Strategies and Considerations for Starting an Undergraduate Research Lab as a New Faculty at a PUI

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Abstract*—*Contribution: **This research paper describes challenges and successes of a new faculty starting an undergraduate-only research lab. Considerations and strategies for future faculty at PUI's are developed through participatory research methods which accounts for both faculty and student perspectives.**

Background: **Previous research addresses the challenges of conducting undergraduate (UG) research and the logistical challenges of building a new research lab designed for UG research. A lot of this work has focused on how to scope a research project appropriately, how to scaffold the projects to create a positive UG research experience, and logistical considerations on how to select and obtain lab equipment from the faculty perspective with less consideration for the student perspective. This study builds upon previous research by using co-deisng to develop strategies and considerations through collaboration between both the faculty and students involved in starting the lab.**

Research Questions: **What are some challenges faculty and students starting an UG-only research lab face? How can the faculty and students in the lab address these challenges to create a positive experience? What aspects of starting an UG-only research lab did the students find beneficial to their overall growth?**

Methodology: **For this research study, a co-design approach was used to obtain perspectives from the faculty and students in a new UG-only research lab. Collectively, a list of questions were developed to capture the overall experience of students and faculty during the first summer of research conducted in the lab. The faculty member and each student had an external party conduct a semi-structured, recorded interview following the same set of instructions. A focus group was conducted between all participants to discuss the interview questions and responses as a group and find common/dissimilar themes between the faculty and students. The small sample size, while a limitation with regards to generality of the results, lends itself to narrative analysis.**

Findings: **The interviews and focus group yielded several important considerations for new faculty including having a structured onboarding process for new student researchers, participating in research activities with the students to build community, and granting the students autonomy to decide their own research direction. These findings can be used by new faculty to guide them as they set up new research labs so that the lab can be set up to mutually benefit both the faculty and the students.**

***Index Terms*—narrative inquiry, undergraduate research, focus groups**

I. Introduction

Undergraduate (UG) research is shown to have many positive effects including increasing student performance in classes, increasing resilience to failure, and increasing student interest in pursuing future research and graduate studies [1]–[6]. These effects are much more pronounced when the UG students are engaging in a well-designed research experience. However, designing a successful UG research experience is incredibly difficult and requires a large investment from the faculty member [6]–[13]. Additionally, UG student researchers face unique challenges that graduate students would not necessarily face which can make it difficult for them to successfully complete an UG research experience. Unlike for graduate researchers, UG researchers main focus is on their school work [14]. Additionally, UG researchers have much less experience working on and managing an independent research project. They require projects with a smaller scope, a formalized mentorship plan, scaffolding within the project itself, and regular meetings with their faculty advisor [7], [12], [15]. UG researchers also face struggles with managing their motivation and expectations surrounding a research project [11], [13], [14]. UG students also tend to have different goals for the research project compared to their faculty advisors due to their focus mainly being on their schoolwork. Students often think of research as a way to start accumulating experience towards a career while faculty see research as a way to advance their career [14]. As a result, UG students have difficulty motivating themselves to spend more time on the project, especially when the project becomes difficult or tedious, because of the misalignment in how they perceive the value of conducting research [14]. Many of these struggles can be mitigated through different support structures that faculty can implement including scaffolding the experience, managing students' expectations on what they can realistically accomplish, more frequent check-in meetings, requiring the students to maintain a weekly research journal, and requiring students to give a midpoint presentation [11], [12], [16].

In order to address the challenges students face, faculty

must endeavor to design the UG research experience in ways that help students succeed. First, faculty need to spend time designing an appropriately scoped research project because UG students do not have as much background knowledge or experience as graduate students [7]. Additionally, faculty also need to spend more time actively mentoring UG researchers. As mentioned above, these meetings are important because they are places where the faculty can help the student with managing their expectations, with maintaining motivation to work on the project, and by providing scaffolding and technical guidance on the project [11], [12], [16]. These challenges that faculty face are seen at both large Research-1 (R1) institutions and at smaller non-PhD granting institutions or Primarily Undergraduate Institutions (PUIs).

There are a multitude of successful UG research programs at both large R1 campuses and small PUIs that have been studied to determine the reasons for their success. Programs that have occurred at large R1 institutions have implemented techniques such as creating a class for UG research that runs through the academic year rather than during the summer [3], [5], [8]. Creating a research program to run during the academic year works well when at a large R1 institution because of the large pool of faculty and students that could participate in the program. This may not be as feasible for smaller institutions. In contrast, programs at other institutions have successful UG research programs by implementing careful screening and selection of students to choose participants who are highly motivated to conduct research [11], [13]. At small institutions, faculty have implemented successful research programs by providing structured mentoring for the students and scaffolding the research work [12], [15]. It is important to recognize that at smaller institutions faculty face additional challenges which include having less funding overall and a higher teaching load. These challenges can make developing a successful UG research program difficult [4], [10].

This paper contributes knowledge for implementing a successful UG research program at PUIs through using data from interviews and a focus group to incorporate input from both a faculty member and UG student researchers. Additionally, by using data from these sources, this paper will center the student experience through the lens of critical engineering agency theory [17] to address ways in which the research experience can be designed to benefit both the faculty advisor and the students. While some of the results presented here are similar to the results from other papers about research at PUIs, there are some important differences. For example, in [9], Schuster and Birdsong looked at strategies from various successful research groups and generalize those results. Additionally, in [7], Wang, Jalalitabar, and Fierson studied a research program that is run by a CS/IT program rather than an individual faculty member. This paper is unique in that it focuses on labs started by single faculty members and potential strategies and considerations when designing a research experience that helps students build confidence in their identity as an engineer.

II. Theoretical Framework

This study will use the critical engineering agency theory as a framework [17] for understanding how to formulate a UG research experience that benefits the student researchers by growing their identity as an engineer through practice. In critical engineering agency theory, the student's identity is authored by themselves within particular contexts and is something that is continuously changing. While there are studies that focus on the results of students' prior experiences, this study focuses specifically on how the student's identity evolves through participating in UG research and how to formulate an UG research experience such that the students identify themselves as engineers [17]. For those UG students who choose to participate in research, it is a critical experience in the development of their identity as engineers.

In conjunction with this framework, other pedagogical tools will also be used in analyzing the results including identity in practice [18] and democratic science pedagogy [19]. These frameworks help identify different aspects of UG research project design that will most benefit the students. Identity in practice is the idea that a student's identity will become apparent in different contexts based on how they behave and interact with those contexts. In essence, a student's identity as an engineer is affected by a large number of interactions and contexts, many of which are outside of the context of UG research [18]. These students may choose to identify themselves as particular roles within a context so it is important to recognize these roles and why students identify themselves in these ways. While these other experiences cannot be controlled for, and UG research program should be designed considering how students identify themselves as engineers and identify with engineering.

At the same time, the amount of work required by the faculty member can be minimized by taking advantage of ideas from democratic science pedagogy which rely on students to help drive the projects [19]. The main philosophy behind democratic science pedagogy is that teaching and learning is more meaningful and authentic when it reflects the beliefs of both teachers and students involved in the process. This philosophy can be easily applied to UG research as a way to help students more strongly identify as engineers through learning and practicing the research process. Previous work on just-in-time research, an application of democratic pedagogy to student-led UG research, demonstrated that using a student-led research approach helped students engage deeply with the research topics and develop a larger sense of ownership of the project. As a result, the faculty can focus on teaching the methodology of conducting research rather than directing the students' research efforts [6].

III. Methods

A co-design approach was used to collect data for this study with the participants in the research being the authors of the paper.

A. Interview

Individual interviews were conducted 5 months after the conclusion of the summer research experience by an unbiased third party following the standard procedure given in A. The interviews were also conducted by a third party to reduce bias in the responses due to the power dynamics between the student researchers and faculty advisor. Each interview was recorded using Zoom and transcribed either using Zoom's built-in transcription service or a free online transcription service [20], [21].

The interview questions were designed to encourage authors to think about their whole experience during the first summer of research for this research lab. The questions were grouped into three categories based on time frame: the beginning of, midway through, and at the end of summer research. For each category, the questions asked the authors about challenges they faced, how they overcame those challenges, successes they had, and support that they received.

Once completed, each author reviewed their own transcripts and coded them for recurring themes in their responses to the questions focusing on similarities and differences in their experiences depending on when during the summer they occurred. Each author analyzed their own transcripts to make sure that there were no misinterpretations of what was said in each individual interview.

B. Focus Group

The focus group discussions took place one month after the individual interviews were completed. During the focus group, the authors discussed the interview questions and their own responses to the questions. Through this discussion, the authors identified themes that were present between their responses and brainstormed strategies to improve the research experience for future students in the lab.

The focus group was conducted online and recorded using Zoom [20]. The recorded was then transcribed using Zoom's automated transcription service. The transcription was analyzed by all three authors for the themes that were pointed out in the focus group discussion and in the analysis of the individual interviews. Additional, concrete strategies for improving how the lab is managed that arose in the discussion were specifically highlighted and related to themes from all of the recordings.

While the small sample size limits the generalizability of the results, it is also the reason why the authors were able to analyze the results in greater detail. The small sample size mean that the results can be analyzed intersectionally and provide valuable insights that may be lost with larger sample sizes and more generalized results [22].

IV. Author Identities

Before analyzing the results, the authors will identify themselves and their backgrounds since these played a role in how they interacted throughout the process of starting a research lab at a PUI.

A. Samantha Hoang, Ph.D.

I am a Vietnamese-American woman who was raised by immigrant parents. I am beginning my third year as an Assistant Professor in the Mechanical Engineering Department at Seattle University. I earned my PhD and MS in Mechanical Engineering from the University of Washington and am the first person in my family to earn a PhD. I earned a BS in Engineering at Harvey Mudd College (HMC). While at HMC, I participated in summer research. Throughout the summer, my lab mates and I had autonomy to choose what direction we took the research while our advisor provided necessary background knowledge, similar to the just-in-time research approach discussed in [6]. Because of this experience, I view UG research as a teaching and learning tool to help my students develop confidence in their engineering identity.

B. Anthony Bui

I am a Vietnamese-American man, raised by immigrant parents and a recent Mechanical Engineering graduate at Seattle University. In high school I worked towards earning my pilot's license and worked as a high school intern in Boeing's C-40A program. These experiences, coupled with my passion for aviation, led me to attend Seattle University for Mechanical Engineering, with the goal of returning to a career in aviation after college. This interest in aviation led me to this research group which focuses on drones.

C. Parth Achwal

I identify as an Indian man who was born in India and immigrated to the United States in 2010. My passion for mechanical engineering started with Formula 1 as I was drawn by the sights of the roaring cars. With this, I wanted to pursue mechanical engineering to end up in the automotive industry after graduation. As a recent Seattle University graduate with a bachelor's in mechanical engineering, Dr. Hoang presented me with an opportunity to research the energy costs of a hexacopter with a suspended payload using an adaptive control system. Although my interest was in the automotive industry, I was drawn to the research proposal and wanted to explore the topic of drone aviation further. Having the opportunity to learn from a professor who was passionate about the drone aviation is what inspired me to dive deep into the research.

V. Results

A summary of results are provided for the individual interviews and the focus group below. Each author has written a short analysis of their individual interviews. All authors analyzed the focus group discussion, the results of which will be discussed after the interviews.

A. Individual Interview: Samantha Hoang, Ph.D.

In my interview transcript, I noted several recurring themes including: (1) strategies for supporting students to be successful researchers and (2) the growth of the students' decision-making confidence throughout the summer. Other themes that arose during the interview were how my expectations biased

my perceptions of research progress, how I needed to ask for my colleagues' knowledge and support, and the importance of proper scoping for a research project.

In the beginning of the summer, I struggled with ensuring that "my students had a good start" to their research experience. Balancing the students' experience with "getting the lab space set up for the students to use" and "other things that I had planned over the summer ... unrelated to the lab work" was difficult since all of these things require time. Just these couple of tasks were especially time consuming because I lacked the experience and confidence to make important decisions quickly. In addition to it being my first time working with UG students, my students' research was experimental, a type of research I had little experience with. As a result, a lot of the challenges I mentioned in the interview were because "the challenges that they [faced] initially trying to get used to using the hardware ... were new to me as well". These challenges also prevented the students from accomplishing tasks as quickly as initially expected. This being their first open-ended project, "it's really hard for them to make choices or make decisions that move the research forward because they don't have that confidence" that they need to make important decisions. I also lacked the confidence necessary to make these decisions and was unable to provide as much guidance as they needed at the time.

As the summer progressed, my students communicated that they wanted me to spend more time in the lab "to answer their questions immediately, ... [help] them troubleshoot a bit, [and give] them suggestions on where to go looking for resources". In response to this request, I began spending 3 hours, twice a week, in lab with the students for the remainder of the summer. By spending time in lab, I was able to help them make progress since I provided support whenever they ran into significant challenges by using these challenges to model a problem-solving process. By the end of the summer and with these experiences, the students gained "more confidence in themselves as engineers" and began to enjoy the challenges they encountered rather than avoiding them as they had at the beginning of the summer. Looking back, I noted that "if I initially spent the first, like 3 or 4 weeks just in lab with them at least a couple of times a week, that would have given them a much stronger base to start from in terms of getting the research going". I also noticed that learning soft skills such as presenting helped "develop a lot of their confidence in themselves and the work that they [did]". They learned how to speak confidently about their work and ask for help when necessary rather than remain stuck when they faced a difficult challenge.

The other themes mentioned appeared in my responses with a smaller frequency. In my responses, I mentioned that I had "initially expected [the students] to be able to do a lot of work in a week". I quickly realized that this was unrealistic as it was their first time conducting research. In addition, I also put "too many expectations on myself" which made me feel like "I didn't really do anything over the summer or produce any real results" because there were no publishable results from my students' research. These expectations came about because I had to balance the research expectations for tenure-track faculty while "making sure that the students have a good research experience".

I also "didn't ask for help initially" because I felt that many of my colleagues were too busy with their own work. Looking back, I noted that I "should have asked for ... more support from other people in my department" since I did not have any other resources at the time. I also mentioned the appropriateness of the research's scope, stating that the current research project has a heavy focus on "software-hardware integration... which is not the most friendly to undergrads because these classes are often taught later" in the curriculum. This project was catered to skills learned later in the curriculum so the skills required to completed it would still be new and unfamiliar to the students. Through my responses, I also noticed a distinct disappointment and lack of confidence in how I managed my first summer conducting UG research.

B. Individual Interview: Anthony Bui

I initially had an interest in drone dynamics that originated from an internship at Boeing. I then became more interested in the controls systems side, due to alumni events as well as a data acquisition class. Even though the lab was new and based on Dr. Hoang's dissertation, she let Parth and I choose our own niche within the research. This allowed me to stay motivated over the summer, since I was able to work in areas I was interested in, and at the end felt like my picture of what a Mechanical Engineer is developed even further.

We first started with a literature review, where Parth and I absorbed lectures, videos, and mockups on control systems within three months, so we could begin working on our chosen projects. We looked at resources such as Dr. Hoang's old work and textbooks, as well as lecture sessions from Dr. Hoang. Since this was my first research experience, we miscalculated how much preparation was needed and rushed into trying to get some results. This inadequate preparation led us to a slow start to the summer, where it was spent doing more literature review than anticipated. This, coupled with Dr. Hoang being away due to conferences, led to some artificial physical barriers which led to mental barriers. I would struggle to ask questions which led to most of the challenges we faced. Over the course of the summer, Parth and I gained the ability to handle the challenges we previously faced more adeptly. Collaboration between Parth, Dr. Hoang, and I began to increase over the course of the summer, especially when Dr. Hoang was in the lab with us. These changes from the beginning of the summer increased our productivity immensely and brought progress like getting our motors to spin.

By the end of the summer, I had gained a lot of valuable skills and experience. The work I was doing would have been something I considered to be that of a software engineer, but I realized this was not the case. This experience expanded my view of what a Mechanical Engineer could do and was capable of doing. I was able to learn C++ and Matlab, as

well as analyzing other people's code. In addition, I learned how to convert code in one language into a different one, which was both challenging technically, and rewarding. I was able trouble shoot my code and see how it affected physical parameters. These skills are not what I originally thought to be synonymous with being a Mechanical Engineer, but now I realize that they are invaluable to one.

C. Individual Interview: Parth Achwal

Since this was my first research opportunity, I was not quite sure what to expect in terms of how the research would be structured. With my first meeting with Dr. Hoang, I was afraid of being overwhelmed by the technical requirements and my lack of them. To my relief, Dr. Hoang explained that the spring quarter would be spent as a planning period for the summer. Dr. Hoang provided us with a catalyst for learning about controls. "My research partner Anthony and I had no previous knowledge about controls, Dr. Hoang recommended one of her old professors, who publishes controls theory videos on YouTube. Dr. Hoang also provided us with her notes and worksheets from her undergrad". Previously, when there was no proper guidance, I tended to panic and have this feeling of "I don't know where to start". Dr. Hoang's resources were effective in calming my nerves and easing me into the research.

There were many challenges associated with doing research in a new lab. The first of which was being able to stick to the timeline we had created for the summer. With no previous research experience, we had miscalculated the amount of time it would take to complete the tasks. Towards the start of the summer, we faced technical challenges such as, "calibrating the electronic speed controllers (ESCs), motors not functioning properly, and establishing proper connection between the flight controller and flight application". With each new problem, we extend the expected completion date of the task. Dr. Hoang provided large amounts of support and guided us through the technical difficulties. For my subset of tasks with the Raspberry Pi, "Dr. Hoang helped me find some helpful forums... that allowed me to proceed with my tasks". Trying to find the solution on my own would've taken twice as long and having Dr. Hoang help made the task more efficient.

This led me to the next challenge which was that Dr. Hoang had a busy schedule during the summer and couldn't always be present in the lab. She was always available for help via Teams or email but as Anthony mentioned, having her in person allowed us to be more productive. If we were stumped on an aspect of the lab, we could immediately turn to her in the lab and work on fixing the problem. We were more motivated in the research as the three of us were there to help each other.

Another challenge was to implement autopilot onto the drone to reduce human error in future drone experiments. Going into this task "I was nervous about coding as there always seemed to be self-doubt in my mind. I've always seen coding as one of my biggest technical weaknesses as I can't seem to wrap my head around it". What this research made me realize is that it was not that I was incapable of coding, it was that I did not have the motivation before. Once I had a clear goal of establishing a connection between the RaspberryPi and the flight controller, coding was fun, and solving this challenge on my own has driven me to learn more about the topic. While starting a lab had its fair share of challenges, it has been a great learning experience and taught me many great qualities such as resilience, adaptability, and cooperation.

D. Focus Group

Following the individual interviews, the authors met and had a focus group discussion on the questions asked in the individual interviews. Throughout this section and the remainder of the paper, the authors will be referred to by last names. For clarity, this section will be divided based on the question (and as a result the time frame) as the authors' experiences and perspectives changed throughout the summer.

1) First Question: Much of the discussion related to the first question focused on difficulties of starting a new lab, many of which stemmed from Bui and Achwal "not having the technical background" to do the research at the start. To try to help, Dr. Hoang provided Bui and Achwal with resources and directed them to online documentation for the hardware they were using. Bui stated that while these resources were "really helpful for us to get a kick start for the lab", the "difficulty was using the resources". Bui and Achwal's difficulties with using documentation stemmed from their lack of research experience and experience with drones since a lot of the documentation and resources that they used assumed "some base amount of knowledge". Bui acknowledged that he and Achwal "didn't spend enough time learning the literature... because we were like trying to read [papers] while also trying to build [the drone]". Despite this difficulty, Achwal emphasized that it was "rewarding to learn ... all these concepts" showing that he appreciated the challenge of learning new concepts outside of the classroom.

Another struggle the lab faced at the beginning was that Dr. Hoang had several trips at beginning of the summer. Dr. Hoang's trips created a "physical barrier" to Achwal and Bui asking questions. Bui stated that "if I can just like walk into your room, that's easier than to type a [Microsoft] Team's message" when he has a question. Achwal added that "it's also easier to explain the problem in person". Their responses demonstrated a need for Dr. Hoang to be physically present in the lab. Bui and Achwal acknowledged that, while her absence set back their progress, "it forced [them] to learn how to do things by [themselves]". As a result, Bui and Achwal learned how to do research with only online support.

In contrast, Dr. Hoang's struggled with choosing an appropriately scoped project for Achwal and Bui to work on. Dr. Hoang noted that she has "never really worked with undergrads prior" to this experience which made it difficult to "gauge what level of work undergrads could do". Because of this, she chose a project that Achwal and Bui did not have the technical background for. She also chose a project with a heavy experimental component, an area that she did not have as much experience in. Both choices led to "a really steep learning curve" and difficulties learning how to use hardware.

2) Second Question: By the middle of the summer, the students' focused more on troubleshooting the hardware compared to the beginning of the summer when they were focused on assembling the hardware and learning to develop experiments. The tone of the conversation shifted as Bui and Achwal became more excited to talk about the challenges they faced and how they addressed the challenges. Bui stated:

> I think it was more fun than the beginning of the summer cause we already had like finished building our drone and seen the motor spin and tried to get it to lift off... It was still pretty cool, you know to be like, 'Hey, I think this is gonna fix it. Let's go try it out.'

Achwal had a similar experience as well with his part of the project:

> In the latter half of the summer, I was working with a Raspberry Pi. And I've never worked with one before, so it was more of a learning curve for me ... trying to understand how it works, how to wire it, and just how it operates. But I think it was rewarding once I understood how it worked and overcame those barriers.

Both of these quotes demonstrate three aspects of the research experience for Bui and Achwal at this point in the summer: (1) the challenges of working with hardware, (2) how rewarding it was for them to be able to face these challenges and continue to make progress on the research, and (3) that they felt able to face these challenges as their summer research experience progressed and they gained confidence.

There were several factors that factored into their responses. First, Dr. Hoang was regularly spending time in lab with them. Achwal and Bui noted that Dr. Hoang's presence increased "productivity by like 3 to 4 times" because "we were able to ask you questions" and then could "look at [the problem] together". Second, Bui and Achwal were "developing these new skills which are helping [them] face more difficult challenges", including how to "troubleshoot within like the [right] area" as the summer progressed and they gained more experience doing research. When asked if they were receiving adequate support from Dr. Hoang as they developed these skills, Bui stated, "I thought it was a good balance of like letting us do what we wanted, but also kind of guiding us". He also found that by letting him "find [his] own niche within the project", he developed skills that were "pretty helpful like in transitioning into other projects".

Finally, at this point in time, Bui and Achwal had finished initial construction of the drone and were troubleshooting connection and hardware issues. Bui expressed frustration with the hardware since the "equipment that seemed like standard ... felt so subpar". The low quality of the hardware was especially prominent for Bui who previously interned at Boeing where you could "click the pieces together" and expect it to work. Bui's past experience at Boeing affected his experience using the drone kits while Achwal did not express the same level of frustration since he had no previous experiences to compare to.

3) Last Question: In response to the last question, the authors discussed their reflections on the summer research experience. Achwal expressed regrets in not asking Dr. Hoang more questions "because there were times where I was stuck for a decent amount of time, and instead of reaching out for help, I tried to find solution myself". This reflects how Bui and Achwal found it difficult to ask questions when Dr. Hoang was traveling and away from the lab when responding to the first question. Despite the slower progress, Achwal did mention that problem solving on his own was fun. Similarly, Bui thought that it "was fun ... learning so many different skills in such a short period of time" because "it's like a new technical skill that I'll probably be using in my future at some point". These responses demonstrated that having these opportunities to learn on their own benefited Achwal and Bui by giving them space to learn new skills.

However, Bui expressed that scaffolding was necessary in the project. He mentioned that, as a research group, "we actually like tried to scaffold" but "towards the end we got into like a lot of stuff that was probably more like outside of what we know". The project being outside all the authors areas of expertise made scaffolding difficult, which highlights the importance of having an appropriate scope. Dr. Hoang acknowledged that despite wanting to scaffold the project for Bui and Achwal, she was unsure of how to "scaffold the research experience" due to her lack of experience. One suggestion Achwal gave that would help with scaffolding the project is to have "a more defined scope, and ... timeline of what we had to do". A more defined scope and timeline would provide more structure for both the UG researchers and the faculty member. Scaffolding could also be built into the timeline so that the UG researchers do not skip important steps in their research process trying to not fall behind.

Out of this discussion came an idea to have a more structured onboarding process for new lab members. Bui mentioned that onboarding would be "be pretty helpful for [new lab members]" to "understand, like where they are in the project and how they're contributing, I think, and that'll kinda help motivate them in doing the research". Related to the onboarding process, Dr. Hoang proposed creating a journal club where "every 2 weeks, [the lab] reads a new paper together and talks about it". Having a structured onboarding process and a journal club would accomplish complementary goals of teaching the lab members context for their research while also helping them learn about the research process. The difficulty with a structured onboarding process and journal club is that both require more time on the faculty member's part. Unfortunately for Dr. Hoang, her "biggest challenge was ... trying to find the time to do research and other things ... over the summer".

VI. Discussions

Relating the themes that arose during the interviews and focus group discussion gives answers to the three originating

research questions of this study. The main challenges the students faced were related to learning the research process and lacking technical knowledge. Dr. Hoang addressed these issues through two methods. First, she purposefully gave students information about the project one quarter before the summer began so that they would have time to learn the background information about the project and plan for the summer as mentioned in Sections V-B and V-C. Second, she also provided resources for Achwal and Bui to learn the necessary knowledge and skills to conduct the research through various modalities including online lecture videos, notes from previous classes, and giving personalized lectures that were relevant to their knowledge gaps. Throughout the discussion of these challenges, Achwal and Bui acknowledged that they lacked the confidence and knowledge to approach an open-ended project because they had never completed one before. Another consequence of them having never completed an open-ended project before is that they do not identify themselves as being able to successfully complete an open-ended project. This is very clear in Achwal's interview responses in Section V-C where he notes that he "tended to panic" without any guidance. The focus group discussions, which broke down the students' experiences based on time frame, demonstrated that facing the challenges of having to learn skills and knowledge outside the classroom (with support from Dr. Hoang) increased the students' confidence in their engineering abilities. Bui and Achwal both mentioned in their responses that learning the skills on their own through provided resources helped to develop their skills and how they identified as engineers. Bui's response shows that he began to see the value of being able to program as a Mechanical Engineer and that he himself was capable of learning new programming languages, an aspect of his engineering identity that he did not have prior to this experience. It is clear in their responses to the second and third questions that Bui and Achwal began to identify themselves as engineers who were capable of approaching open-ended, interdisciplinary problems with confidence because they went through the challenges mentioned.

In contrast, Dr. Hoang's main challenges were project scoping and time management. Both of these challenges were not adequately addressed during this summer research experience. Potential solutions for these challenges were discussed during the focus group for future implementation. As mentioned in Sections V-A and V-D, Dr. Hoang chose a project involving the integration of hardware and software, a skill that is not taught until late in the Mechanical Engineering curriculum. As a result, Bui and Achwal did not have a lot of the necessary preparation. Dr. Hoang tried to compensate for this lack of experience and preparation by providing necessary resources, but just giving students resources was not necessarily enough. As demonstrated by Section V-D, Achwal and Bui found it difficult to use some of the resources since these resources required a certain amount of base knowledge to use. Bui and Achwal suggested building in more scaffolding within the project timeline so that future research students did not feel as rushed Bui mentioned in Section V-B. Scaffolding also gives the students time to develop confidence in their engineering skills through practice, a necessary part of the identity in practice pedagogy for student identity development. One way that was proposed to incorporate more scaffolding was to have a structured onboarding process for new lab members that included the faculty spending time in the lab. The onboarding process would ensure that students start with the basic knowledge necessary to get started in the lab, something that Bui and Achwal did not necessarily get since they were the first members of Dr. Hoang's lab and she had not developed a specific onboarding process for them. Additionally, spending time in the lab with the students initially will give them a chance to ask more questions without a physical barrier, thus accelerating their learning process.

Other scaffolding methods mentioned included a regular journal club where lab members read and present on different papers every 1-2 weeks over the summer. In this way, students are able to (1) learn more about their research area, (2) learn how to read academic papers, and (3) apply the knowledge they learned in classes in a controlled environment. The journal club meetings and presentations are another way to relay information from the faculty advisor to the student researchers in a relevant context, thus reinforcing any important knowledge from classes. Through reading these papers, the students can further practice skills that will ultimately shape them as engineers in the future. Other solutions to project scope challenges include choosing a project that incorporates skills from classes earlier in the curriculum so that students have already developed confidence in those engineering skills.

Despite the many challenges faced by the authors, Bui and Achwal mentioned one main to being the founding members of an UG-only research lab: having the ability to choose their own research direction. The faculty advisor, Dr. Hoang, struggled with time management and project scope definition due to her lack of experience, which made it difficult to fully define a research direction for Bui and Achwal. Another reason that Dr. Hoang did not fully define a research direction is because of her belief that UG research is a teaching tool. As a result of this decision, Bui and Achwal had autonomy to choose their research direction which helped them to feel more motivated about the work. This is highlighted as a benefit of democratic science pedagogy where the students' perspectives and ideas are considered in the research decision-making process. Bui and Achwal both developed more confidence in their decision-making and problem-solving skills because Dr. Hoang gave them the autonomy to make these decisions, with her support and without giving directions. Practicing these skills benefited them as the research project progressed and beyond because these lessons they learned evolved their identities as engineers. Because of the small sample size, the generalizability of the discussed results are limited, but the rich discussion of personal experiences lends evidence for implementing these strategies for a successful first UG research lab experience.

VII. Conclusions

This co-design study completed by the faculty advisor and UG research students in a new research lab used interviews and a focus group discussion to answer three research questions related to the challenges faced by faculty and student researchers when starting a new lab and the benefits of the lab-starting process. The perspectives of current UG students were considered by using a democratic approach. The authors found that the main challenges the faculty advisor faced were project scoping and time management. New faculty members do not necessarily have experience scoping projects for UG researchers or managing a research program while teaching. New faculty should scope projects to include skills and knowledge that students learn earlier in the curriculum. If they choose projects with skills and knowledge that are learned later in the curriculum, faculty should be prepared to spend time helping the students learn and practice the more difficult skills and complex knowledge. Even if the faculty are heavily involved in the project, such as in the case of a more difficult project scope, it is still important to let the UG student researchers have autonomy. Student autonomy has two purposes: (1) to free up more time for the faculty advisor to do other tasks that are necessary as a new faculty member and (2) to give the students a chance to start building their engineering decision-making and problem-solving skills which in turns helps them develop their engineering identity.

The main challenges that the students faced were related to project scope, but focused more on lack of preparation for conducting research. Dr. Hoang addressed this challenge by spending time with Bui and Achwal in lab to answer their questions and teach them important research skills. Further suggestions for addressing this challenge including more scaffolding including a structured onboarding process to orient the students to the research process and a journal club where students can learn more about their research area and think about how they can conduct their own research.

While starting a new UG-only research lab is difficult, there are several benefits for the students. As mentioned previously, the main benefit is that the students learned how to choose their research direction because of the autonomy given to them. Another added benefit is that this autonomy accelerates the students' own engineering identity development because they have more opportunities to put it into practice. Finally, the students learn skills that benefited them later including engineering decision-making and problem solving. One last benefit for the students that was not discussed explicitly, but is evident in this paper, is developing a close relationship with their faculty advisor. This paper was mainly possible because of the relationship that Dr. Hoang has with Achwal and Bui that allows them to be comfortable sharing aspects of the research experience that could be improved. New faculty advisors at PUIs can consider the challenges and suggestions presented here to help them build their UG research labs in a way that benefits both the students and the faculty advisor.

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Appendix A
Interview Questions and Instructions

Instructions:

For the first phase of this participatory research project, you will need to answer the following questions. For this process, please have someone you know (this can be a friend

or family member, but not a coauthor on this paper) ask you the following questions. Your interviewer can only ask the following questions. No additional follow-up questions should be asked.

When you are being interviewed by this person, please record your responses using Zoom with the camera on. Zoom has a transcription feature which will make it easy to return to your initial responses to the questions when we are writing the final paper.

After the first phase where you do the recorded interview, we (Sam, Anthony, and Parth) will schedule a time to have a recorded discussion about our responses to the questions. This discussion will be the jumping off point for writing the paper and should hopefully give us some good results to write about.

Questions to ask:

1) Tell me about how it was setting up the lab at the beginning of the summer.
    a) What was challenging about setting up a new lab? Did you have to do any new-to-you tasks such as sourcing equipment or software packages?
    b) How did you handle those challenges?
    c) What support did you receive in facing these challenges?
    d) What was rewarding about this initial set up process?
2) Tell me about your experience about halfway through the summer (beginning of August).
    a) Did new challenges arise? Were these challenges related to setting up the lab or to the research itself?
    b) How did you handle these challenges?
    c) What support did you receive in facing these challenges?
    d) Did research get more fun/rewarding? In what ways?
3) Looking back at the end of the summer, what aspect of the experience did you find the most challenging? The most rewarding?
    a) What do you wish you had done differently?
    b) What do you think Dr. Hoang did well throughout this experience? What do you wish Dr. Hoang would have done differently?
    c) Is there anything about your experience that sticks out to you?
    d) Was your experience as you had expected or different than what you expected when you first started?