Undergraduate Research Impact on Students' Retention and Academic Development Based on Their Study Field and the Mentoring Approach

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Abstract - The impact of undergraduate research experiences on students' academic development and retention in STEM fields is significant. Students' success in STEM fields is based on developing strong research and critical thinking skills that make it essential for students to engage in research activities throughout their academic programs. This work evaluates the effectiveness of undergraduate research experiences with respect to its influence on student retention and academic development. The cases presented are based on years of experience implementing undergraduate research programs in various STEM fields at Colorado State University Pueblo (CSU Pueblo) funded by HSI STEM Grants. The study seeks to establish a correlation between students' retention rates and academic development and students' involvement in undergraduate research experiences and programs during their academic journey. The work also delves into different mentoring approaches, including group-based and mentoring by individual faculty. This study provides the engineering and STEM education community with a deeper understanding of the advantages of undergraduate research experiences in enriching STEM and mentoring practices that can increase students' participation and mold their academic and professional character.

1. Introduction

Undergraduate research plays a significant role in advancing student development in different disciplines. It provides students with an opportunity to apply theoretical concepts learned in classrooms to real-world problems, thus enhancing their critical thinking, problem-solving, and analytical skills. Through research, students gain hands-on experience working on research projects, learn how to collect and analyze data, and develop an understanding of the research process. Additionally, undergraduate research promotes innovation and creativity by encouraging students to explore new ideas and concepts.

Moreover, research at the undergraduate level contributes to the creation of new knowledge, theories, and methodologies that help advance the field's understanding. Undergraduate research also helps identify gaps in existing knowledge and provides avenues for further exploration. Furthermore, it can lead to the discovery of new applications of existing knowledge, which can have significant implications for various industries.

A study was conducted at California State University, Monterey [1] to gain insights into the mentoring experiences of students from underrepresented backgrounds and those in diverse environments participating in undergraduate research [1]. Of the students involved, 44% were from low-income families, 53% were from traditionally underrepresented minority groups (URM), and 65% were the first-generation college students. The study used institutional data on student success and post-research survey data to explore the impact of mentoring on students' research experiences. The study found that mentored research has a positive impact on academic

performance for a diverse student population. The duration of time spent working with mentors and the quality of mentoring were key factors that influenced student development during research experiences.

Studies have shown that women and minority faculty and students are not adequately represented in academic healthcare institutions and universities. Mentoring has been identified as a critical factor in addressing this issue [2]. This work highlights the effective mentoring efforts of two institutions of higher learning (Creighton University Health Sciences Schools and Wake Forest University School of Medicine) that have helped women and minority students, and faculty members achieve academic success. The mentoring programs described have attracted over 130 students and more than 50 women and minority faculty members, with the number of participants increasing over time, indicating the program's growth. While the programs have shown success in the short term, further evaluation of measurable outcomes is necessary to determine their true impact. The mentoring models at Creighton University Health Sciences Schools and Wake Forest University School of Medicine can serve as a valuable template for other educational institutions and programs seeking to support women and URM faculty and students.

The Summer HIV/AIDS Research Program (SHARP) was established at the San Francisco Department of Public Health for URM undergraduates as a 12-week program of hands-on research experience, one-on-one mentoring by a senior HIV investigator, didactic seminars for content and research methods, and networking opportunities [3]. The program was designed to provide hands-on research experience to URM undergraduates. The program has successfully developed research skills and confidence, as well as identified more URMs as scientists. SHARP alums have entered or are pursuing graduate degree programs in fields related to HIV prevention and are employed in research positions.

Mackiewicz et al. [4], proposed integrating transferable professional development (PD) skills into research learning environments for marginalized undergraduate students. This article explores methods for integrating transferable PD skills into research-based learning environments for marginalized undergraduate students. The undergraduate research experience has evolved to include competencies necessary for success and belonging within the chemistry community. However, these transferrable PD skills often go unnoticed in traditional classroom settings despite being essential for student learning and success. Unfortunately, current practices often perpetuate inequality and fail to highlight these critical asset-based skills necessary for marginalized students to navigate academic, industrial, and professional environments effectively, resulting in many students leaving STEM communities. To tackle this problem, the authors have identified six core PD skills implemented in a diverse undergraduate research environment to equip students with the skills necessary to succeed in various STEM fields. These skills include Effective Communication, Negotiation, Leadership, Networking, Interpersonal Skills, and Active Listening. By focusing on these skills, mentors can help pre-professional, marginalized students build a network, develop self-advocacy, implement interpersonal skills, manage conflict, and navigate spaces that may not fully represent them.

The Building Infrastructure Leading to Diversity (BUILD) initiative at California State University Long Beach has established an Associates Program to support marginalized students pursuing behavioral and biomedical research [5]. This program provides undergraduates with early exposure to research and encourages their interest in a research career during their sophomore year. Furthermore, the Associates Program boasts retention rates exceeding 90% and serves as a pathway to other research opportunities on campus. More than half of the students who complete the program continue to an intensive, upper-division research training program at CSULB. Early intervention program has resulted in significant growth for student trainees in several key areas, including their sense of belonging to the BUILD Program, their interest in science and research, and their understanding of the skills required for conducting research (such as scientific writing, oral presentation, and data analysis). Comparisons between students who continued to upper-division research training and those who did not showed that those who continued reported higher levels of science and research interests, regardless of when they were surveyed. They also demonstrated a more significant increase in their perception of gains made in research during the latter half of the training program. The results showed that the Associates Program is equally effective for trainees regardless of their discipline, URM status, or gender. This early intervention program for undergraduate students effectively develops research skills and serves as a valuable pipeline for diverse students into more intensive upper-division training programs.

Mentors often overlook the impact of cultural diversity factors, such as race and ethnicity, on research mentoring relationships. A mentor training intervention was tested in a randomized controlled trial to address this issue at several training programs in the United States [6]. The aim was to increase mentors' awareness and skills in addressing cultural diversity in research mentoring relationships. The study involved 216 mentors and 117 mentees from 32 undergraduate research training programs across the United States. The experimental group reported more significant gains than the comparison group in their confidence in mentoring students across diverse cultural identities and the relevance of their racial/ethnic identity to mentoring. Mentees of mentors in the experimental group also rated their mentors higher in respectfully broaching and creating opportunities to address race/ethnicity matters. The research findings suggest that culturally focused mentorship education is effective.

Most top-ranked universities have established research programs to give their students opportunities to engage in research activities. These programs are designed to provide students with hands-on research experience and help them develop essential skills such as critical thinking, problem-solving, and communication. Students can work with experienced faculty members on cutting-edge research projects in various fields through these programs. This enhances their academic learning and prepares them for future careers in research and related fields. For example, the University of Texas at Austin's College of Natural Sciences offers an innovative program called the Freshman Research Initiative (FRI) that enhances the learning experience of undergraduates [7]. Approximately half of the students in the program are life science majors. FRI consists of three courses. First, FRI participants complete a research methods course (Course 1) and then can take

up to two semesters of course-based research (CUREs) in one of over 25 different research streams (Courses 2 and 3). These streams cover diverse scientific disciplines such as biology, biochemistry, bioinformatics, chemistry, computer science, physics, and astronomy. Each course is worth three credit hours, meaning students must commit roughly nine hours of lab-related work per week. Furthermore, each course helps students progress toward their degrees.

The Massachusetts Institute of Technology (MIT) offers the Undergraduate Research Opportunities Program (UROP)) [8]. Participating in UROP is an excellent way for students to develop the technical competencies necessary for effective research. In addition, UROP helps students build critical skills such as problem-solving, effective communication, and critical thinking. By participating in this program, students can establish valuable connections with faculty, graduate students, and other mentors, which can help expand their professional network.

Cambridge University offers a unique opportunity for undergraduate students not in their final year of study [9]. The students can apply for a paid ten-week placement during the summer vacation, enabling them to work with world-class research teams in various departments, including Engineering. This scheme provides an excellent opportunity for students to gain valuable insights into the research being undertaken by their academic teachers. Additionally, it helps them develop the technical and transferable skills necessary in a top research environment.

In conclusion, undergraduate research programs are pivotal in providing students with practical experiences that complement their classroom learning. These programs offer research opportunities in various fields, thus bridging the gap between academic research and real-world applications. It is worth noting, however, that the effectiveness of undergraduate programs is contingent on careful design that caters to the specific needs and backgrounds of the targeted student population. This is especially critical when working with marginalized groups. In addition, the success of a fruitful undergraduate research experience program heavily relies on the availability of research resources and infrastructure. While large research universities may find it relatively easy to meet these needs, small regional comprehensive universities face challenges due to a lack of funding, infrastructure, faculty workload balance between research and teaching, academic preparation of students, and logistical considerations.

2. Project description: CSU Pueblo's Communities to Build Active STEM Engagement (CBASE)

Described in this section is an undergraduate research program implemented at CSU Pueblo as part of Title III, Part F (HSI STEM) grant activities supported by U.S. Department of Education. The purpose of Title III, Part F grants is (1) to increase the number of Hispanic and other low-income students attaining degrees in the fields of science, technology, engineering, or mathematics; and (2) to develop model transfer and articulation agreements between two-year and four-year institutions in such fields.

The CBASE Grant offered five prominent programs to enhance the retention and program completion rates of Hispanic, low-income, and minority students. These programs encompassed

Research Communities (RCs), Science Learning Center, STEM Center for Engagement and Education (SCEE), PASSChem, and STEM Curriculum Redesign.

The RCs Program is designed to create a community of undergraduate students interested in research and provide them with a rigorous academic program. The program is aimed at retaining students and helping them complete their academic degrees. In Year 6, CBASE facilitated six RCs in Biology, Chemistry, Engineering, Civil Engineering Technology, Physics, and STEM Teacher Education. Each RC consists of multiple Research teams: first year and rising sophomores (Research Interns), third and fourth-year students (Research Fellows), and Faculty Mentors.

As a comparison, TABLE I shows the institution-wide enrollment, retention, and graduation rates, while TABLE II shows the same for students engaged with RCs.

In the sixth year of implementing CBASE, the target was set to have 80% of participants in the RCs Program persist or graduate from CSU Pueblo with a STEM degree. Of the 110 students in the Year 6 cohort, 47 persisted to the Fall 22 semester, while 48 obtained a STEM degree upon graduation. This resulted in an impressive overall retention, persistence, and graduation rate of 86%.

CSU Pueblo saw a slight uptick in graduation rates during Year 6 of the CBASE Grant. Specifically, the 4-year graduation rate rose to 24% compared to the 20-21 academic year, while the 6-year graduation rate experienced a small decline to 35%.

The RCs Program fosters a research-intensive and supportive community that offers close camaraderie and support to participating students. The faculty-student mentorship model has proven to be a successful retention and graduation strategy for STEM research students at CSU Pueblo by providing them with tailored mentorship and hands-on training to augment their STEM identity and career alignment. Although the RCs Program targets STEM students, it is expected to positively impact graduation rates institution wide.

CSU Pueblo's student persistence/retention rates saw a slight dip during the sixth year of the CBASE Grant. In comparison to the previous academic year, the Fall-to-Fall persistence/retention rate dropped from 63% to 62%. The COVID-19 pandemic has had a significant impact on enrollment and retention rates, which has continued to affect students during the sixth year of the CBASE Grant. Despite the college returning to its pre-COVID operations, remote learning has affected incoming and current college students' readiness and success.

The RCs Program has become the gold standard for mentoring research students at CSU Pueblo and has inspired numerous grant-funded and institutional programs. By focusing on STEM undergraduate research, the RCs Program has significantly transformed the identity and landscape of CSU Pueblo and serves as a unique differentiator for the institution.

TABLE I

Institutional measures reporting total fall enrollment, fall-to-fall retention, and graduation rates

Grant Year Collection Year	Pre-Grant (2015-16)	Year 1 (2016-17)	Year 2 (2017-18)	Year 3 (2018-19)	Year 4 (2019-20)	Year 5 (2020-21)
Total Fall Enrollment	4,244	4,242	4,055	3,847	3,720	3,609
Fall-to-Fall Retention %	66	63	69	65	68	61
4-Year Graduation Rate (2- & 4-Year) %	18	21	18	21	21	22
6-Year Graduation Rate (4-Year) %	35	29	35	36	36	39

TABLE II

CBASE measures reporting on fall-to-fall retention and graduation rates based on RCs

	mentoring approach (I-individual, G-Group)	Year 1 (2016-17)	Year 2 (2017-18)	Year 3 (2018-19)	Year 4 (2019-20)	Year 5 (2020-21)
Retention or Graduation %	Biology:(I)	14/14 (100%)	34/34 (100%)	34/34 (100%)	42/44 (95%)	50/50 (100%)
	Chemistry:(I)	6/6 (100%)	15/16 (94%)	11/11 (100%)	20/22 (91%)	9/9 (100%)
	Engineering (G)	4/5 (80%)	16/16 (100%)	14/14 (100%)	15/16 (94%)	12/12 (100%)
	Civil Eng. Tech. (I)	0	0	0	1/1 (100%)	2/2 (100%)
	Physics (I)	0	0	0	2/2 (100%)	1/1 (100%)
	STEM Teacher Ed. (I)	0	0	0	4/4 (100%)	5/6 (83%)

The ongoing evaluation indicates that implementing CBASE programs at CSU Pueblo has yielded positive outcomes. STEM students have been able to participate in valuable mentored research, which helps them establish themselves as STEM professionals and gain practical training. The support provided by CBASE has also helped create strong connections and mentorship between

STEM students and their faculty mentors. Formative evaluation has shown that participation in the CBASE RCs Program has significantly impacted students' retention and graduation rates. As a result of the program's success, CSU Pueblo has introduced an institutionalized first-year research experience program called Discovery Scholars, which aims to provide research opportunities for first year and transfer students across the campus, regardless of their field of study.

3. Discussions

3.1 Influence of mentoring model on retention and graduation rates in RCs

This section presents an analysis of student retention within the undergraduate research program CBASE and the education program, based on their field of study and monitoring approach. The purpose of this analysis is to examine the effectiveness of the programs in retaining students and to identify any differences in retention rates based on field of study or monitoring approach. The study evaluates the retention rates of students across programs and identifies areas where improvements can be made to enhance student retention in undergraduate research activities.

The project involves five research communities that will include students from various STEM and STEM-related programs during the grant period. The number of students involved in each RC are as follows: Biology 113, Chemistry 37, Engineering 42, Physics 2, Teacher Education – STEM 9, and Civil Engineering Technology 2. The analysis will compare project outcomes for biology, chemistry, and engineering RCs that involved most students. Research activity began in 2017 as shown in Fig. 1.

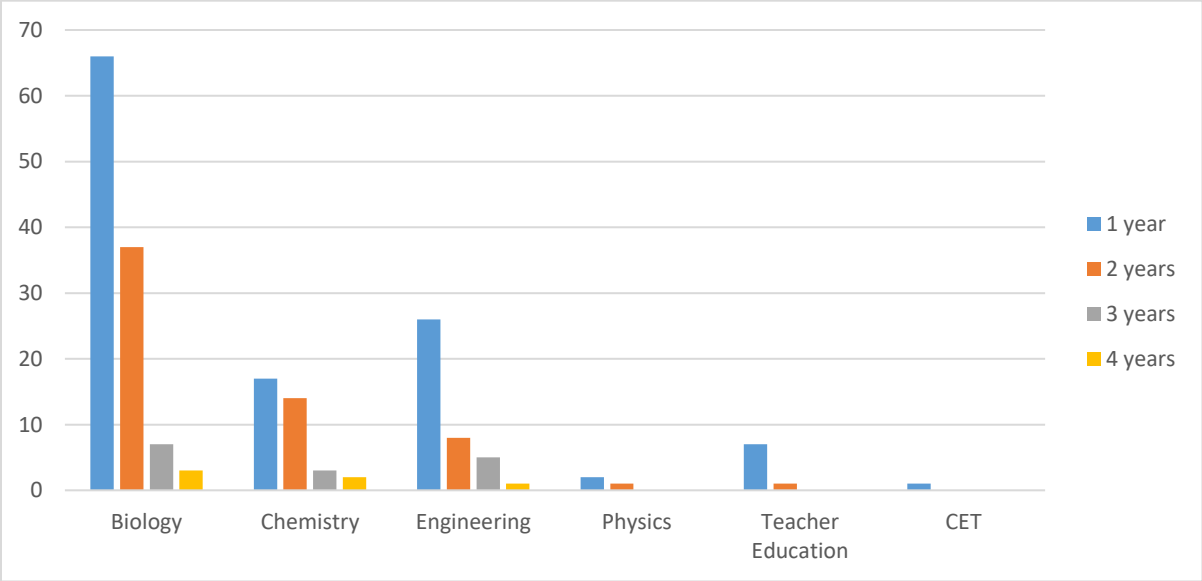

Fig. 1. Number of students involved in the CBASE program, categorized by study and field and number of years.

While engineering RCs were mentored by a group of faculty mentors for all projects, the students in all other disciplines were mentored by individual faculty per student or student group. It is

postulated that students' familiarity with a larger number of faculty would lead to increased retention and graduation rates than if students interacted with only one faculty member.

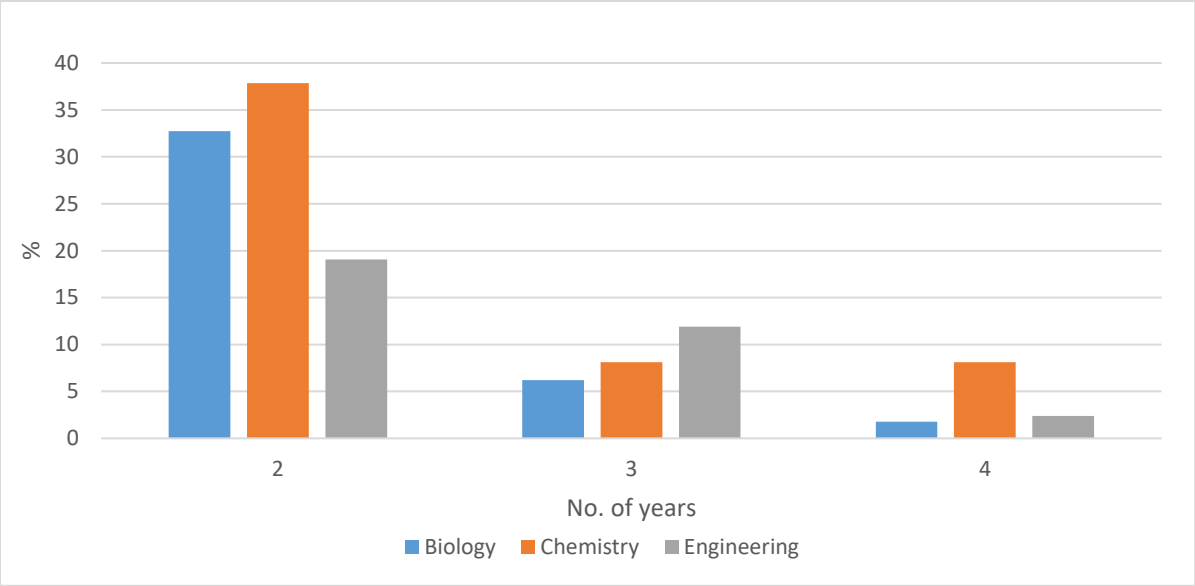

Fig. 2. Percentage of CBASE program students who continued for more than one year by study field.

The data presented in Fig. 2 reveals the percentage of students who have participated in RCs projects for a duration exceeding a year, classified based on their area of specialization, namely Biology, Chemistry, and Engineering. The figures have been derived from the cumulative number of students listed in Table 3 for each discipline. The results indicate that approximately 37% of Chemistry major students have participated in research projects for a year or more. In contrast, the percentage for Engineering and Biology majors is approximately 32.5% and 18%, respectively. The findings suggest that Chemistry majors have a higher inclination towards research activities compared to their peers in Biology and Engineering.

During three years of engagement, there has been a noticeable increase in the enrollment of engineering students. Meanwhile, four years of research engagements for Chemistry major students are more noticeable. Several factors influence the percentage of students who continue in the program. One of these factors is the timing of their enrollment in the program or their change of interests.

Students are often engaged in research activities at a beginner or intermediate level in their study program. Another factor that can contribute to student engagement is the type of study field. For example, biology students are usually more interested in completing a professional study program such as nursing, medicine, dentistry, or veterinary medicine. Therefore, their interest in gaining professional health-related skills is attractive to them. The same applies to engineering students

who are more likely to pursue a career as professional engineers than to be involved in research work.

Fig. 2 shows that the group mentoring approach (group or individual) for engineering research students had limited influence compared to the study major. However, a good number of students involved in the undergraduate program had shown interest in completing the 3+2 master's program.

The group mentoring approach was beneficial in several ways, as noted by mentors, especially with the group meetings. Through active participation in discussions on various projects, students became more aware of different scientific ideas and concepts. This helped them better understand multiple scientific knowledge and improve their teamwork and communication skills through participation in the RC group meetings. Also, Engineering RC has a large number of students from different genders, countries and races that make it a good learning environment to increase confidence in mentoring students across diverse cultural identities and the relevance of their racial/ethnic identity to mentoring.

As a result of the group mentoring model, students were better equipped to change their project within their field of interest or if a faculty mentor terminated their original project for any reason. Therefore, they could easily switch to new projects more closely related to their interests or career goals. This approach helped students gain a broader perspective and develop a more diverse skill set.

3.2 Implications for practice and policy

CBASE was partially institutionalized and expanded via the creation of Discovery Scholars, which is a targeted first-year research program. It has continued with the successful impact of CBASE.

Additionally, it is worth mentioning that funding programs like this is always a key barrier. A notable example of partially institutionalizing programs like this is supporting faculty and students via Type B instruction and building up a culture of students doing research to fulfill their course credits partially.

Finally, partnering with local organizations and companies to provide funding towards specific research projects is another non-grant-based way to create programs like this. It is important to remember that when not funding via a large grant, there is no "one size fits all" or silver bullet to cover all costs.

4. Conclusions and future work

Here are some important lessons learned from this study:

1. Undergraduate research is crucial for all fields of study and should be designed to align with students' career goals. This will increase student involvement and retention.

2. Encouraging students to participate in research projects early in their study program is crucial as it allows them to explore research work and make an impact on their perspective about the importance of scientific research and their career field.

3. Group mentoring approach effectively enhances communication and teamwork skills, especially among diverse groups.

4. Group mentoring is an effective way to increase students' and mentors' awareness of different study subjects and to increase productive engagement.

Future work:

The success of the CBASE project has paved the way for further expansion of the research community through another grant that aims to enhance the academic achievements of STEM students from 2021 to 2026 as part of a research program implemented at CSU Pueblo under Title III, Part F (HSI STEM) grant. The researchers plan to collect the necessary data and information to compare the two projects and present their work in a future conference or peer-reviewed journal.

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