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Challenges and Supports Experienced by Students Completing a Multi-Semester Capstone Undergraduate Research Experience: Reflections from Program Graduates

ABSTRACT

Undergraduate research experiences (UREs) have been recognized as high-impact teaching practices in post-secondary science education programs. The variety of structures and strategies to facilitate UREs provide institutions and faculty with many options to foster students' exposure to scientific research, particularly in primarily undergraduate institutions (PUIs), which often utilize capstone UREs as part of undergraduate science programs. This qualitative research explores graduates' experiences completing a multi-semester capstone URE while attending a small PUI in the United States. Sixteen recent graduates of STEM undergraduate degrees shared their experience in semi-structured interviews which aimed to identify the perceived challenges and support students experienced during their URE. From a thematic analysis of the data, eight themes emerged that described challenges and supports recognized by students during their UREs. These results, although limited to the participants of our study, detailed students' challenges related to time investment and unexpected obstacles with research. Several sources of support for students, like peer collaboration, access to research facilities, and faculty mentorship, also emerged from the data. Based on these findings, we offer recommendations to reduce student challenges and create robust support structures for similar capstone UREs.

KEYWORDS

experiential learning, independent research, faculty mentorship, student perceptions, undergraduate thesis

INTRODUCTION

Over the last several decades, educational reform in the United States has moved science education into a new student-centered era that challenges students to think and act like scientists. Recent initiatives have influenced post-secondary science education at the undergraduate level. Among the most notable is Vision and Change in Undergraduate Biology, an initiative spawning from a collaboration between the National Science Foundation (NSF), the National Institutes of Health (NIH), the Howard Hughes Medical Institute, and the American Association for the Advancements of Science (National Science Foundation 2012). Vision and Change provided a roadmap for universities and colleges to make meaningful reforms to their design and delivery of undergraduate science courses and programs. The roadmap called for more student-centered learning, student engagement and collaboration through inquiry-based learning, and student exposure to authentic research. When students learn science through their own scientific investigations and discovery, they can better

develop the skills and competencies required of the twenty-first century (National Research Council 1999).

The popularity and use of undergraduate research experiences (UREs) have expanded in response to the need for high-impact teaching practices that situate students as scientists. A plethora of research supports the value of UREs as a high-impact practice focused on student outcomes. Example outcomes from UREs include gains in students' subject matter knowledge (Olimpo, Fisher, and DeChenne-Peters 2017; Wolkow et al. 2019), building students' scientific identities (Camacho et al. 2021; Frederick et al. 2021), and improving students' skills in critical thinking (Carson 2015; Jones and Lerner 2019), problem-solving (Pierrakos, Zilberberg, and Anderson 2010), communication (Bruthers et al. 2021; Julien et al. 2012; Swanson et al. 2016), and research (Brownell et al. 2012; Laungani et al. 2018). Furthermore, UREs have been found to improve the recruitment and retention of underrepresented students in STEM (Adedokun et al. 2013) and to improve the likelihood of students pursuing science-based careers or graduate study (Harsh, Maltese, and Tai 2012; Hernandez et al. 2018; Mastronardi et al. 2021).

The many structures and designs of UREs provide flexibility in how they can be implemented into science education programming (Weaver, Russell, and Wink 2008). One common approach is a course-based undergraduate research experience (CURE), which incorporates an extensive, student-led, and authentic research project that is part of the curriculum for a disciplinary course taken for academic credit. Although the CURE structure offers broad student exposure to undergraduate research (Bangera and Brownell 2014), it may lack high levels of research mentoring due to the time constraints of mentoring several students simultaneously (Eagan et al. 2013).

Some UREs are stand-alone supplements to degree requirements and provide a cohort of undergraduate students who receive intensive exposure to faculty-mentored research over an extended timeframe (e.g., several weeks). Furthermore, they can involve students from multiple institutions and can cultivate a learning community of novice and experienced researchers (Davis, Wilson-Kennedy, and Spivak 2021; Kumbhar, Attar, and Telsang 2018; Prince et al. 2023). Another mechanism for delivering UREs is the student apprenticeship structure, including faculty-recruited undergraduate volunteers or students hired to provide research assistance in campus laboratories (Linn et al. 2015). Despite the advantages of stand-alone and apprenticeship URE structures, student exposure is limited by the motivation of individual students to find and apply for such opportunities and for them to be successful in an often competitive selection process (Ahmad and Al-Thani 2022).

A distinct URE structure that embeds undergraduate research within a required curriculum is called capstone research, alternatively referred to as senior theses or bachelor final projects (Healey 2014). Many capstones position the URE as a culminating experience for degree completion (Kumbhar, Attar, and Teslang 2018). Additionally, URE capstones often align with students' programs of study and allow them to demonstrate the competencies and skills gained in prior coursework. Thus, URE capstones can provide strong evaluation metrics to inform academic programming (Berheide 2007; Healey 2014). Despite the growth of UREs in higher education, capstone-based UREs are usually used as a requirement in small, primarily undergraduate institutions.

We conducted this study as part of a larger research project that assessed students' lived experiences completing UREs and extended learning outcomes associated with completing their URE (Colclasure et al. 2024). In this study, we explored the challenges and supports experienced by students when completing a required three semester capstone URE at a small liberal arts PUI.

The research questions guiding this study were:

1. What challenges did students encounter during a multi-semester capstone URE?
2. What supports and resources did students utilize during a multi-semester capstone URE?

CONTEXT OF INVESTIGATION

We investigated the capstone URE sequence at a small liberal arts PUI located in the Midwest region of the United States. The university enrolls approximately 1,000 residential undergraduate students per year and boasts an active student life on campus. The college of arts and sciences houses science programs in biology, chemistry and biochemistry, engineering, physics, and natural resources and environmental sciences. The university's science programs have a long history of prioritizing student-centered teaching and promoting student-led research. Faculty at the university contributed to the Vision and Change in Undergraduate Biology initiative. Additionally, science programs at the institution are well-equipped with student research laboratories and scientific equipment. Students majoring in STEM programs are consistently exposed to student-led scientific research in science coursework (i.e., CUREs), and many students take advantage of supplemental URE programs (i.e., apprenticeship UREs, stand-alone UREs, cohort-based UREs, etc.). All students majoring in biology, biochemistry, chemistry, or environmental science are required to complete a three-semester capstone URE during their junior and senior years.

The capstone URE consists of three courses, with each course being a full semester or 16 weeks in length. Students enroll in research I during their junior year. This two-credit course introduces a cohort of students to the URE capstone sequence. Students learn about the URE capstone, explore research areas, identify a faculty member who agrees to mentor their research, and design their anticipated research program. Students enroll in research II and III during their senior year. Students receive variable credits (two to four) for these courses and work with their faculty mentor, typically through one-on-one mentorship, to conduct their research project. The mentorship structure varies by faculty member; however, the inclusion of mentoring undergraduate researchers in the faculty's teaching load dictates an expectation that faculty provide a comprehensive and robust mentoring experience to students. Students also maintain a full course load (e.g., at least 12 credits) each semester. Toward the conclusion of research III, seniors are required to present their research through a poster or oral presentation at an undergraduate research symposium hosted by the university. Lastly, students produce a written thesis. Some students seek the opportunity to disseminate their research at state or national science conferences or in peer-reviewed journals.

METHODS

Due to the exploratory nature of our research and the small size of our population, we utilized a qualitative, hermeneutical phenomenology research approach (van Manen 1990). Hermeneutical phenomenology uses participants' lived experiences to interpret meaning related to a particular event or phenomenon they engaged in (van Manen 1990). This methodology allowed us to generate a robust understanding of our participants' experiences and perceptions of their capstone URE through their subjectivity, perspectives, knowledge, and interpretations of their own experiences (Creswell 2007). The population for this study consisted of university alumni who completed an undergraduate degree in chemistry, biochemistry, environmental science, or biology between 2016 and 2020. The university provided a list of these graduates with their updated contact information. This list served as our sampling frame, and it contained a total of 86 alumni (N = 86). We sent each alumnus an email invitation to participate in this research. Following the recommendations by Dillman, Smyth, and Christian (2014), we individualized invitations and sent two follow-up emails to non-respondents. Additionally, all participants received $50.00 as an incentive to improve recruitment. Sixteen (n = 16) of the 86 alumni (18.6%) responded to our invitation and agreed to participate. We believe this was an appropriate sample size, as between five and 50 participants is traditionally an acceptable sample size

for qualitative research employing in-depth, one-on-one interviews (Dworkin 2012). In addition, we believe we reached data saturation by the last quarter of our interviews, thus supporting our sample size (Fusch and Ness 2015).

We collected data through in-depth, one-on-one interviews with each participant. We used a semi-structured interview guide to facilitate the interviews (Naz, Gulab, and Aslam 2022). The guide contained six sections and 35 open-ended questions (Appendix). We designed the guide to offer the interviewer flexibility to ask follow-up and probing questions and to elicit thick and rich data from respondents (Lincoln and Guba 1985; Morse 2015). However, since this study was part of a larger project, data relating to this paper's research questions primarily came from the first half of the interview guide. Two faculty members in biology and one in science communication served as a panel of experts and reviewed the interview protocol for face and content validity of the instrument (Kerlinger and Lee 1986). We conducted interviews with each participant via Zoom due to the COVID-19 pandemic and geographical barriers. However, prior research has supported the use of web conferencing technologies as a mode to conduct high-quality, one-on-one, virtual interviews for qualitative research (Gray et al. 2020). The interviews took place in June and July of 2021 and ranged between 37 and 80 minutes each, with an average duration of slightly over one hour. During each interview, both the interviewee and interviewer had their cameras on, and a secondary researcher observed and took detailed notes. We conducted member-checking after each participant interview (Lincoln and Guba 1985). Member-checking consisted of sharing the main findings with each participant and asking them to confirm the accuracy of those findings (Creswell 2005). We transcribed the interviews verbatim for data analysis.

Two researchers worked together to analyze transcriptions using MaxQDA software. These researchers collaborated and used inductive coding to establish a codebook for this study (Liu 2016). After several iterations, a final codebook containing descriptions and example passages for 15 codes was created. After the researchers finalized the codebook, they worked independently to code four complete interview transcripts, approximately 20% of the total data. After initial coding, the two researchers met to discuss their codes, using the Kuder-Richardson formula to establish intercoder reliability, which refers to the consistent interpretation of data across multiple coders (Hayes and Krippendorff 2007). After the initial coding, sufficient intercoder reliability could not be established; therefore, the researchers conducted coding iterations, where the coders further discussed their similarities and differences until intercoder reliability was sufficient. The third coding session resulted in an intercoder reliability of .82, which is deemed reliable (Hayes and Krippendorff 2007). The coders split the remaining transcripts for further coding. Throughout the duration of the project, we established an audit trail to improve the dependability of the research (Lincoln and Guba 1985). Using triangulation from coded data, audit trails, researcher discussion, and interview notes, we produced and confirmed thematic findings (Lincoln and Guba 1985). Although generalizability is not a primary intention of qualitative research (Creswell 2007), we acknowledge that the sample size and subjectivity of the data limited this study. The Doane University Institutional Review Board approved this study (#S21 0007 DC IRB HS).

RESULTS

Sixteen alumni responded to our request to participate in one-on-one, in-depth interviews that explored their perspectives toward completing the required three semester capstone URE. Of our participants, nine identified as male, and seven as female. At the time of the interviews, a majority of participants were in graduate school (n = 9). To provide context to participant quotes, we provided participant narratives in Table 1.

Table 1. Participant narratives

Pseudonym	Participant description
1. Thomas	Thomas graduated in 2018 and was attending medical school at the time of the interview. He majored in biochemistry and did not have prior supplemental research experience before starting his capstone URE.
2. Sherry	Sherry was in a graduate program studying chemistry at the time of the interview. She completed her undergraduate chemistry degree in 2017 and had prior research experience before starting her capstone URE.
3. Raquel	Raquel entered a science-related career after receiving her biology degree in 2017. She participated in other UREs offered by the university prior to the start of her capstone URE.
4. Riley	Riley completed her bachelor's degree in 2017 and was in a science-related doctoral program during the time of our interview. She did not participate in supplemental UREs prior to starting her capstone.
5. Paul	Paul entered a career in chemistry after graduating with his bachelor's degree in chemistry in 2018. Paul did participate in supplemental UREs before starting his capstone research.
6. Molly	Molly graduated with a biology degree in 2017, completed graduate school, and was working in the medical field during the time of our interview. She did not participate in non-class UREs beyond her capstone research.
7. Matt	Matt received his bachelor's degree in biology in 2018. He participated in several supplemental UREs prior to starting his URE capstone. Matt was completing a biology graduate program at the time of our interview.
8. Mary	Mary was in medical school at the time of the interview. She completed her bachelor's degree in 2017, majoring in biology. Mary had prior research exposure before starting her URE capstone.
9. Megan	Megan majored in biology and received her bachelor's degree in 2018. At the time of the interview, Megan had just completed a graduate degree in a medical field. She had research experience prior to her URE capstone.
10. Kane	Kane was working full-time in a conservation-related career at the time of the interview. He graduated in 2016 and majored in environmental science. Prior to starting his capstone URE, he participated in other UREs.
11. Clark	Clark was in a doctoral program at the time of the interview. In 2017, Clark received his undergraduate degree in chemistry. He did not participate in supplemental UREs during his undergraduate study.
12. Dominique	Dominique was completing a doctoral program in the medical field at the time of the interview. He received his bachelor's degree in biology in 2018. Dominique had prior research experience before starting his capstone URE.
13. Denton	Denton entered a science-related career after he graduated with a biology degree in 2017. Denton completed additional UREs beyond his capstone research during his undergraduate study.
14. Carly	Carly was working in a science-related career at the time of the interview. She graduated in 2018 with a bachelor's degree in biology. Carly participated in additional UREs beyond her capstone.
15. Bryan	Bryan received his bachelor's in biology in 2018 and did not participate in additional UREs beyond his capstone research. Bryan completed a doctoral program and was working in the medical field.
16. Brent	After graduating with a biology degree in 2018, Brent worked in a science-related career. He was attending medical school at the time of the interview. He participated in various UREs as an undergraduate student.

Research question one: What challenges did students encounter during a multi-semester capstone URE?

We identified three themes pertaining to our first research question: time commitments and constraints, competing responsibilities and opportunities, and unanticipated research problems.

Time commitments and constraints

Participants described the time commitments and constraints as a significant challenge. Students' time commitments toward their URE varied between several hours each week to nearly 40 hours each week. Although all students described prioritizing time for their capstone research, several students described that time commitment caused strain. Raquel reflected, "I think I probably put a little too much [time] in [my research] on some weeks." Molly stated, "Oh gosh, it was a headache. I basically spent a billion hours looking up and making sure there wasn't already a patent on what we wanted to do." Molly described spending "full days, up to five days a week," on her research, which was straining. Some students, like Thomas, described spending "a lot of hours in the lab," but to them, that was not a big deal. Thomas stated, "I was obsessive, and I was willing to go above and beyond for my project because I liked it."

Students utilized various strategies to manage the time commitments required for a successful research project. Dominique described spacing out the research components to avoid becoming overwhelmed. Mary described treating her capstone URE like a "part-time job." Molly would "focus [her] time first on the research" and use the remaining time for coursework and other activities. Paul described using the summer to collect data. He explained, "I was very grateful that I was able to have collected [data] during the summer. If I wouldn't have been able to collect this stuff during the summer, I would have been even on a tighter time constraint." Similarly, Raquel also worked on her URE over the summer, which was not a requirement.

Although some students recalled being initially frustrated about the time spent toward their URE, nearly all of them described being glad for the time they spent on their research. For example, Megan stated, "I spent a lot of time in the lab . . . and that was frustrating, but I can say that at the end of it . . . I was incredibly happy and fine with the amount of time that I had dedicated to it."

Competing responsibilities and opportunities

Most of the participants in our study described being extremely busy during the junior and senior years of their undergraduate programs. Students discussed being college athletes, leaders of student organizations, and members of sororities and fraternities. They also described studying for upper-level courses, holding part-time jobs, and trying to maintain a healthy social life. Matt recalled, "Being [an officer] of the fraternity my senior year with being an athlete and everything was definitely a lot of work to add on top of school and research." He continued, saying, "I was very stressed out during the year . . . there was a lot on my plate for sure." Raquel shared a similar experience, "I was already [a college athlete]. That took a lot of time, and I had a part-time job, and then I had classes, you have study time . . . it's just a nightmare."

Students reflected on making decisions on what they were able to do with the time they had. Interestingly, most students described prioritizing their research projects over other opportunities. Riley stated, "I had cleared out my schedule like I knew I just wanted to do research . . . I tried to release a lot of other involvement in things so I could just try really kind of do research." Several students recalled their capstone research negatively impacting their social life. Megan expressed being frustrated in the moment and stated, "I had so much going on, and I wanted a social life." Mary elaborated:

> I know with the amount of other commitments I had, I definitely was missing out on things. I was going to a football game and then at halftime I was running to the lab to work on my project. I felt like I didn't have enough time for myself, but I don't think that was just on the research. I just put my priorities on my school and in those jobs versus my social life and personal life.

Unanticipated research problems

"The scientific process is messy, and my research project really showed that to me . . . there's a lot of twists. I would say it's like a roller coaster," stated Mary when describing her research capstone. Like Mary, most participants described running into unexpected problems during their research projects and being particularly frustrated by them. For example, Brent described troubleshooting instruments and said, "It took a lot of troubleshooting and reconfiguring or resetting to get the program to work correctly." Kane recalled his research being outdoors and "accepting variable changes and figuring out how to get around them while still following the same exact protocol." Notably, students discussed learning how to work through unexpected challenges by thinking critically about the issue and employing problem-solving skills. Bryan remembered thinking, "How can I make that, or how can I think through that, or how can I fix that and use all those processes?"

Although students described frustration in the moment, they also reflected fondly on being able to experience and overcome the issues they encountered. Clark illustrated the sentiment shared by many students:

> If you interviewed me at the time, I would have been like "Oh, I can't get it to work. This is horrible. I hate this project," but now that it's done in the past, I have good memories of it. So yeah, I think the level of frustration, it was a good level, to be honest. But that's real research, I definitely can attest to that now. Some projects are just very frustrating. Knowing that research isn't just going to go completely smooth the whole time I think that's also quite a real realistic way of training.

Research question two: What support systems and resources did students utilize during a multi-semester capstone URE?

Analysis of the data for our second research question resulted in five themes: preparation, research advisor mentorship, other professional support, peer support, and access to space and materials.

Preparation

Nearly all students positively described having prior coursework or supplemental research experiences that prepared them to effectively manage and produce a successful capstone research project. Eleven of our sixteen participants described engaging in URE programs beyond CUREs and their capstone URE during their undergraduate education. These programs benefited the students in many ways, including improving their confidence in conducting research, enhancing their knowledge of the scientific process, and exposing them to various research instruments. Riley elected to continue his capstone research on a topic similar to what he had previously researched. He stated:

> I think having the backing underneath me before the [capstone research sequence] probably really helped move that forward or it may have taken a lot more work for me

> to kind of get there. I kind of already . . . had some experience working on those related things . . . so getting the opportunity to do research [before the capstone].

Similarly, Paul said, "I did a three-year research project over the same thing I did my capstone on. I started that my sophomore year . . . I knew exactly what I wanted to do and the question that I wanted to ask."

The students who did not participate in supplemental UREs before starting their capstone URE expressed that their prior scientific coursework prepared them for their capstone research. For example, Clark stated, "I [remember doing] lots of like mini projects for like [research] reports in class . . . I must not have actually hated it right, it influenced me in some way or another, like knowing I could do research." Other students, like Dominique, mentioned the research culture that was established in the science programs at the university. He recalled being introduced to research while a freshman. He stated:

> I remember it was [Introductory Biology] or something like that, one of those earlier science classes, they would take us to where [upperclassman] were presenting their research. So just hearing people say "oh, I'm working on my research and stuff" . . . so that was my introduction to what research looks like.

Research advisor mentorship

All participants described their relationship with their research advisor as a critical element of their capstone research success. Although students described varying structures and styles for how their faculty mentors worked with them, they all expressed appreciation for the commitment and effort their research advisors contributed to their growth as students, scientists, and people. A few key traits emerged on what students appreciated about the mentorship and support they received from their faculty research advisor. Several students described knowing their faculty mentor cared about them and their success. Matt stated:

> I think there was a lot of trust that was built up to where I knew [my advisor] had my best interest in mind. They actually cared about me as a student, and I was not just a person in their lab who would push out results and get work done for them so they could publish or something.

Megan described the relationship she formed with her advisor, "My advisor and the relationship we had, regarding the research, made it a lot more enjoyable, and it wasn't as much like a chore or something I just had to get done." Paul described how his advisor provided flexibility as needed. He reflected:

> I had a lot of tough days, and I was able to sit down with [my advisor], and they would be like "Hey, it's a tough day, and I understand . . ." They would guide me with what I needed to do and also understand that when I came short a couple of the days they let me know that was okay and that I would hit the ground running and get the next steps in the next day.

Additionally, several students spoke about appreciating how their research advisor provided guidance without micromanaging. Molly said, "My [research advisor] didn't micromanage, and you

know [they] trusted us to go out and do what we thought was appropriate and needed, but then [they were] there to guide us or give us questions along the way." Similarly, Kane stated, "My [advisor] never really told me to do anything but would kind of question some things that I would be doing, like, 'Okay, are you sure you want to do it that way?' or pushed me to figure it out."

Many students described their faculty mentors as extremely busy individuals who were teaching classes, mentoring several undergraduate research projects, and managing grants, among other tasks. However, despite their full schedules, participants believed they had access to their faculty research mentors when needed. Thomas described using his mentors' Google calendar to propose times to meet. Students described that many advisors had open-door policies. For example, Matt stated, "I guess having immediate access to professors was probably one of the best aspects of my time at [university] . . . if they were there with their door open and they were free, I was always able to go in." Matt continued by saying, "I had their phone number. So, if I had any, like, immediate issues, I could text them." Raquel shared a similar experience:

> I had, like, their personal cell phone, and like, if I had a problem in the lab, I could just text . . . it was just the kind of relationship, but they were like that, with all their advisees, they really make sure that no one got left behind, and I think for me, that was very admirable because they were so busy.

Other professional support

Although faculty research mentors served as the primary individuals who guided undergraduates during their capstone research, participants often mentioned other individuals who served as resources during their capstone research endeavors. The students described the culture at the university as very supportive of undergraduate research and that faculty, beyond their research mentor, sought opportunities to support research-related projects. Paul recalled meeting with other faculty about his research capstone "on a monthly basis to go over what [he] needed to do." Paul appreciated the ability to talk to professors from other scientific disciplines to guide the interdisciplinary components of his project. He stated, "It helped me to talk to professors in other fields. The chemist and biologist to go over problems that I had, and for them to bring up stuff, impact-wise."

Riley mentioned several individuals beyond his research advisor from whom he garnered research mentorship, including a postdoctoral researcher at the university and other faculty members. He described his experience:

> You know, like, in so many ways in your life, but especially as a scientist, different mentors support you differently. So [postdoctoral researcher] was really more of a scientific, technical advisor for me. They really helped me to get some statistical things going and help teach me about different statistical or computational approaches that at the time I'd never even heard of. [A professor] was more of [a] broad kind of larger picture driver of things, and [another professor] was more of like an education focus mentor. I got really valuable experience from all three of them in different ways.

Some participants sought professional support beyond other faculty, including library staff and industry professionals. A few students mentioned using the library to obtain scientific articles related to their research. Carly recalled seeking assistance from librarians to "access data or literature" that she needed for her research. Other participants described networking with industry

professionals in order to assist them with their research projects. For example, Kane discussed working with a wildlife biologist to "try to figure out exactly what sort of tests [he] could run with the data [he] collected." Other participants, such as Mary, remembered being connected to faculty from larger universities and/or their industry to seek guidance on their research projects.

Peer support

Participants described forming strong support groups with their peers who were majoring in science disciplines. These support groups and friendships were formed through taking many of the same courses and engaging in the same or similar social circles. When it came to students' capstone UREs, students supported each other in multiple ways. Sherry described her experience:

> One of my biggest support systems was one of my really good friends. We had done the major together all four years and we took a lot of the same classes. With the research project we kind of did what we did with any other class and you're like "how's this going for ya? Do you need any help with anything?"

Megan discussed having friends who were also in the biology department and described how they would help her conduct research. She stated, "[My peers] would come and help conduct the research because how I was setting it up, I needed multiple people and multiple sets of hands to actually conduct part of the study."

Some faculty intentionally set up time and space for research students to meet, discuss successes and challenges, collaborate, and problem solve. Raquel described her experience, "We started having these [peer] meetings where we were immersed in our project . . . and try to help with each other's project or brainstorm. If you were struggling, other students who say, 'Oh, have you thought about trying X, Y, or Z?" Clark described a similar experience from his research group:

> It was nice having a research group. We all kind of knew each other's projects so we could always talk to each other or even if you need someone to complain to about how things weren't working or whatever. It definitely fosters a good environment to have kind of a group setting like that, because it makes you feel like you're part of a team, even if you're not working on the same projects.

Access to space and materials

Participants discussed the various resources that they utilized during their research capstone experience. Students believed they had adequate research space to complete their projects. While the space required to complete capstone research projects varied by each participant, several students described utilizing laboratory space and scientific instruments to run experiments. They described how their program assigned lab space to them; however, they sometimes had to share space with other students. For example, Brent shared a lab space with other peers who were working with the same research mentor. However, he stated, "I felt like everything I needed was provided, and I didn't have to compete for it." Brent continued by describing that sharing lab space actually had its advantages. He mentioned, "It was helpful, too, to have some other people in your research lab that maybe weren't working on the exact same project but were able to lend a hand when we needed it." Mary, as well as several other participants, believed they had access to "any lab space they needed." Denton fondly reflected on the variety of equipment and scientific instruments available in the math

and science building. He stated, “Being in the [math and science building] all the time was kind of the biggest resource for me.”

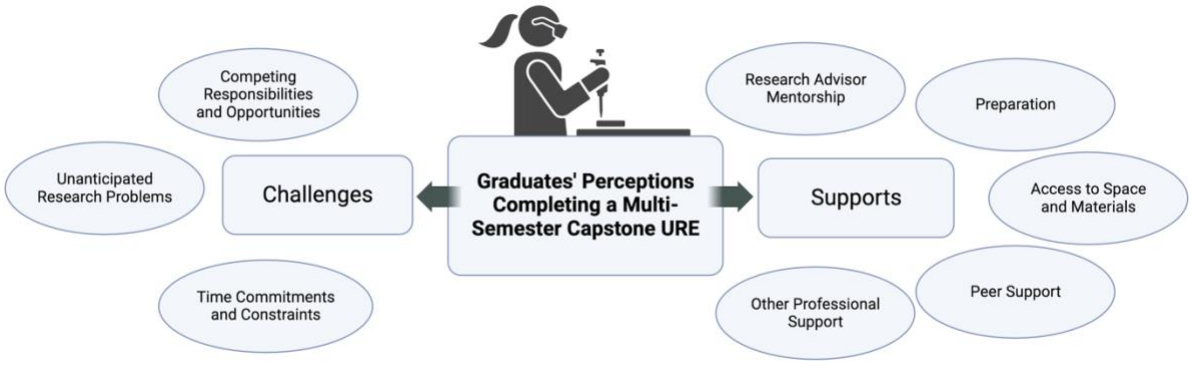
In addition to utilizing research space and scientific instruments, students also described their use of supplies during their capstones. Some students described having supplies readily available in the lab. Dominique summarized his experience by saying, “I had plenty of, like, supplies and access to stuff. [My advisor] hooked me up with all the [supplies].” Other students described the need to order supplies but found financial support to do so through their research advisor or department. Clark described his experience by stating, “I was able to, like, order supplies. I mean I obviously wasn’t asking for a lot. I don’t know what [my research mentor’s] actual research budget was, but I didn’t have any problems in getting resources or anything I needed.” Megan shared a similar experience and stated, “The department as a whole was really helpful because they set aside a budget for research so that if I needed to purchase supplies or anything that was coming out of the department’s budget versus paying for it ourselves.”

Although all students believed they had access to the resources they needed to successfully complete their capstone URE, a few students recalled challenges in obtaining needed equipment. For example, Riley recalled having difficulty finding a software program. However, at the time, she did not consider the process a major resource limitation but rather a hiccup in the research process. Now, as a graduate student at a major research university, she acknowledged some budgetary and equipment limitations from conducting her URE at a PUI.

DISCUSSION AND CONCLUSIONS

This study examined the student experience of completing a multi-semester capstone URE at a PUI. Although the experiences described by the participants in our study are limited to a specific setting, we believe our findings can be used to guide the design and facilitation of capstone UREs on a far broader scale in conjunction with the results from similar studies and unique institutional needs (Kumbhar, Attar, and Teslang 2018). To best conceptualize our findings, we produced a model to illustrate the types of challenges and supports experienced by the participants in our study.

Figure 1. Model of challenges and supports experienced by students who completed a multi-semester capstone URE



Conducting a high-quality capstone URE requires students to invest a significant amount of time. The variation in time that students committed toward their research capstone in our study illustrated a flexible approach in the scope of research capstones, allowing some students to be successful through smaller time commitments while allowing other students to become fully engulfed

in their projects. Students' time commitments toward their capstone URE often compete with other responsibilities and opportunities. To promote students' mental well-being, programs or mentorship on time management and work-life balance could be incorporated into aspects of UREs. Such programs can promote better work prioritization skills while also reducing student burnout.

We found that students encountered unexpected research problems as part of their capstone URE. For many students, these obstacles resulted in frustration toward their project. Although students ultimately appreciated these challenges after they overcame them, proactively teaching students to expect challenges in scientific research and fostering critical thinking and problem-solving skills may reduce students' initial negative emotions when encountering research challenges.

Prior research has indicated that a lack of preparedness for research may impede students' ability to conduct high-quality research capstones or thesis projects (Hinckley, McGuire, and Danforth 2019; Tucker, Mulliner, and Wilson 2017). In the design of capstone UREs, the use of scaffolding in scientific coursework may better prepare students. If an academic unit currently has students completing capstone UREs, an analysis of student work may yield insight into the strengths and weaknesses in the curriculum and provide potential areas for improvement (Berheide 2007; Healey 2014). Additionally, prior exposure to supplemental UREs or CUREs provides students with the preparation needed to be successful in their capstone experiences. The participants in our study acknowledged their ability to access the space, materials, and supplies required to conduct their capstone UREs. When designing capstone URE programs, we recommend considering the necessary space, equipment, and costs of supplies to adequately support student research.

We found that peer discussion and collaboration created a valuable and supportive learning community between students completing capstone UREs. Therefore, we recommended establishing structured or organic opportunities for collaboration, such as peer working groups. Lastly, prior research has heavily emphasized the importance of faculty mentorship in the URE process (Estrada, Hernandez, and Schultz 2018; Thiry and Laursen 2011). Our findings corroborate the importance of dedicated faculty who not only guide students on their research projects but also take the time and effort to get to know their students. Despite our study's emphasis on STEM students, their perceived challenges and beneficial supports may translate to undergraduate work in other fields, particularly those that include an honors thesis (Medaille et al. 2022). We recommend future research to investigate the influence of gender and race on the student experience of capstone UREs. As UREs are becoming more common in higher education and as faculty are often heavily engaged in many responsibilities, we recommend administrators provide the space, time, and resources required to effectively mentor undergraduate research.

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DISCLOSURE

The authors report that there are no competing interests to declare.

ETHICS

The Doane University Institutional Review Board reviewed this research (#S21 007 DC IRB HS).

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APPENDIX

Semi-structured interview guide sections and questions. Researcher flexibility and additional probing questions were used in conversational tone in order to elicit in-depth participant responses. Instrument previously published in Colclasure et al. (2024).

Section	Questions
Introduction / Ice Breakers	1. Please briefly tell us about your overall undergraduate experience and experience majoring in [major]. 2. Please tell us a little about what you have been doing since you graduated from Doane University.
Section 1: Initial Expectations	3. What were your initial expectations coming into the capstone research? 4. What did you hope to gain out of the capstone research? 5. Please tell us about your research I course where you identified your research project and faculty advisor.
Section 2: Capstone Research Overview	6. Briefly tell us about your research capstone topic. 7. How did you decide your research topic? 8. How did you identify the research advisor that you ended up working with?
Section 3: Faculty Relationship	9. How would you describe your relationship with your faculty research advisor during your senior capstone research? 10. Describe the accessibility of your faculty research advisor. 11. How would you describe the level of guidance/mentorship that the faculty mentor provided you during the project? 12. How did the relationship with your research advisor impact your overall experience?
Section 4: Challenges	13. Please describe the time commitment required of you to complete your capstone research. 14. How did you feel about this time commitment? 15. How did your other responsibilities influence your capstone research? 16. How did the capstone research influence your other academic work and classroom grades? 17. Please describe the availability of your faculty advisor when you needed him or her. 18. Please describe the availability of appropriate workspace for your capstone research. 19. Please describe the availability of materials required for you to complete your capstone research. 20. Please describe any support you received from others for your capstone research.
Section 5: Impact	21. Please describe the skills, if any, that you believe to have gained because of completing your capstone research. 22. Do you believe your capstone research had any impact on your ability to think critically or problem solve? 23. Do you believe your capstone research had any impact on your understanding of the scientific/research process? 24. Do you feel that the capstone experience had any impact on your confidence as a STEM major? 25. If so, what do you believe specifically contributed to this change? 26. Please describe whether you found the research enjoyable or more of a drag to get through. 27. Do you believe the senior capstone research had an impact on your post-graduate plans?

Section 6: Career &/or Graduate School	28. *Please describe your beliefs toward whether your capstone research prepared you for your career. 29. *Based on your exposure to similar work colleagues, did you feel more or less prepared than them when entering into the workforce? Why or why not? 30. **Please describe your beliefs toward whether your capstone research prepared you for your graduate school program. 31. **Based on your exposure to similar graduate students, did you feel more or less prepared than them when entering into graduate school? Why or why not?
Conclusions	32. How would you recommend the senior capstone research experience be modified to improve the experience for future students? 33. What advice would you give future undergraduates about completing their capstone research? 34. [Provide summary of main points from discussion]. Please describe if this was an adequate summary. 35. Please describe if we missed anything or if you have any other comments about the senior undergraduate capstone experience.

Note. *Denotes questions only asked to participants who entered a career; **Denotes questions only asked to participants who entered graduate school.