]. Students also reported experiencing feelings of self-doubt about their abilities in engineering, leading them to feel as though they were imposters [22].

While Latinx STEM students experience barriers, they also have several strengths they bring to their experience in STEM [19]. While the family does have the potential to act in conflict with students' ability to continue in STEM, students have also described them as a source of support [19], [23]. Additionally, both teachers and peers provided students with support in continuing in their STEM field [19]. Latinx students have reported positive interactions with faculty being one factor that led to further engineering retention of underrepresented minorities [24]. Holistic approaches in undergraduate research programs where culturally relevant aspects are included result in students feeling appreciated and valued [25]. Given the mixed evidence of benefits and challenges, this study aims to address the gap in the literature by identifying how Latinx students make meaning of their research experience as undergraduates and what personal, academic, and professional changes students had.

Conceptual Framework

The structure of the ROLE program consisted of student cohorts of six to nine undergraduate students led by a research team. The ROLE model seeks a holistic approach given the current diversity of higher education institutions by addressing the urgent need to better serve minoritized students through mentorship [2], [26]. Crisp and colleagues' [27] conceptual framework provides a model that integrates vital elements to understand the effectiveness of mentoring in educational contexts, see Figure 1. The framework includes elements such as the academic setting, student characteristics, relationship structure, forms of support, and intermediate as well as long-term outcomes. When applying this model to research activities and a minority student body, we consider it essential to integrate other components into the framework, such as the mentor characteristics, cultural relevance, discipline culture, and student expected outcomes.

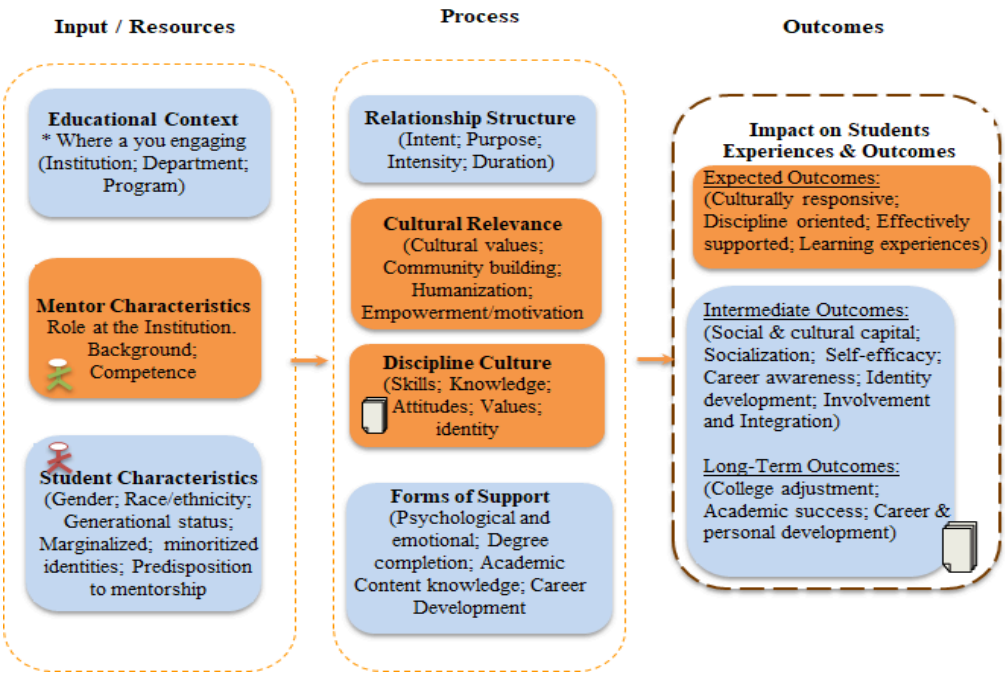

Figure 1. A model for mentoring college students, including **Culturally Relevant** and **STEM-oriented** approaches. The original elements proposed by Crisp and colleagues [27] are shown in blue, and the proposed components are colored in orange.

Methods

A mixed-method approach is used to collect and analyze qualitative and quantitative data [28]. Qualitative research was used to gain insight into participants' learning experiences and outcomes. The qualitative component will include interviews and journaling. Quantitative research was conducted to understand the efficacy of high-impact research-oriented learning experiences for minoritized undergraduate students. The research team conducted pre- and post-experience surveys. The Institutional Review Board (IRB) approved this study.

Data Collection

The research team conducted two rounds of interviews with students, one in the first weeks of the program and one by the end of the year of involvement in the program. Students were invited to participate in data collection both in person and via email. The post-experience interview collected data on students' experiences in terms of the technical, professional, and interpersonal skills gained throughout the program. Additionally, data were collected using pre- and post-experience surveys, where students rated their program's expectations, research outcomes, and future professional plans. For this study, pre- and post-survey and post-interview information have been included. In total, 19 students were interviewed and 17 students responded to the surveys. The students were part of three different annual cohorts from Spring 2022 to Spring 2024. Most interviews were in person, and a few were via Zoom. Surveys were

distributed using RedCap to ensure the protection of data per IRB guidelines.

Data Analysis

The audio collected through the interviews was transcribed and uploaded into Dedoose, a software to assist researchers in the analysis of qualitative data. Researchers read the transcripts several times to become familiar with the data and find patterns that could respond to the research question. Once the researchers identified patterns, what followed was the unitization of data and the creation of labels for themes and categories, using constant comparative techniques and content analysis [29]. For the data collected through surveys, the researchers used descriptive statistics. Furthermore, surveys included a scale ranging from 5 (Strongly Agree) to 1 (Strongly Disagree). The data was not normally distributed; therefore, the researchers performed a Mann-Whitney U analysis to determine whether students' scores for each of these variables differed before their involvement in the ROLE program as compared to after their involvement in ROLE. Such analysis assessed a possible increase in student learning due to their involvement with ROLE.

Participants

Most student participants self-identified as Latinx or members of other minoritized groups, such as Native American and White women. In terms of declared gender, each cohort was composed of half males and half females, with a higher percentage of junior and senior students. Table 1 below shows other important characteristics of student participants.

Table 1. Other student demographics

	Cohort 1 6 students	Cohort 2 8 students	Cohort 3 9 students
First-generation			
Yes	17%	25%	33%
No	83%	75%	67%
First research experience			
Yes	83%	75%	89%
No	17%	25%	11%

Qualitative Findings

The findings revealed that most student participants lacked research experiences for different reasons; therefore, the first theme addresses students' *First Research Experience*. The second theme, *Broadening Opportunities and Possibilities*, covered changes in students due to their participation in the ROLE program and its impact on future decisions. What follows are both themes explained in detail:

First Research Experience

For most students, participating in the ROLE program represented their first research experience. Such novelty made participants show great interest and motivation to be involved in research activities in the college setting. Some of them expressed concerns about performing the activities well in the laboratory and keeping up with the work. Others showed more self-reliance and confidence to accomplish the tasks and were more vocal and open to interacting with their peers. All of them were more aware of what it feels like to be in a research laboratory and what researchers do daily. Students reflected on their limited involvement in research activities, and they expressed:

> *I haven't really had research experience before, and some of the internships and the jobs I'd be applying for, I'd be a freshman or a sophomore in college, and they'd probably prefer a junior or a senior who has had more academic experience in those fields…or they find someone else that's more qualified (Gene).*

> *I've always been the person that's afraid to go out of my comfort zone. So I never thought I would get picked for research… I'm an over-thinker. So I'm like, "No, too many people are going to apply. You're not going to get it." (Zero).*

> *I was always interested in research because my friend did a research program in high school, so I was always just interested about it, but I never applied to any research programs before (Jaylen).*

As a new experience, students were willing to invest time and effort in accomplishing the tasks and were motivated to keep learning and trying. The students' quotes also showed how being selected to participate in this research experience improved their confidence and helped them plan for the future. Additionally, research mentors had a great influence on participants. Participants not only reported having acquired a new set of skills but also admitted having been positively influenced to consider doing research, seek other internships or research opportunities, and think about graduate school. For example, Jose mentioned,

> *I think we had a wonderful relationship. My mentor was always there 100% with me through it all. Anytime I had questions or issues or problems, he would always help me out and whenever I had any problems, he would always guide me to be able to solve anything or any issues that I had.*

Likewise, another student also reflected on finding this important role model in college. Juan added, "*I think that it was honestly one of the newer experiences that I've had in not only research, but in academia…being able to develop that connection with the mentor."* In addition, Leo commented on such an influential role to be interacting with individuals with higher degrees, she vented, *"For my mentors, you know, I look up to them to be able to go for my PhD, go for my graduate school. Having those as role models for me."* Participants felt highly influenced by other students pursuing master's and doctoral degrees. Also, participants noticed how knowledgeable graduate students and faculty mentors were about their research, triggering in students a sense of motivation and enthusiasm to continue their education.

Broadening Opportunities and Possibilities

This theme covers different students' perspectives in terms of how their participation in the ROLE program influenced different aspects of their personal, academic, and professional lives. One common comment among participants was how they discovered something about themselves after navigating this new research experience. For example, Troy mentioned, *"A thing I learned about myself is not to be afraid of learning a totally different skill set."* This quote reflects this student's discovery of facing something new and different through research. Also, Xiomara expressed, "*I never thought I would do that [coding and programming], or I would use that. I thought that was a computer science job, not an engineer's job. So, I think those things definitely helped me learn or broadened my experience."* This student revealed how, through her involvement in research, she found herself learning and practicing something completely unknown to her. Furthermore, students reported other changes that have to do with the influence of the lab environment and working with students and faculty with different backgrounds and statuses. Kiera commented, "*It [participating in the ROLE program] helped me understand that progress is different for everyone, and that my own ability, like, is not determined by my age or my degree. It's by what I seek out and who I like to connect with."* Likewise, another student talked about how their involvement and participation in the ROLE program brought major changes to their academic pathway. Pepito vented,

> *When I joined the [ROLE] program, I was a chemical engineering student, which I've never done coding...I just associated coding with being bored. Okay. So, I never touched it until I joined this lab and then I saw an application and then I saw expertise and I was like, oh wow, you can do all this with this knowledge. That's what helped me transition to computer science in the past.*

In the case of Pepito, he was greatly influenced by the learning opportunities that he experienced in the laboratory through the ROLE program. With hands-on activities, he could see the application and multiple possibilities he could access by gaining research skills. Overall, students as participants of the ROLE program discovered, learned, and experienced new concepts and practices that helped reinforce their knowledge and future possibilities. For some students, this new knowledge came with catalyst changes in their academic and professional areas.

Quantitative Findings

The pre- and post-surveys included several questions that can be divided into three broad categories: research understanding in engineering, research skills, and professional and social skills. Due to this study's scope, only research understanding in engineering and research skills, and information data were included. The following two tables, Table 2 and Table 3, contain count numbers and descriptive statistics:

Table 2. Pre- and post-survey responses on research understanding in engineering

Research Understanding in Engineering				
	Pre-Survey (N=33)		Post-Survey (N=17)	
	Strongly Agree/Agree	%	Strongly Agree/Agree	%
I possess a basic understanding of the process of research in this area.	19	57.6	16	94.1
I possess a basic understanding of the research literature in this area	17	51.5	16	94.2
I possess a basic understanding of the research skills and/or lab techniques in this area	22	66.7	14	82.3

Table 3. Pre- and post-survey responses on research skills

Research Skills				
	Pre-Survey (N=33)		Post-Survey (N=17)	
	Strongly	%	Strongly	%

	Agree/Agree		Agree/Agree	
I am able to write a research abstract	15	45.4	10	58.8
I am able to create a research poster	17	51.5	11	64.7
I am able to give an oral research presentation	24	72.7	15	88.3
I possess a basic understanding of how to interpret research data	**24**	**72.7**	**16**	**94.2**
I possess a basic understanding of how to apply research data.	23	69.7	14	82.4

A Shapiro-Wilk test was conducted to assess the normality of the data for research understanding in engineering (p. = .001) and research skills (p = .003). This indicated that the data was not normally distributed as the p-values were less than .05. Due to the lack of normality in the data, the researchers conducted a Mann-Whitney U test. A Mann-Whitney U test was performed to evaluate whether research understanding in this area and research skills differed by whether students had been involved in the ROLE program.

The results indicated that there was no significant difference between the research skills of participants before and after involvement in the ROLE program, z = -1.753, p = .080. However, the results indicated that after completing the ROLE program, participants had significantly higher research understanding in the specific area than before taking part in the program, z = -3.791, p = <.001. In terms of specific items, the only item from Table 3 on Research Skills that was significant was the following statement: "I possess a basic understanding of how to interpret research data". There was a significant increase in scores on this item after completing the ROLE program, z = -2.271, p =.023.

Discussion

This study explored the high-impact research-oriented learning experiences for the Latinx undergraduate student participants of the ROLE program and how they developed strong technical skills in a shared community with peers and mentors. The first research question addressed the qualitative data of the study investigating: How did undergraduate students change their perspective about being researchers in their field after participating in the ROLE program? First, it is important to understand students' familiarity with research as undergraduates. From all three cohorts, on average, 82% of students experienced for the first time being involved in a research experience, creating in students a sense of accomplishment when they had their first opportunity in the ROLE program. The fact that 25% were first-generation students and some students were the first in their families to study in the U.S. can be related to this low participation

in research-based programs. Despite prior research documenting multiple benefits for students involved in UREs [5], [6], [8], this study demonstrates a still low participation of minority students in research programs. Furthermore, Pierszalowski and colleagues [14] emphasized not only individual issues that may restrain higher minority students' involvement in research but also institutional and group reasons that can be barriers for students.

For student participants, their first research participation contributed to expanding their knowledge and understanding of engineering in practical terms. Additionally, students often expressed how performing new activities allowed them to increase self-reliance and confidence. Other scholars have also found similar benefits for students who participate in UREs, in particular the ones who develop meaningful relationships with mentors [19], [21], [24]. For some students, this was the first time they were interacting with graduate students and faculty, with whom some of them shared students native language - Spanish, facilitating understanding and communication. Such experience made students aware of advanced research projects, approaches, and opportunities. Also, students were able to learn more about graduate school through informal conversations with graduate students in the laboratory. Most students showed more interest in graduate school after completing the ROLE program, and several applied to master's and doctoral degrees. The influence of the ROLE program deeply impacted some students in their decisions about their careers, with some of them even switching majors more aligned with the research performed within the program. Such impacts align with Crisp and colleagues' [27] framework about the influential role of mentoring, considering both mentors' characteristics and laboratory climate.

The second research question examined whether student participants' understanding of research in engineering improved after completing the ROLE program. Descriptive statistics showed the changes in students' responses from pre- to post-surveys, in terms of research understanding in engineering and research skills. While all the statements had positive changes from the first survey to the second, a Mann-Whitney U test was performed, showing only statistical significance in the research understanding in engineering. This section of the first survey included information on basic understanding, specifically on engineering research, literature, and skills and techniques. The different phases of the ROLE program contributed to students gaining a better understanding of operating systems and programming to control robots. A specific area of engineering in which students gained knowledge and expertise. One particular item from the research skills section of the survey that resulted statistically significant was possessing a basic understanding of how to interpret research data. This statement could be linked to students' perceptions of applying hands-on activities, the theory learned in their courses. These results align with Stephens and colleagues' [5] research stating that participating in UREs learn the process of working as STEM researchers.

Conclusion and Future Work

The educational journey of minority students changed after they participated in the ROLE program. Students became aware of their abilities and knowledge to perform research activities, which, despite being challenging, allowed them to broaden their professional aspirations. Furthermore, students could see other opportunities and possibilities, for example, to seek other research programs on and off campus, and consider graduate school as their next step. Students also expanded their technical skills and noticed a deeper connection between theory and practice during the activities and tasks performed in the laboratory. Lastly, students boosted their engineering education by adding a research experience that was enriching, challenging, and rewarding. Additionally, future work could administer this research to larger sample sizes to allow for greater statistical power. For example, future research could involve engineering students who had not been involved in ROLE and compare their performance on the survey to students who were involved. This may allow for a better understanding of the impact that ROLE has on students' experiences.

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