Exploring How Mechanical Engineering Undergraduate Researchers' Understanding of Research Change Over Time

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***Abstract*—This research full-paper explores how undergraduate mechanical engineering students' understanding of research changes over the course of a year-long, apprenticeship-model research experience. Undergraduate research programs are pivotal in fostering academic and professional development among students and provide students with hands-on experiences which can foster a deeper understanding of the discipline. Moreover, undergraduate research experiences can build students interest in and understanding of research as well as shape students' career aspirations. Previous studies have looked at undergraduate students' perception of what research is, however, there is a need to understand if participating in a year-long, apprenticeship model research experience helps undergraduate engineering students develop a more nuanced understanding of what research is. This study focuses on the research questions: How do undergraduate mechanical engineering students' definitions of research change over the course of a year-long research experience? To answer these research question, we conducted qualitative interviews with 10 participants at the beginning and end of their year-long research experience. We employed reflexive thematic analysis to analyze the data and address the research questions. Specifically, we compared participants' responses after the experience with their expectations before the experience. This comparative approach allowed us to identify themes describing how undergraduate research influenced their definitions of research and career aspirations. The findings revealed a significant evolution in the participants' definitions of research, indicating a shift towards more nuanced and realistic understandings. The findings from this study will be useful for faculty who mentor undergraduate researchers as well as those designing and administering undergraduate research programs.**

Keywords—undergraduate research, apprenticeship model, mechanical engineering

I. INTRODUCTION

Undergraduate institutions in the United States are actively pursuing the implementation of research-based learning, which is a key recommendation outlined by the Boyer Commission [1]. A significant aspect of this initiative involves expanding participation in undergraduate research experiences (UREs) across diverse formats and frameworks, with the National Science Foundation playing a crucial role in advocating for and facilitating opportunities for undergraduates to engage in active research endeavors. These UREs vary in their defining characteristics, such as the role of mentors, duration of the experience, compensation for students, associated costs, and the procedures for selecting research topics [2]. They encompass a range of programs, including research experiences for undergraduates (REU), apprenticeship models, international research experiences for students (IRES), capstone experiences, internships or co-ops, course-based undergraduate research experiences (CUREs), project-based programs, and community-based research programs [3], [4]. These UREs have been shown to have widespread benefits for students, faculty, and institutions.

In exploring the benefits of undergraduate research, scholars have primarily focused on research outcomes, collaborations, decisions to pursue graduate school, and persistence and retention in STEM fields. Some of the benefits associated with students' participation in UREs include enhanced cognitive and personal skills, increased likelihood of pursuing graduate degrees, and the shaping career aspirations and educational trajectories [5], [6], [7]. These experiences provide students with hands-on exposure to their field [8], facilitating their transition into the workforce and helping them explore specific career paths within their discipline [9]. Students who engage in UREs demonstrate a higher likelihood of expressing their intentions to pursue graduate or professional degrees in STEM-related fields compared to those who did not engage in these programs [10]. Furthermore, UREs clarify students' research interests, confirming paths for graduate school or research careers [4].

Additionally, Faber et al. [2] conducted a study that provided a comprehensive exploration of undergraduate engineering students' perspectives on what it means to do research and be a researcher emphasizing the multifaceted nature of UREs and their potential impact on students' researcher identities and epistemic cognition. However, there are limited studies on how the perspectives of undergraduate researchers evolve over the course of their research experience. Hence, this study aims to investigate whether participation in a year-long, apprenticeship-model, undergraduate research experience influences the development of a more nuanced understanding of research among 10 mechanical engineering undergraduates at a university in the Midwest. This study contributes to scholarship on undergraduate research and how students' perceptions of research change over time. It will also help educators and institutions tailor undergraduate research programs to better meet the needs and goals of students.

In order to understand how opportunities for undergraduate research affect students' prospects for careers and understand how these experiences broaden their

perceptions of research; we pose the research question: How do undergraduate mechanical engineering students' understanding of research change over the course of a year-long research experience?

II. Literature Review

A. Students Perception of Research

Understanding students' perspectives on research is crucial, as their beliefs shape their motivation, affective states, and actions [2], [11]. Students' perceptions have "behavioral consequences on the learning approaches they adopt, which in turn influence learning outcomes" [12]. Faber et al. [2] emphasized the need to explore students' perspectives about the research process, revealing that students perceive research as leading to discovery, involving dissemination, and integrating findings into society. However, Cartrette and Melroe-Lehrman [13] highlighted that students often have preconceptions about research, expecting a well-defined and planned process, only to encounter the inherent messiness of authentic research. Hence, studying changes in students' perspectives about research, the process, and the outcomes is essential. However, of studies focused on changes in engineering undergraduate students' perceptions throughout their research involvement, most did not monitor changes in students' perceptions over time but rather documented their perceptions at the culmination of the research process.

B. Benefits of Undergraduate Research

Studies have extensively investigated the benefits of undergraduate research experiences (UREs) by faculty and students who have participated in research endeavors. There is a consensus regarding the importance of UREs to the development of students' academic and professional skills. Participants in undergraduate research describe it as a profound experience that shapes their emergent adult identity, career direction, and intellectual and professional development [14]. Russell et al. [15] found that research outcomes increased students' understanding of research methods, confidence in research skills, and awareness of graduate school. Additionally, Idiaghe and Deters [16] reported that undergraduate student researchers in mechanical engineering often found the outcomes of the research process surpassed their initial expectations. Literature highlights numerous benefits of UREs, including improvement in research skills, clarity in STEM career paths, interest in graduate school, communication, critical thinking skills, and personal and professional growth [14], [15], [17], [18].

C. Apprenticeship Model of Undergraduate Research

The apprenticeship model of research, also known as the individual faculty research group or traditional URE model, allows students to gain practical laboratory experience through part-time work in a faculty research lab or team, typically involving one-on-one mentoring [4], [19]. This hands-on/practical experience enables them to learn the fundamentals of research before taking on more advanced responsibilities [4]. Students spend extensive time in a research facility, developing, refining, and executing research projects under the guidance of a mentor [19]. Within this research-oriented environment, students enhance problem-solving and critical-thinking skills, explore their own research topics, and cultivate qualities essential to becoming a scientist[19]. Ahmad and Al-Thani [19] highlighted several strengths of the traditionally apprenticeship-styled model of research, including the development of core abilities, authentic research experience, a strong sense of community, and effective mentoring. However, they also identified limitations of this model, such as detrimental competition among students for participation, limited student engagement, and a lack of theoretical gains.

III. Methods

This qualitative study draws on longitudinal interviews with 10 undergraduate students who participated in a year-long, apprenticeship-model undergraduate research experience in a mechanical engineering department at a land-grant university in the Midwest region of the United States.

A. Participants

The participants in this study were 10 undergraduate students in a mechanical engineering department. These students participated in a year-long research experience within their department, funded through an external donor, throughout the 2022-2023 academic year. The participants, comprised of six men and four women, were at various stages of their undergraduate education ranging from sophomore to senior year in engineering as at the time they participated in the research program. Each student collaborated with their faculty mentor to develop a research proposal and were selected through a competitive process. The participants engaged in 10 hours of paid research weekly and worked directly with a faculty mentor in the faculty mentor's lab.

B. Undergraduate Research Program

The program utilizes an apprentice research model which emphasizes close collaboration between students and faculty mentors. As part of the program, students are expected to present research posters at the end of the academic session showcasing their findings to the broader academic community. Students often participate in various phases of the research process and may contribute to publications with their advisor. The program spans a full academic year, with students having the opportunity to reapply in subsequent academic years. The scope and nature of the research projects that students engage in varies depending on student and faculty mentors' interest across the different labs.

C. Data Collection

Institutional Review Board approval was obtained prior to data collection. Data collection involved two semi-structured interviews conducted at the beginning and end of the research program. These interviews were open ended in nature and designed to explore different facets of the students' research experiences and track changes in their perspectives over the course of the experience. Both entry and exit interviews included questions about the participants' definition of research, career aspirations, and decision-making regarding graduate school. A specific question, "how has your understanding of what research is, changed over the course of your research experience?" was included in the exit interview protocol.

Twelve participants took part in the entry interviews, but only 10 students continued to the exit interviews. The pre and post experience interviews were approximately 45 minutes and 60 minutes respectively. The interviews were conducted either in person or via Zoom, depending on the participant's preference. Audio from the interviews were recorded with participants' permission, and an assurance of anonymity. Participants were informed of the voluntary nature of the study and were assured that their responses would not affect their

course grades or their relationship with the researchers. They were also given the option to decline answering any questions they felt uncomfortable with.

TABLE I. RELEVANT INTERVIEW QUESTIONS

QQ1	Pre interview	How do you define research?
QQ2	Pre interview	After this experience, how do you define research?
QQ3	Post interview	How has your understanding of what research is changed over the course of your research experience?

D. Data Analysis

Data analysis included a comparative analysis between the responses from the pre and post interviews. The pre interview data of two students who did not present themselves for the post interviews were excluded from the analysis. A transcription software was used to transcribe the interview data, which was then thoroughly reviewed for accuracy. A reflexive thematic analysis approach described by Braun and Clarke [20] to categorize the patterns within the collected data was adopted as the data analysis approach. Initially, relevant sentences and quotes that had to do with participants understanding of research, definition of research and the research process were extracted from both the pre and post-interview transcripts. The codes from the pre interviews were compared with that of the post interviews to explore for changes in participants understanding of research. Most of the insights presented in the results were obtained from participants responses to interview questions QQ3 shown in Table 1, while the responses for QQ1 and QQ2 served as a source of cross referencing and further exploration where necessary, enabling a comparison of students' responses before and after the research experience. Collaborative meetings were held by the research team to discuss and review the emergent codes and theme to promote quality of the emergent results. The identified themes were then finalized to address the research questions effectively.

IV. RESULTS

The results of this study showed an evolution in perception of study participants in having more nuanced understanding and interpretation of what research is and as well as the processes involved.

A. Research Pace and Progression: Research is More Gradual

This theme highlights a shift in students' perception regarding the pace of research. Undergraduate student researchers expressed a realization that research progresses more slowly and incrementally than they initially thought. Initially, participants perceived research as a fast-paced process characterized by rapid experimentation, learning, and paper writing. Participant 2 said, "I think it's definitely changed because I used to think being, you know, in research, I thought research happened a lot faster. You know, we were learning things, running experiments, you know, writing papers was quicker, everything was just faster and faster than what it is."

Participant 9 discovered that the research process required significant time and effort, leading to a reassessment of their expectations regarding the pace of research activities:

> I think, I've realized it's a lot more gradual than I thought, I think especially for so much of the bio stuff. It's like, there is this big, big paper that everybody cites, and it's talking about, like, three more of the thousands of markers in like this specific cell, or that kind of thing. Like some much of it is just like, here's a paper about how to improve this one specific process. In order to like this one specific process to extract this one specific thing with one specific cell by like, you know, 10% and it's just, it's like that level of improvement. But then there's just like, you know, have hundreds and thousands of those. But like, so much of the research that we see for like, that makes like a bigger step that's like more relevant to especially for like healthcare stuff. Like, in order to get that bigger step, you have to so much of the like groundwork stuff had to get built out first. Which, yeah, I think that's the biggest change, because I just see how much like, all the citation lists are like, [name removed], for you know, what a small improvement.

As time went on, they understood that in the research process, getting the overarching big result may need several relatively small successes and contributions to get to the desired destination and this takes time to build upon.

B. Definition and Scope: Research is Not Clearly Defined

Students discovered that research is not strictly procedural, but rather dynamic and unpredictable and sometimes involves trial and error in experimentation. They found that researchers must be adaptable rather than rigid in their approaches. An example is Participant 4 who said:

> I thought research would be more clearly defined, I thought it would be more kind of step-by-step process, but that's not always the case. And researchers, I found have to be pretty adaptable to you know, oh, it's not going to plan. So how am I going to change the plan and figure out what the next steps are. It's not always defined what those are.

Participant 4's perspective changed as they realized the need for flexibility when engaging in research, they discovered that unexpected trends, challenges or setbacks will come up during the research process and that researchers must be ready to be confronted with the unexpected. They went on to say:

> It's not a clearly defined path. So I, when I first came into research, I thought it should be fairly organized, I should know, you know, what my next steps are going to be. And I think there's certain aspects of that, that are true, but every step of the way, you're kind of seeing something differently. Or you're maybe seeing a change that you didn't expect and because of that, you have to alter your route. So, my first thought, I thought I'd be reading about it, then I'd be put into something, doing tests, looking at the results, I would see clearer trends and from there, I would be able to make conclusions, but it's more, you know, reading about it, realizing that this is a kind of new topic that people are interested in, but don't know much about. Kind of trying to figure out, well, what do I want to test? And what do I want to see about it, performing making those tests getting results that maybe are not super conclusive, but you have to make, you have to make a conclusion from nonetheless, changing your hypothesis going back. Doing the tests again, you know, trying to trying to get to the end goal of a super clear conclusion, but it's not a straight path, I have to think, you know, we take for granted the scientific method that we learn in high

school and in middle school and stuff like that. But, I mean, that's pretty much how research goes, it's, you know, learning about something hypothesizing, testing, kind of seeing, does it confirm or contradict re doing that? So I guess it's a process of discovery, if I could sum it up in one sentence. [Participant 4]

Participants 1's perspectives agree with the position of Participant 4. Participant 1 initially perceived research as limited to traditional scientific methods, such as data quantification or particle analysis, but they found out that the research process can be flexible and follow an unconventional format. Their perspective evolved to recognize the diversity and flexibility of research approaches within engineering. They realized that the research process is not a path that is cast in stone, but encompasses innovative design projects and unconventional problem-solving:

Yeah, I think at the beginning, it was like, I've learned that it's a lot more flexible that like you can kind of do a cool design project and as long as it hasn't been done before, like there's pure science research, which this is I don't do as much but like the engineering kind of research, as long as it's a novel approach. There's a lot of like research besides just like, hey, what about what if we applied this idea to something like this? Does it work? Or how well does it work? Are there advantages or disadvantages? That was something that I didn't quite realize was a research, very viable research method that you can take on. You don't have to be like, proving stuff about particles, or like in material science, you don't have to be just doing a bunch of data quantifying, you can do some pretty bulk design, stuff that's like unconventional rover locomotion and stuff that people in our lab have done. [Participant 1]

Participant 2 identified that problem solving through research, did not follow a stepwise process but involved trial and error processes:

I would define research as like problem solving through trial and error, through failure as, like you, you've got an overall goal and you just you kind of have to keep throwing things at it to try and figure it out. And then you may not have even solved your problem, or I guess learning through problem solving and trial and error because like at the end, you're you will have learned stuff whether or not you've solved your initial problem, I guess that's more engineering. But research is like you, by the end of it, you have more information that's like this works, this doesn't work. We went in a totally different direction. But we found out this thing that's really cool. I guess it's just like learning through trial and error.

C. *Research can be Done by Everyone, it is not Meant for Only Graduate Students*

At the beginning of the research experience, some undergraduate students believed that research was too hard to be performed by undergraduate students and it was exclusively the domain of graduate students, with undergraduates merely assisting in basic tasks. However, through their participation in research experiences, they discovered that undergraduates can actively engage in and contribute meaningfully to research projects with the right learning mindset:

Um, I think it would more just so be like, I thought research was this big, huge thing um, that was so hard to do. And you had to be like a grad level student to do it, and if you weren't a grad level student, you were just kind of like helping them do like, you know, like basic calculations or like working with like, maybe like you help them make a spreadsheet or something to collect all of the data that they're running, but you don't really understand what's going on. And now like being on the other side of it, I realized, like you everyone can do research, you just have to be willing to, like, learn new things while you're doing research. And like, make those mistakes, and then learn again from those mistakes, and just kind of yeah, be willing to learn new things outside of the classroom. [Participant 7]

Participant 11 shared another example highlighting the shift in their perception regarding professors and graduate students having all the answers in research. They observed that through their active participation in the research process, they discovered that even graduate students and professors did not possess all the answers. Instead, they were actively engaged in experimentation to address identified research objectives. Undergraduate researchers observed that all individuals involved in the research process were equally dedicated to achieving results and pursued the research objectives with the same level of commitment. They also reported that the process involved trial and error.

I mean, I guess my view of research and like what it is hasn't changed a ton. But I have a better understanding of like, what it means to do research because like, you don't have all the answers. I thought, like, grad students and professors doing research, like they knew exactly what they were doing, like it was easy for them, they're just kind of investigating fields they were already experts in. But then I found that most of us have no clue what we're doing, we just have to figure it out as we go along and like just test things and read prototype over and over again, until we get like, results that, like, we're until we get it to work and get like results that like actually look reasonable. So, it's a lot of just trial and error and like, oh, we need to do this, so now we have to spend time googling and like watching YouTube videos to teach ourselves how to do this thing, because the project requires us to know how to do it. So, I didn't realize there was that much like going on in labs, but I guess with hindsight, it makes sense. Since you know, no engineer is good at everything. [Participant 11]

D. *Better Understanding of the Scientific Method / Research Process*

Participants in this category noted that engaging in the research process did not drastically change their understanding of research, but it did enhance their comprehension of scientific methods and the research process. Participant 5 expressed that while their overall definition remained unchanged, their involvement provided deeper insight into the research process:

Broadly, not so much, but specifically, I got to understand more of the in-depth caveats. Like I wouldn't say my overall definition has changed my understanding of like the research process, especially more like the academic side of it with paper publishing and, like data publishing has evolved a lot because I didn't really have know anything about that before I started research. [Participant 5]

This sentiment was echoed by Participant 10, who acknowledged having preconceived ideas of what research entailed but found their understanding expanded through active engagement in research projects and scientific methodologies:

> Yeah, I think I definitely have like, just a general, like better understanding of like, the scientific method just how to, like create research projects that have validity, and purpose. So yeah, I don't know, I feel like I've always had like the idea in my head of what research is, but seeing how it's actually applied, and like seeing the steps and, like, even like what it takes to like interview humans, like there's more steps in like the world of science that you got to rather take. [Participant 10]

Participant 8 reported to believing that research was more theoretical, but their engagement in the research process has exposed them to a more hands on approach to research:

> Prior to joining the lab, I assumed that research is 70% at least, literature review. So, it's more conceptual and theoretical, more than the simulations in the lab. So I envisioned it as more analytical. And some research labs are, they, they are actually more analytical, but I am very happy with my experience because I do get a lot of hands-on, time, most of it. So there is very little CAD work that I do, I design. There is sometime- downtime at my desk when I design experiments, I plan I read, but I guess I spend more time actually doing simulations and all that. [Participant 8]

Participants acknowledged gaining insight into various aspects of research process, including funding pitfalls and non-relevant information that could disrupt the process:

> It [research] is also a lot more, you know, you have to spend a lot of money, you have to get a lot of money. And there's this whole background of research that has nothing to do with what you're learning, or what you're trying to prove or gain. That is so much more complicated, and you need, you need so much more time with it that sometimes that overtakes the actual research itself. And so, I think research is still the quest for knowledge, it's still trying to go further with what we know. But I think the research that I've done can also show that there's so many hoops, you have to jump through to learn the smallest bit because you have to prove every little thing to move forward and that's sometimes can bog down what research is and, and kind of hide that it's still you know, we're trying to learn as much as we can [Participant 2]

V. Limitations

This study was conducted within one department at a university, which may limit the transferability of the findings to a broader population of mechanical engineering students at other universities. Researchers and practitioners are recommended to assess their own contexts in relation to the study's parameters when transferring findings. Moreover, this study represents an investigation with a limited dataset, which may restrict the depth of the analysis. As a result, while the overall project aims to investigate the influence of long-term undergraduate research experiences vs. short-term experiences, this paper does not have enough data to make definitive claims in this regard.

VI. Discussion

This study is unique in that it provides a long-term (1 year) research experience for undergraduate mechanical engineering students. This extended duration offers insight into how students' perceptions evolve over time compared to those engaged in relatively short-term experiences (over a few weeks or a semester). One notable aspect of this study is the development of more nuanced understandings of research among the students. They came to realize that research is a messy process involving many non-linear steps. Some of our findings align with existing literature, such as the notion that research is not clearly defined and involves trial and error, as noted by Cartrette and Melroe-Lehrman [13]. This study further emphasizes the importance of researchers being adaptable and flexible in their approach, adding to the literature on essential qualities for researchers [21]. Our results also highlight the importance of undergraduate researchers being open-minded and willing to learn. Participant 7 said, “I realized, everyone can do research, you just have to be willing to learn new things while you're doing research.” This quote underscores the need for open-mindedness and inquisitiveness in research endeavors. This study also pointed out to how engaging in research can help students correct misconceptions they have about research, such as professors and graduate students having all the answers, or that undergraduate students can only engage in menial jobs in the lab. While undergraduate researchers may start as novices, they gradually take on more advanced responsibilities in an apprenticeship model of research [4].

VII. Conclusion

In this study, we investigated the impact of year-long undergraduate research experiences on mechanical engineering students' perceptions of research. Through qualitative analysis, we found that students' definitions and understanding of research evolved significantly, reflecting a deeper engagement with the research process. These findings underscore the importance of providing significant research opportunities for undergraduate students to enhance their intellectual growth and inform their future academic and professional decisions.

References

[1] Boyer Commission, “Reinventing Undergraduate Education: A Blueprint for America’s Research Universities,” Boyer Commission on Educating Undergraduates in the Research University, Room 310, Administration Bldg, 1998. Accessed: May 01, 2024. [Online]. Available: https://eric.ed.gov/?id=ED424840

[2] C. J. Faber et al., “Undergraduate engineering students’ perceptions of research and researchers,” J. Eng. Educ., vol. 109, no. 4, pp. 780–800, 2020, doi: 10.1002/jee.20359.

[3] Mary Beckman and Nancy Hensel, “Making explicit the implicit: Defining undergraduate research,” CUR Q., vol. 29, no. 4, pp. 40–44, 2009.

[4] Gentile, K. Brenner, and A. Stephens, Eds., Undergraduate Research Experiences for STEM Students: Successes, Challenges, and Opportunities. Washington, D.C.: National Academies Press, 2017. doi: 10.17226/24622.

[5] C. O. Alm and R. Bailey, “Scientific Skills, Identity, and Career Aspiration Development from Early Research Experiences in Computer Science,” J. Comput. Sci. Educ., vol. 13, no. 1, pp. 2–16, Apr. 2022, doi: 10.22369/issn.2153-4136/13/1/1.

[6] Gabriella Torres, Edward Berger, David Evenhouse, and Andres Torres, “Design and Implementation of Large-Scale Summer Undergraduate Research Programs,” 2023 IEEE Front. Educ. Conf. FIE, pp. 1–9, 2023, doi: 10.1109/FIE58773.2023.10343271.

[7] A. L. Zydney, J. S. Bennett, A. Shahid, and K. W. Bauer, "Impact of Undergraduate Research Experience in Engineering," J. Eng. Educ., vol. 91, no. 2, pp. 151–157, 2002, doi: 10.1002/j.2168-9830.2002.tb00687.x.

[8] I. E. Salami and L. A. Perry, "Assessing Priorities in Engineering Design Through Augmented Reality," presented at the 2023 ASEE Annual Conference & Exposition, Baltimore, MD, Jun. 2023. 10.18260/1-2--42303

[9] P. Bass, N. Washuta, J. Howison, R. Gonzalez, and C. Maier, "Benefits and Challenges of Undergraduate Research," presented at the ASEE Southeastern Section Conference, Daytona Beach, FL, 2018, pp. 1–10.

[10] M. K. Eagan, S. Hurtado, M. J. Chang, G. A. Garcia, F. A. Herrera, and J. C. Garibay, "Making a Difference in Science Education: The Impact of Undergraduate Research Programs," Am. Educ. Res. J., vol. 50, no. 4, pp. 683–713, Aug. 2013, doi: 10.3102/0002831213482038.

[11] A. Bandura, Self-efficacy: The exercise of control. in Self-efficacy: The exercise of control. New York, NY, US: W H Freeman/Times Books/ Henry Holt & Co, 1997, pp. ix, 604.

[12] A. Ferreira and A. Santoso, "Do students' perceptions matter? A study of the effect of students' perceptions on academic performance," Account. Finance, vol. 48, no. 2, pp. 209–231, 2008, doi: 10.1111/j.1467-629X.2007.00239.x.

[13] D. P. Cartrette and B. M. Melroe-Lehrman, "Describing Changes in Undergraduate Students' Preconceptions of Research Activities," Res. Sci. Educ., vol. 42, no. 6, pp. 1073–1100, Dec. 2012, doi: 10.1007/s11165-011-9235-4.

[14] A.-B. Hunter, S. L. Laursen, and E. Seymour, "Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development," Sci. Educ., vol. 91, no. 1, pp. 36–74, 2007, doi: 10.1002/sce.20173.

[15] S. H. Russell, M. P. Hancock, and J. McCullough, "Benefits of Undergraduate Research Experiences," Science, vol. 316, no. 5824, pp. 548–549, Apr. 2007, doi: 10.1126/science.1140384.

[16] N. I. Idiaghe and J. R. Deters, "Board 131: Investigating the Impact of a Mechanical Engineering Undergraduate Research Experience on Student Learning (Work in Progress)," presented at the 2023 ASEE Annual Conference & Exposition, Baltimore, MD, Jun. 2023. 10.18260/1-2--42445

[17] R. Hathaway, B. Nagda, and S. Gregerman, "The Relationship of Undergraduate Research Participation to Graduate and Professional Education Pursuit: An Empirical Study," J. Coll. Stud. Dev., vol. 43, Jan. 2002.

[18] E. Seymour, A.-B. Hunter, S. L. Laursen, and T. DeAntoni, "Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study," Sci. Educ., vol. 88, no. 4, pp. 493–534, 2004, doi: 10.1002/sce.10131.

[19] Z. Ahmad and N. J. Al-Thani, "Undergraduate Research Experience Models: A systematic review of the literature from 2011 to 2021," Int. J. Educ. Res., vol. 114, pp. 1–17, Jan. 2022, doi: 10.1016/j.ijer.2022.101996.

[20] V. Braun and V. Clarke, Thematic Analysis: A Practical Guide. SAGE Publications Ltd, 2022.

[21] L. H. Toledo-Pereyra, "Ten Qualities of a Good Researcher," J. Invest. Surg., vol. 25, no. 4, pp. 201–202, Aug. 2012, doi: 10.3109/08941939.2012.701543.