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Work-In-Progress (WIP): Exploring STEM Undergraduate Research Skills Development in Interdisciplinary Projects

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Work-In-Progress: Exploring Interdisciplinary Undergraduate Research Skill Development in Long-term Projects

Abstract:

In this work-in-progress paper, we examine the skill development of students from a variety of disciplines in science, technology, engineering, and mathematics (STEM) following their extended involvement in an interdisciplinary undergraduate research experience. Undergraduate research in STEM is an important step in student learning and has been shown to help students prepare for further studies and jobs. There are many forms of undergraduate research experiences, but a common method is for a student to work closely with a teacher in research. Students often find these hands-on experiences very useful and learn to work in teams, manage projects, and communication skills. In the scope of this work-in-progress study, our program, originally rooted in engineering, now draws one-quarter of its students from departments outside the College of Engineering. The program objective is to offer students early in their programs hands-on project experiences and enhance their collaboration skills across diverse disciplines and projects. Our study centers on an innovative, faculty-led interdisciplinary undergraduate research program. We interviewed 10 participants, evenly split by gender, of whom four have transitioned to the workforce and describe what they gained from the experience. The findings offer insights into student skill development and provide perspectives on the benefits of the experience from recent alumni who have transitioned to the workforce after participating in the undergraduate research experience.

Introduction

The 2012 "Engage to Excel" report emphasized the significance of dedicated research projects in enhancing undergraduate STEM (Science, Technology, Engineering, and Mathematics) education. Supporting this idea, initiatives aim to increase active learning while decreasing reliance on traditional lectures [1]. Undergraduate research experiences (UREs) are believed to be an important approach for actively engaging students, a key goal of these teaching reforms. Such experiences are seen as vital for the broader aims of increasing inclusivity and expanding participation in STEM fields. UREs have made important contributions to the career development and success of many students. Practitioners often credit their early undergraduate research experiences as pivotal in shaping their professional paths [1]. In recognition of this, the National Science Foundation has provided substantial funding to give students valuable opportunities to participate in UREs. These opportunities have been shown to help prepare students for further studies and careers [1], [2], [3].

UREs come in many modalities, such as traditional faculty-student collaborations, project-based initiatives, community-based projects, capstone projects, internships, co-ops, course-based undergraduate research experiences, international research opportunities, and programs like Vertically Integrated Projects (VIP). These initiatives provide students with versatile chances to participate in hands-on experiences, acquire methodological expertise, and make meaningful contributions to advancing knowledge in their respective disciplines. [1], [4], [5]. Moreover, the scholarly literature reveals that participation in UREs yields substantial benefits for students pursuing STEM careers. Research findings show that UREs can lead to a better understanding of the research process, build critical skills, and increase interest in STEM careers for students [6]. Participating in UREs helps clarify students' academic and professional interests [4], [7]

Our research explores engineering students' skill development from interdisciplinary undergraduate research within the context of the Vertically Integrated Projects (VIP) model. The VIP approach represents a distinctive pedagogical paradigm designed to enrich the academic path of undergraduate students. Distinguished by its emphasis on long, extended projects, VIP allows students to immerse themselves in and contribute substantively to ongoing research work [8]. The process prompts active learning, and the VIP initiative involves students in hands-on collaboration within faculty-led teams, involving a high level of engagement with project-specific tasks [5]. Our study seeks to understand students' development of practical, transferable skills through interdisciplinary UREs that follow the VIP model. This study also seeks to explore how these skills prepare engineering students for advanced coursework and professional roles where they must apply knowledge to solve complex real-world problems. The following research questions guided this study:

1. What skills do engineering students develop by participating in interdisciplinary undergraduate research through Vertically Integrated Projects (VIP)?
2. How does VIP interdisciplinary undergraduate research help prepare engineering students for advanced classes?

Background

Over the past two decades, there has been a growing body of research dedicated to examining the landscape of UREs. These studies highlight a broad spectrum, exploring not only the nature of these experiences but also the multiple benefits they grant to their participants [1], [2], [3], [4], [6], [9]. The focal points of these studies span from explaining the different UREs to understanding their impact on diverse aspects of student learning and future goals. Exploring the outcomes, researchers have found that UREs facilitate students' development of fundamental research skills (e.g., data analysis, problem-solving, and critical thinking) [6], [10] [6], [10], [11].

One notable aspect of UREs is that the experiences vary depending on the particular program or model students choose. For instance, the nature of the research undertaken by undergraduates working on capstone projects differs from that involved in study abroad opportunities. Students participating in capstone projects have reported the development of professional skills such as project management, teamwork, and communication abilities [12], [13]. Alternatively, undergraduates conducting research abroad consistently demonstrate growth in areas like cultural awareness, emotional resilience, linguistic skills, and research self-efficacy [4], [14], [15]. Extended involvement in undergraduate research has been shown to result in more pronounced skill development [16]. While both models represent enriching hands-on learning experiences, capstone projects and study abroad research excel at cultivating partially distinct skill sets geared toward entering engineering fields or global scholarship respectively.

Though these differences exist, we can still find shared traits and parallels in different forms of UREs. A study shows that juniors and seniors who participated in undergraduate research are often more interested in pursuing graduate degrees than those who do not participate [7]. Similarly, in alternative URE formats, when students collaborate and conduct research abroad, there is a common tendency to show interest in pursuing graduate education [4]. The combination of results from various studies strongly confirms that UREs not only push undergraduates toward advanced degrees but also help develop crucial research skills like data analysis and problem-solving [6], [11]. The diverse nature of UREs leads to a range of skill development and interest among participants, adding complexity to the landscape of undergraduate research experiences. Thus, the type of UREs could develop a varying degree of skills and interests.

Theoretical Framework

In the development of this research, we have applied the theoretical framework of engineering student identity [17] to develop our interview protocol for a large project. In this framework, there are three key constructs that contribute to one's identity as an engineering student. The first is engineering student interest, which reflects curiosity and engagement with the field of engineering. Godwin [17] explained interest as what an individual enjoys or is interested in regarding a topic, activity, or hobby. Thus, this construct encompasses both desire and curiosity for learning engineering concepts, an inclination towards solving technical problems, and immersion in engineering activities whether course-based or extracurricular. The second core construct is performance or competence in engineering tasks. This refers to one's self-efficacy and belief in being capable of doing an engineering task [17]. In our context, it refers to understanding engineering material, applying knowledge to projects, and successfully completing technical work in undergraduate research. Demonstrating these abilities involves confidence in taking on research challenges, learning new skills, and contributing to the project team. Finally, recognition by others plays a pivotal role in solidifying an engineering identity. It can be defined as "recognition (i.e., beliefs that they are seen as a good student in the subject by peers, parents, and teachers) as being the type of person that can do a particular subject" [17, p. 2]. In the context of this study, recognition reflects both interpersonal validation from engineering peers and mentors as well as personal internalization of external recognition. Through others identifying their engineering talent and technical contributions, students begin to think of themselves as good engineers worthy of that field. With engineering interest, performance, and recognition by others as central pillars, our interview protocol aims to assess the development of an engineering student identity through participation in VIP-organized undergraduate research. However, for this study, we will focus on the second construct which is performance or competence to explore student skill development in an interdisciplinary undergraduate research program. The adopted framework can be found in Figure 1.

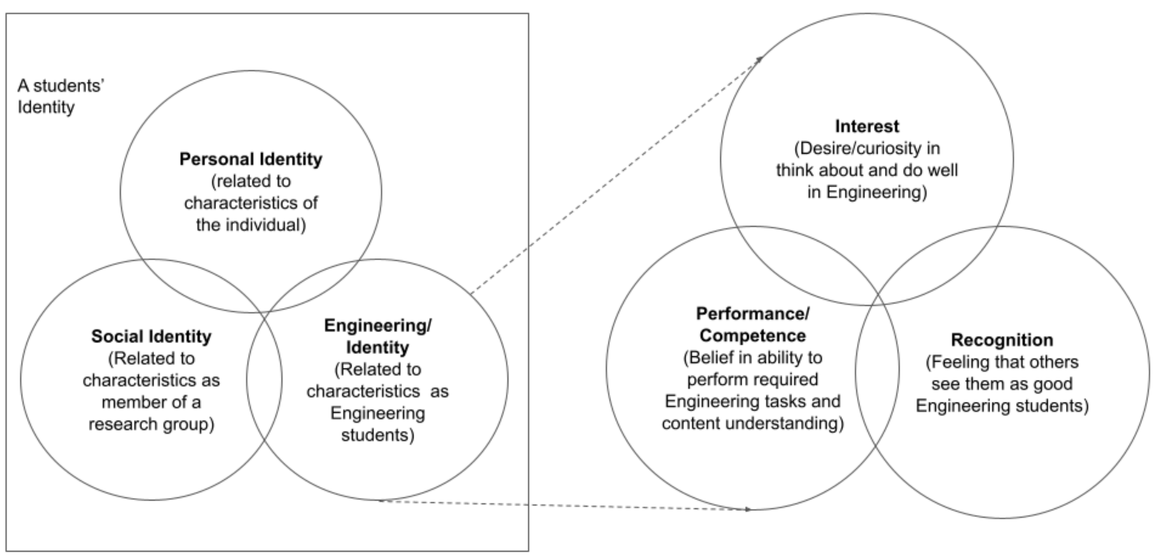

Figure 1. Adopted framework for student identification with engineering [17]

Methodology

This study is an intrinsic case study that explores undergraduate research experiences within a unique interdisciplinary program that follows a VIP approach and its influence on engineering students' skill development. Semi-structured interviews were conducted with a sample of undergraduate students who participated in an interdisciplinary research program. The program provided opportunities for collaborative projects across science and engineering fields. We sought to understand participants' experiences in the program and explore how those experiences helped students develop skills that assisted them throughout their college journey and into their early careers. The qualitative methodology provides insights into the meaning students associate with undergraduate research and disciplinary communities.

As an intrinsic case study contained in one research program, findings detail the particular ways this program shaped and developed participants' skills through authentic research activities.

Undergraduate Research Context

This study examines an interdisciplinary undergraduate research program situated within an engineering education department at a major research university. The R1 institution houses a program offering unique undergraduate research (UR) opportunities for students across various disciplines and majors outside engineering. Grounded in principles of project-based learning, the program aims to foster hands-on research skills, interdisciplinary collaboration, communication abilities, and project management expertise among participants. Self-assembled teams enjoy autonomy in directing research pursuits under broad faculty guidance. Both recruitment and selection processes emphasize candidate motivation for learning through research. While centered in engineering contexts, over time the program has evolved an interdisciplinary and inclusive ethos attracting diverse participants beyond engineering majors. At present, close to 25% are from non-engineering disciplines, bringing alternative perspectives that enrich projects and shape research directions.

To recruit students to the program, descriptions of current projects, including nominal objectives and tasks, are distributed across the institution. Interested students can apply for as many projects as they choose. Continuing student members of the research group review application materials and conduct interviews with prospective students in collaboration with the faculty PI between semesters, with a majority of the recruitment conducted in the late summer for a fall semester onboarding process. Candidate selection favors students from different disciplines than those currently on the team as well as early academic career students. Typical team sizes range from 2 to 8 students on a team, with the entire research group including between 12 and 40 students in a given semester.

Students in the group work on projects that span multiple facets of design, engineering, and social sciences. Example projects include the design, fabrication, and validation of an autonomous, fixed-wing drone; the demonstration of a coupled optical/acoustic nondestructive inspection system for composite materials; or exploring how student teams use online productivity tools in a first-year engineering design course. For projects in their first semester, student teams are tasked with developing a team culture, refining the scope of the project, and developing a written proposal for execution in a subsequent semester. Continuing projects see students working to make technical progress in addressing their research questions, and culminate with a public presentation of results and a written final technical report.

Data Collection

In the recruitment phase for the interdisciplinary undergraduate research, an email was sent out to all previous program participants, encompassing students actively engaged in the experience, as well as individuals who had temporarily paused their participation or had graduated and entered the workforce. Notably, nearly all participants in this study have contributed to these projects for a minimum of two semesters, with some dedicating even more time. Only one student has participated for one semester. We conducted semi-structured interviews, both in-person and via Zoom. The utilization of semi-structured interviews provided a balance between flexibility in conversation and maintaining consistency across interviews. Zoom was used to record the audio of the interviews and generate audio-to-text transcripts.

Our study protocol was developed based on the Engineering Identity Framework. To develop an interview protocol aligned with this engineering student identification framework, we mapped specific interview questions to each of the three constructs: Interest, performance/Competence, and Recognition. Questions about what students learned and the projects they worked on assess students' interests and skills developed in the UR. Asking if students developed new skills and feel those skills are beneficial maps to evaluating their engineering competence and performance. We also asked whether students recognize their achievements and skill growth after participating in the UR. Finally, broader questions about how the research experience impacted their skills and career goals sought to address the second research question.

Participants Demographics

The participants are from a range of engineering and non-engineering majors, including Industrial Systems, Mechanical, Aerospace, Electrical, Computer Science, and Biology/Neuroscience. This disciplinary breadth shows the interdisciplinarity of the research context. Gender distribution is balanced between men and women participants. Racial diversity is also captured within the sample. Academic levels at the time of the interview span junior to senior years, plus a few already graduated, reflecting a range of educational stages. Table 1. summarizes key demographic information about each participant to situate their commentary within the broader sample.

Table 1. Participants, Major, Gender, Race and Year

Participants	**Major**	**Gender**	**Race**	**Academic level**
1	Industrial and Systems Engineering	Female	White/Mixed	Junior
2	Mechanical Engineering	Female	White	Junior
3	Aerospace Engineering	Male	White	Graduated/working
4	Electrical Engineering	Female	Other	Junior
5	Industrial and Systems Engineering	Male	White	Senior
6	Computer Science	Male	Multiracial	Junior
7	Mechanical Engineering	Male	White	Graduated/working
8	Biology and Neuroscience	Female	Asian	Graduated/working
9	Mechanical Engineering	Male	Asian	Senior
10	Mechanical Engineering	Female	White	Graduated/working

Coding and Analysis

We employed thematic analysis of the 10 interview transcripts. Thematic analysis, a qualitative research technique, identifies patterns in transcripts that provide meaningful themes [18]. This method involves breaking down the data (e.g., conversation or answers) into smaller pieces, such as words or phrases, for a detailed examination, followed by the organization of these units into meaningful groups or themes [18]. Our study followed established principles for thematic analysis, as suggested by Braun and Clarke [18]; the analytical process commenced with multiple readings of the data, specifically the transcripts, along with the creation of memos to understand its content. Initial codes were then assigned to capture key elements within the transcripts. Subsequently, a comprehensive review with the team led to the determination of final codes. The diagram below provides an overview of the entire process, encompassing data collection, codebook development, and analysis refinement.

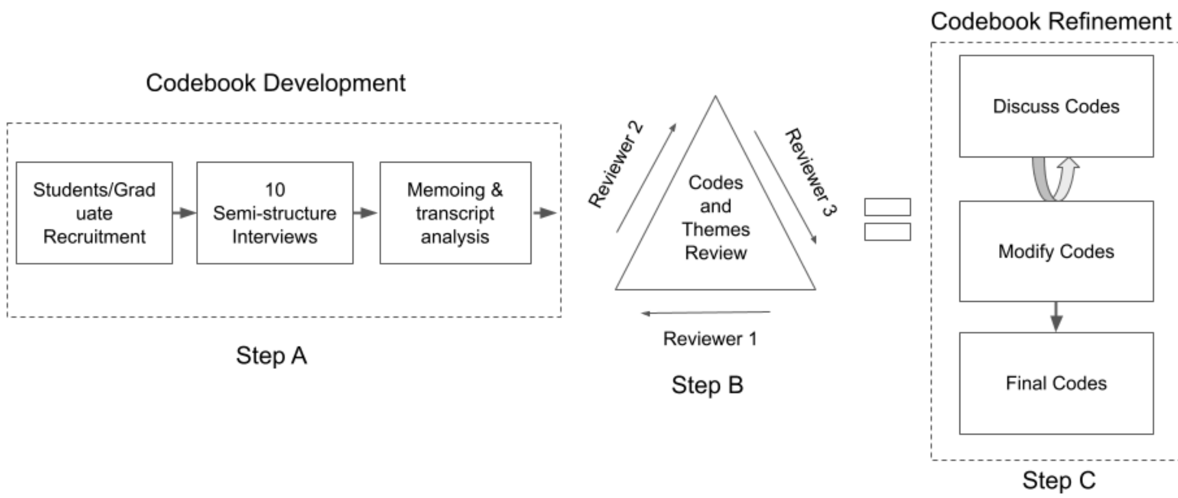

Figure 2. Overview process of data collection, codebook development, and refinement

Initial findings

Existing research demonstrates that undergraduate research projects have multiple benefits for students. For example, studies have shown that participating in undergraduate research improves students' motivation to learn and enhances their collaboration skills [19] Additional research found that undergraduate research opportunities strengthen students' communication, investigation, and documentation abilities [20]. Beyond skill development, undergraduate research also makes students more competitive applicants for graduate programs and jobs after graduation [21]. Our interdisciplinary VIP course allowed students to gain a wide range of skills through team-based research projects. In terms of teamwork, students improved their teamwork dynamics and ability to collaborate effectively. They also built technical skills including engineering and technological competencies such as software proficiency, research methods, and understanding the IRB review process. Conducting hands-on research experiments in interdisciplinary teams, students developed valuable research, technical, and teamwork skills.

Moreover, in terms of skill development, one participant expressed

> “Yeah, I learned how to breadboard. I learned how to deal with it, we have used Adobe Premiere and stuff to show scenarios of like driving in Siberia… Definitely, I learned new skills, like with just research in general, like, collaborating in a team in that sort of environment, because I've never been exposed to that before. And like the pace of research and IRB”

This quote illustrates the participant's perspective on gaining new research skills through undergraduate research experience. The participant used terms like "never been exposed to that before" and "pace of research" to imply this was a novel experience outside their prior knowledge. Learning to collaborate in a team environment also appears to be something new learned on the project. Specific new technical skills like breadboarding and Adobe Premiere were learned which exposed the students to both technical and technological skills. There is also a suggestion that the participant gained an understanding of the broader research process, including navigating institutional review boards.

> "I will say Student C is like the spokesperson of the team… our dynamic, like, you know, the electrical guy does all the little hard wiring of our car horn system. And then like you do programming. Then I'm there like, scheduling, budgeting, and stuff like that"

The participant describes a collaborative team environment with each member taking on distinct roles and responsibilities based on their strengths. They identify Student C as the "spokesperson" of the team, implying Student C serves in a leadership or project management role. Other members are highlighted for their technical contributions - electrical wiring and programming. Meanwhile, the participant positions themselves as focused on the scheduling and budgeting aspects, taking on more of an organizational role. The quote indicates an effective team dynamic where members divide up complementary duties, allowing each person to contribute their skills to the project. The participant's perspective on how differentiating roles within the team composition enables a collaborative process. Each member can focus on their area of expertise, whether technical skills or organizational management which shows team dynamic development.

Students also developed technical skills through hands-on collaboration in applied engineering projects. By working with peers across disciplines to solve real-world problems, students gained proficiency in areas like programming, electronics, and integrating hardware and software systems. With mentoring and structure, these experiences allowed students to cultivate practical abilities and engineering judgment. The hands-on nature provided training beyond theoretical classroom learning alone. In sum, collaborative project work enabled students to build valued technical competencies.

> "We're working with hardware, like controllers and servos, and motors and electronics, and then tying that into the software. That's stuff I do everyday now. Working with hardware and, you know, figuring out how it ties in with the software, how to program everything, how to make sure everything is talking to each other the correct way."

The participants highlight the hands-on experience with technical skills like working with electronic hardware components and writing software to integrate and control the hardware systems. It shows they are gaining practical engineering abilities in a way that classroom learning alone cannot provide.

> "On top of that, it's just learning how to work with peers and with other people. I mean, it's still an academic setting, but learning how to kind of blur those lines."

Here the participants points to the value of collaborating with other students from different disciplines. Applied team-based work allows them to learn how to communicate and problem-solve effectively alongside peers with diverse backgrounds and skill sets.

> "They're just a problem solving. On top of that, managing money was really, really useful. We were given budgets, and we had to figure out how to spend it in the best way to spend it."

This quote emphasizes the problem-solving nature of the work and the chance to develop project management skills like budgeting and resource allocation. It gives the students experience in practical, real-world engineering constraints and trade-offs.

> "Even even little things like learning how to manage bureaucracy, learning how to deal with purchase requests, and learning how to deal with the politics of being under a department."

The student notes how navigating organizational requirements, even ordinary ones like purchase orders, provides a valuable chance to learn how large institutions and systems operate. While frustrating, handling bureaucracy is portrayed as a useful skill. These quotes reinforce the initial themes of gaining technical skills, cross-disciplinary teamwork, problem-solving ability, project management skills, and experience navigating different systems. The hands-on, collaborative environment provides very important real-world training.

Conclusion and Future Work

In conclusion, the quotes shared by students highlight how getting involved in hands-on research transforms them into more skilled and confident engineers. The framework used to understand this journey focuses on their interest in engineering, their ability to do engineering tasks well, and how others recognize their contributions. The students talk about learning new things, like using tools and software, working in teams, and even dealing with the paperwork side of things. The experiences they describe go beyond regular classroom learning, giving them practical skills and a deeper connection to the field of engineering. This research program plays a big role in shaping students into capable and well-rounded individuals.

The quotes highlight the process of skill development in undergraduate research, viewed through the framework of engineering student identity. This framework helps us understand experiences in a VIP undergraduate research program. The first key aspect is students' interest in engineering, shown in their curiosity and engagement. Experiences like working with hardware and navigating research challenges contribute to this interest. The second aspect is competence in engineering tasks, seen in the acquisition of technical skills like breadboarding and using Adobe Premiere. The participants' acknowledgment of facing new challenges emphasizes the importance of self-confidence. The third aspect is recognition by others, observed in collaborative teamwork. External validation, like designating a team member as a "spokesperson," plays a role in shaping the participants' identity as competent contributors to the field.

In our future work, we want to answer our research questions:1) What skills do engineering students develop by participating in interdisciplinary undergraduate research through Vertically Integrated Projects (VIP)? 2) How does VIP interdisciplinary undergraduate research help prepare engineering students for advanced classes? We also plan to carefully look at students' transcripts and make a codebook. This codebook will show the different skills and abilities students picked up while doing VIP undergraduate research. We want to highlight not just what they learned in theory, but also the practical skills they gained during their research. This close look will help us better see the actual advantages and real-world uses that students get from being part of the VIP program.

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