Exploring Group Dynamics in a Group-Structured Computing Undergraduate Research Experience

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ABSTRACT

While the computer science community has explored the importance of Undergraduate Research Experiences (UREs) and, separately, collaboration in computing (e.g. pair programming), little research has studied collaboration in the context of a URE. We performed a qualitative thematic analysis of how students collaborate within a group-structured, academic-year, inclusive computing URE catered towards second-year students at two large public research universities in the United States. We analyzed free-response and Likert-scale survey data collected early and late in the program from a total of 106 students who comprised three program cohorts. We studied their overall group function, what aspects of group work led to positive or negative group experiences, how their group affected their feelings of being supported, and how their group affected their sense of belonging in computing. We found that group experiences were overwhelmingly positive. Further, we found that students' experiences in groups centered around three themes: group fit and belonging, emotional and academic support, and logistics. Within each theme, their experiences were rich and nuanced, and we observed variations by gender, and to a lesser degree by race. Our work suggests that group-structured UREs are both feasible and beneficial for students, and we give concrete suggestions for how to make these experiences successful.

CCS CONCEPTS

• **Social and professional topics → Computing education programs**.

KEYWORDS

Sense of Support, Sense of Belonging, Undergraduate Research, Diversity, Collaboration, Group Work, Computing

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1 INTRODUCTION

Although the stereotypical view of a programmer is someone who codes alone for hours on end, the field of computing is, in reality, deeply collaborative. Collaboration in educational settings has been shown to better teach students the essential teamwork skills for the workforce [22] and improve learning [20]. Furthermore, pair programming is a commonly used technique, particularly in early programming courses, that has improved students' learning [9, 12, 16, 25, 32, 33, 37, 48] and increased confidence in programming skills [12, 16, 17, 32, 33]. Studies about collaboration have revealed that teamwork leads to increased retention in computing [15, 32, 33], especially with students from underrepresented groups [6, 22]. On the other hand, some studies have shown that individual work tends to warrant higher grades than those submitted by groups [9, 20] and pair programming may negatively affect student contribution from some demographic groups [26].

Much less is known about collaboration in the context of Undergraduate Research Experiences (UREs) in computing. UREs are regarded as beneficial in increasing major retention [5, 29, 30, 36, 38], the likelihood of graduate study [5, 29, 36, 38], learning gains for underrepresented students [30], increasing feelings of belonging for students from groups that are underrepresented in computing [39], and diversifying the future of computing professors [40]; however, most of these studies do not focus on group-based UREs. While some UREs encourage group work, little is known about what benefits or drawbacks working in a group might provide in this context.

To gain insight into this question, we conducted a study within the Early Research Scholars Program (ERSP), a scalable program for early undergraduate research in computing that runs at multiple universities in the United States. ERSP is a group-based, structured, full-academic-year research program targeting students in the second year of a computing major. ERSP has a strong focus on diversity and inclusion, with most of the participants in ERSP being women or non-binary, and/or Black, Latinx, or Native American students.

We administered surveys to students in three cohorts of ERSP at two large public universities asking students to reflect on their group experience via Likert-scale and free-response questions. We performed a qualitative thematic analysis on their responses and found that students predominantly report positive sentiment towards their group with three prominent themes: emotional/personal experience, academic support, and logistical factors. Within these three categories we found variations by gender and group composition (i.e., the number of men and women in the group), and, to a lesser degree, by race.

Our results shed light on the value students perceive from a group-based structure for research (which goes far beyond just assistance with the research project), the logistical challenges and solutions of research collaboration, and important differences when considering research group composition. Based on our results, we believe that group work in computing research programs is underused relative to the value it provides to students. We suggest that more undergraduate research programs include a formal group structure, and provide suggestions on how to maximize the success and benefit of this approach.

2 THEORETICAL FRAMEWORK AND PREVIOUS WORK

Our exploration of group work in a formal research setting is grounded in theories around sense of belonging in higher education and offers a unique understanding, compared to prior work, of the emotional, academic, and logistical impacts a collaborative URE can have on students.

2.1 Theoretical Framework

One of the earliest theories around sense of belonging was described by Astin in 1984 [4]. Frustrated with frameworks that focused solely on inputs to (e.g. policies, educational methods) and outputs of (e.g. test scores, graduation rates) student learning, Astin proposed the Interaction Theory which argues that any policy or approach, in order to be successful, "must elicit sufficient student effort and investment of energy to bring about the desired learning and development" ([4], p. 522). He explored a number of aspects that could elicit such involvement (e.g. type of college, place of residence, student-faculty interaction), but one area in particular he cited as worthy of more research was the role of peer groups in potentially enhancing student involvement.

Astin's theory has been extended and refocused in the decades since it was developed. Tinto [43] explored students' persistence in higher education and developed a highly influential and cited model of student departure (i.e. non-retention) that is centered around students' ability to become incorporated into the academic and social structures at the institution. While Tinto's model became popular, some scholars objected to Tinto's model for its suggestion that retention can only be improved by assimilation into the dominant culture [42]. More recent work has focused around models of cultural broadening and acceptance. For example, Tucker argues that a sense of community (rather than an adoption of the dominant culture) may be more important in student persistence [44]. Similarly, Hurtado and Carter, specifically studying Latinx students, revised Tinto's model to capture the idea that organization membership—even if the organization is not centrally in line with the university's culture—is a critical factor in belonging and retention [23]. These theories have continued to be refined in the years since their introduction [11, 13, 28]. Yet, what remains common to these theories is that groups and communities have a strong influence of students' sense of belonging and persistence.

Our work is shaped by these theories in that we study how group work in a formal computing research context is related to students' feelings of support and belonging in computing, specifically. We explore the ways in which a student's experience with their research group might (or might not) provide a sense of membership or community described by these scholars, specifically within the computing culture.

2.2 Collaboration in Computing

Much of the prior work that examines collaboration in computing focuses on the context of pair programming and often reports conflicting results [9, 12, 16, 17, 26, 34, 46–48]. Several studies have found that pair programming improved students' grades in class assignments [37] or increased retention within computing [15, 27, 32, 33]. On the other hand, one study found that students who worked alone overall scored higher than students who worked in pairs [9].

Pair programming does not benefit all students equally. Layman found that while most students enjoyed pair programming, those who did not were already stronger coders [25]. This result is furthered by studies that found that the partner a student worked with directly defined their success; a large disparity in students' knowledge levels and/or programming experience led to low-achieving students struggling to keep up [12] while demotivating high-achieving students [17]. Lewis and Shah found that a focus on speed can lead to a pattern where one student becomes dominant while the other is marginalized [26].

Beyond pair programming, computing courses that meaningfully teach and structure collaborative work are relatively less frequent. Mason found that collaborative learning in most courses was constrained to informal group work, and faculty emphasized development of individual over teamwork skills [31]. However, there do exist studies that have examined classes that explicitly teach collaborative techniques. One such study found that if a course simply handed out an assignment and did not explain *how* the team should work together, then new teamwork skills did not develop [19]. Another study found that negotiating a successful group work arrangement can be particularly challenging when students have different strengths and background knowledge [18]. When studying why many computing students avoided "true" collaboration, another study found that some computing students' inability to work together stemmed from procrastination, wanting to work independently to receive sole credit, and a general unwillingness to help one's own team members [45].

The high attrition rates of women and Black, Latinx and Native American students in computing has been studied with regards to how pair programming and other collaborative experiences can affect underrepresented students' social and academic integration into the computing field, thus leading to greater persistence in the major [6]. Mandatory collaboration in computer science classes has been found to increase retention for women in computing by providing a platform to hold intellectual discussions with their peers while minimizing the chances of being stereotyped or invalidated on the basis of gender [7]. Other studies found that collaboration on programming assignments led women to feel a greater sense of belonging and more likely remain in a computing major [6].

However, not all group work has been found to be beneficial. Barker found instances where female students faced stereotypes of inferiority, belittlement, or even explicit harassment while working with male students. Instead, gains in confidence came from working in all-woman groups [5].

2.3 Collaboration in computing research

While there have been several studies showing the benefits of undergraduate research in computing [3, 10, 35, 39, 41], there are relatively few that specifically study the impact or experience of students in group-based computing research. An analysis by the Center for Evaluating the Research Pipeline (CERP) found that participants in CREUs (Collaborative UREs) and DREUs (Distributed UREs) were up to twice as likely to attend graduate school compared to traditional URE participants. In CREUs, undergraduates worked in teams of 2-3, while in DREUs, female and minority undergraduates were paired with faculty mentors who identified likewise [14]. It remains uncertain what specific aspects of these expanded UREs contributed to their success, leaving room for new findings regarding collaborative computing UREs.

Our computing URE's unique structure of putting students in groups of 2-4 delivers a unique understanding of how students' sense of belonging and support within computer science can be shaped by their peers. Our study is not about pair programming or collaboration techniques, rather it is about the emotional, academic, and logistical impacts a collaborative URE can have on students. We seek to dissect how students collaborate successfully and unsuccessfully within the free-form context of research, rather than the context of curated classwork, to encourage more UREs to pursue group-based undergraduate research and maximize their success. This work adds to our collective understanding of the importance and feasibility of group work in computing on students from both majority and underrepresented groups in computing.

3 APPROACH

To investigate how students experience group-based research, we studied the Early Research Scholars Program (ERSP), a group-based, structured early research program in computing. ERSP leaders (one of whom is a co-author of this paper) have previously found that teams almost always stay together for the full academic year and complete high quality research projects; however, ERSP leaders did not have a sense of what benefits or struggles students were experiencing in these teams, or why they were successful (or not).

We seek to understand how students experience working in a group throughout the program. Specifically, we formulate the following research questions:

- RQ1: How does working in a research group in this context affect students' sense of belonging and support in computing?
- RQ2: What are the successes and struggles of working in groups of 2 to 4 in a computing URE?
- RQ3: Do these experiences vary based on demographic factors and group composition?

3.1 ERSP Overview and Group Structure

ERSP was founded in 2014 at UC San Diego, a large American research university, as a way to scale early undergraduate research opportunities in a supportive and inclusive way. In ERSP, students in their second year (or first-year transfer students) of the computer science (CS) or related computing major participate in an academic-year-long research apprenticeship. Here we provide an overview of ERSP, focusing on the aspects of the program that are relevant to the students' group work experience. Full details of ERSP and its mentoring structures can be found in previous work [1–3, 8] and on the ERSP website (ersp.ucsd.edu).

ERSP selects for a diverse and inclusive community. Students apply to the program in the prior spring or summer, and they are selected using an inclusive selection process that values their understanding of the challenges facing students from marginalized groups in CS and their ability to add to a diverse and supportive community (see [2] for more details).

Once students are accepted into ERSP, groups are formed based on both students' interests and (fall) schedules. Just before fall, accepted participants rank their interest ("very interested," "somewhat interested," or "not at all interested") in available research projects that have been provided by faculty mentors. Project areas span the full range of computer science (e.g. bioinformatics, computer architecture, security, algorithms, machine learning, etc.); previous ERSP projects can be found on the UCSD ERSP website (ersp.ucsd.edu). Participants also state whether or not they are free to attend the research group's scheduled meeting times. ERSP leaders then match students with projects in groups of about 4 students[1]. Matching is done so that students are (1) at least somewhat interested in the project (with a preference for very interested) and (2) available to attend the group's research meeting. Leaders try to avoid forming groups with only one woman or non-binary identifying student, or only one student from a marginalized racial group, although it is not always possible.

Students are minimally trained on how to work successfully in a group. In the fall, students in ERSP take a research methods course as they start to learn about the research area they will be working in. Early in this course, they work through a scenario-based exercise on group-dynamics, designed to teach them about challenges that might arise within their group and strategies for avoiding/mitigating these challenges. They also receive practical training about how to run a meeting and how to organize tasks.

Firm expectations for group work are maintained throughout the program. Groups are not allowed to split up and are expected to coordinate their activities throughout the year; several structures are in place to ensure that projects are truly a group effort. In addition to meeting weekly as a group with their technical mentor and an ERSP central mentor, groups are expected to schedule at least two hours per week to work together as a team on top of any time they spend working individually on their research. Students are not required to pair program, but many choose to do so. Each group maintains a research log documenting the team's activities. If issues arise that cannot be resolved by the group members themselves, one of the ERSP leaders steps in to help the students get past the challenge and back on track with successful group collaboration. Technical mentors are instructed to treat their students as a team working on a single unified project. While they are told to encourage students to work on complementary tasks (often in pairs), they are instructed that it is not acceptable to have each student work on their own independent project.

[1]The vast majority of groups are of 4 students. There are a few groups of 3, but groups of 5 or 2 are rare.

3.2 Data Collection

We collected data from three cohorts of ERSP participants: two cohorts from UC San Diego (2019-2020 and 2020-2021 academic years) and one cohort from UC Santa Barbara (2019-2020 academic year). Our analysis includes both UCSD and UCSB to generalize our results to more than one site. We show the demographic breakdown of respondents by gender, transfer status, and race in Table 1.

We used a survey-based approach that combined Likert-style questions with open-ended prompts. This combination allowed us to gauge overall student sentiment and group success, coupled with a more nuanced examination of students' feelings of support and belonging.

The following survey questions were distributed to each student at two points in the program: approximately three months into the program (which we will refer to as the "beginning of ERSP "), and a few weeks before the end of the program:

- Overall, how well does your group function? [Extremely well, Pretty well, Just OK, Not well]
- To what extent do you feel that group members are contributing equally to the success of the project? [1-Very unequal to 5-Very equal]
- Does your team help or hinder your feelings of being supported? [They make me feel very supported, They make me feel somewhat supported, They don't affect my feelings of being supported, They make me feel somewhat unsupported, They make me feel very unsupported]
- Does your team help or hinder your feeling of belonging in computing? [They very much make me feel like I belong in computing, They somewhat make me feel like I belong in computing, They don't affect my feelings of belonging in computing, They somewhat make me feel that I DON'T belong in computing, They very much make me feel that I DON'T belong in computing]
- In what ways does your team help or hinder your feelings of being supported? [open-ended]
- In what ways does your team help or hinder your feeling of belonging in computing? [open-ended]
- (optional) What suggestions do you have, if any, on what would have made your team function better? [open-ended]

All students were expected to complete this survey (and other surveys) as part of the ERSP program (though not all did), but consenting the use of their survey data for research was optional. Students were informed that their responses would not affect their grades and that the ERSP instructors would have no knowledge of who had or had not consented to the research. In addition to being used in this research, survey responses were reviewed and used by ERSP instructors to help improve students' experiences in the program.

Following our approved IRB protocol, we sent all survey responses to a third party who de-identified the data, removed students who had not consented to the research, and added demographic data including race/ethnicity, gender (male/female only), transfer status, and major from registrar records. In total 115 students in ERSP consented to having their data used for research; 106 students (92.2%) filled out at least one of the two surveys: 17.4% submitted only the first survey, 1.7% only the second, 73% submitted both, and 7.8% did not fill out either.

Table 1: Demographic information for all 115 students who consented to research. Demographics were obtained from university records, following our approved IRB protocols. Both schools collected gender as a binary category during this time frame. "Transfer" refers to students who transferred from another 2- or 4-year college or university while "Non-transfer" refers to students who entered the university directly from high school. Due to small numbers of participants and the research protocol at UCSB, we could only obtain aggregate data on race, grouped into Black, Latinx, Native American/Naive Alaskan, and/or Native Hawaiian/Pacific Islander (BLN)—which are the racial groups traditionally considered underrepresented in computing—and non-BLN.

	UCSD 2020-2021	UCSD 2019-2020	UCSB 2019-2020	Total
Women	28	25	9	62
Men	21	25	7	53
Transfer	18	14	0	32
Non-transfer	31	36	16	83
Asian Amer.	24	27	-	51
Black	2	3	-	5
Hispanic/Latinx	14	6	-	20
White	2	5	-	7
Foreign Nat.	5	7	-	12
Other/Unknown	2	2	-	4
BLN	-	-	2	2
Non-BLN	-	-	14	14
Total	**49**	**50**	**16**	**115**

3.3 Data Analysis Methods

We performed a qualitative thematic analysis using the open-ended responses from the 106 students who submitted at least one survey. This process involved open-coding followed by a deeper examination of individual responses guided by the coding process. We began with two coders (the first two authors) working together to develop and iteratively refine codes on a growing subset of the data. Each coder independently created and applied codes to a new subset of the data (5%), coders met to reach code agreement (i.e., add, refine, or remove codes as needed), and then they repeated the process. Codes were applied to a student's entire response to a single question on one survey, rather than individual sentences, and coders were allowed to apply as many codes as applicable to each response. We used Kraemer's kappa, an extension of Cohen's kappa that allows for multiple codes on a single given response, to measure inter-rater reliability for one response [24]. The cycle of independent coding and discussion continued until the coders had an inter-rater reliability of 0.8 on a new set of data prior to discussion, which occurred after 40% of the data was coded. The coders then each independently coded half of the remaining responses.

The entirety of this coding was done without knowledge of the respondents' demographics.

After coding was completed, we found that most codes spanned responses across the different prompts, so we analyzed the codes holistically, rather than question-by-question. We calculated code frequencies and both coders grouped together the codes into higher-level themes. To get a deeper understanding of codes that were either frequent or surprising (or both), excerpts were extracted and re-examined by both coders to better understand students' reasoning behind using these codes. Codes were also grouped into themes to facilitate higher-level comparisons between demographic groups and between the two survey times.

Part of our analysis included examining our data for any response patterns that varied by gender, race/ethnicity or transfer student status. Using raw code counts, we looked for codes that appeared more frequently for different demographic groups, which might suggest different experiences by demographic group, which we then explored further by examining individual excerpts.

In our analysis, we used Likert-scale questions to get a quantitative sense for how students felt about their groups. Likert-scale analysis is limited to responses from the 84 students who completed both surveys to allow us to examine changes over time.

3.4 Positionality Statement

The research team includes three researchers: two undergraduate students and one faculty member with 15 years of education research experience who is also the director of the ERSP program at UCSD. All team members identify as women; one identifies as White, one as East/Southeast Asian and the third as White/Latina (though she presents as simply White). All three study or have studied a computing-related discipline. The instances of the ERSP program we studied are run through the Computer Science departments at two two large public, selective, research-focused universities in the United States. Both departments have slightly more than 20% women; both departments are predominantly Asian.

Although we have tried to use objective methods, we recognize that our identities and positions necessarily shape this work. The faculty member's position as both the program director and researcher provides both benefits and potential biases. On the one hand, she can better contextualize the students' responses, while on the other hand, she is susceptible to confirmation bias. The researchers' identities as gender minorities sensitize them to struggles faced by women, while their identities (mostly) in the racial majority may cause them to overlook or impose their own cultural interpretation on statements made by those from marginalized racial groups.

3.5 About Demographic Categories

In the sections that follow, when presenting quotes, we give the broad racial category, gender, and transfer student status for each respondent to provide additional context for the reader. Table 1 shows that the numbers of participants from several racial categories is quite small. To preserve students' anonymity, we report students' races as either one that is traditionally marginalized in computing following the NSF's definition for marginalized races (Black, Hispanic/Latinx, Native American/Native Alaskan, and/or Native Hawaiian/Native Pacific Islander), or one that is in the set of racial groups well represented in computing (Asian American or White), even if it is not necessarily well-represented in the program (e.g. White). We refer to the first category as "Marginalized" racial groups and the second as "Majority" racial groups. Additionally, we include Foreign National students and students who listed their race as "Other" in the "Majority" category. The reason for the former is that nearly all of our Foreign National students at both institutions are Asian, while the reason for the latter is that we wanted to ensure that the Marginalized category included only students we know belong to a marginalized racial group.

Our choice to aggregate racial categories as we have done comes from privacy concerns, limitations in obtaining fine-grained racial data, and the additional power that can arise from analyzing larger groups whose members (might) share similar experiences based on demographic factors. However, we acknowledge that grouping races (and indeed genders) into broad categories has problems. For example, White, Asian American and International Asian students certainly have different experiences, both in ERSP and more generally. Furthermore, while "Asian" is generally considered to be a racial category that is not underrepresented in computing, we know that this broad category includes a wide range of Asian subcultures, not all of which are well-represented in the computing field. In fact, we have reason to believe that due to the selection process used for ERSP, many of the Asian students in the program in fact identify with these less well-represented sub-groups. We recognize that the field of computing education has a long way to go in how we examine race, and we try not to draw too many firm conclusions based on our racial analysis, but rather use our work to suggest future areas for study.

4 RESULTS: OVERVIEW

Table 2: Responses to the survey question "Overall, how well does your group function?" at the two points in time.

Answer options	Beginning of ERSP	End of ERSP
Extremely Well	44.0% (37/84)	33.3% (28/84)
Pretty Well	45.2% (38/84)	60.7% (51/84)
Just OK	9.5% (8/84)	4.8% (4/84)
Not Well	1.2% (1/84)	1.2% (1/84)

Overall, we found that group experiences were largely positive. Responses to the Likert-scale questions, shown in Table 2, reveal that students felt that their groups generally functioned well, with 89.2% of respondents saying their group functioned "extremely well" or "pretty well" near the beginning of the program, and 94% saying their group functioned "extremely well" or "pretty well" toward the end of the program. Only one individual stated that their group functioned "not well."

Ratings between the two surveys were largely stable (see Figure 1). Interestingly, while the percentage of groups that rated their function as "just OK" decreased from the beginning of the program to the end of the program, the percentage of groups that rated their function as "extremely well" also decreased (Table 2).

Table 3 shows that students generally perceived their groups as helping their sense of belonging in computing, and again these

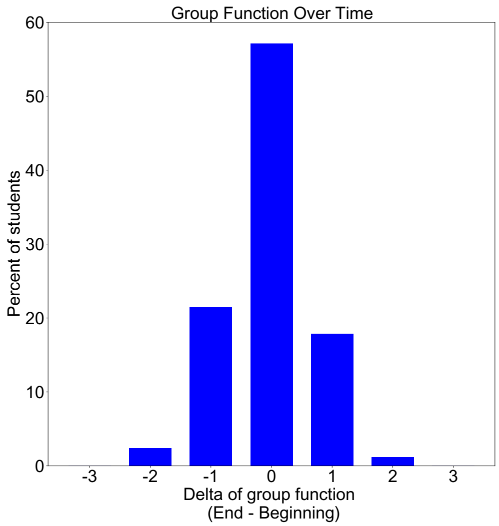

Figure 1: Histogram of the changes in individual students' responses to the question "How well does your group function?" between the two surveys. Positive numbers indicate an increase in perception of how well the group functions.

perceptions were fairly stable on from the beginning to the end of the program, though a minority of individuals' ratings (10%) changed 2 points from the beginning to the end (see Figure 2).

While these results are encouraging, they hide the complexities of student experiences in their groups. In the next two sections, we present the results of our qualitative analysis which revealed not just the quality of the group experience, but also the value that students perceived from their group work. We tie these results back to our research questions in Section 7.

5 RESULTS: GROUP FIT AND SUPPORT

Perhaps unsurprisingly, when we asked students to reflect on the ways in which their team supported them and affected their sense of belonging in computing, many students wrote about the emotions and personal feelings they experienced while working with their group. In this section we explore the personal and emotional responses from students that arose primarily in response to the two open-ended questions about belonging and support.

5.1 Sense of Belonging and Personal Group Fit

Students' responses to the question "In what ways does your team help or hinder your feeling of sense of belonging in computing?" revealed two common sentiments that spoke about how their perception of their personal group fit shaped their sense of belonging: the feeling of psychological safety and being heard by their group, and their relative knowledge compared to others in the group.

Nearly half (45 out of 106 responses) of students' responses discussed aspects of psychological comfort and inclusion in their group, including the following feelings: not being afraid of asking questions, asking for help, or making mistakes; feeling that their

Table 3: Responses to the question "Does your team help or hinder your feeling of belonging in computing?" at the two points in time.

Answer options	Beginning of ERSP	End of ERSP
They very much make me feel like I belong in computing	56% (47/84)	54.8% (46/84)
They somewhat make me feel like I belong in computing	23.8% (20/84)	23.8% (20/84)
They don't affect my feelings of belonging in computing	20.2% (17/84)	19.0% (16/84)
They somewhat make me feel that I DON'T belong in computing	0% (0/84)	2.4% (2/84)
They very much make me feel that I DON'T belong in computing	0% (0/84)	0% (0/84)

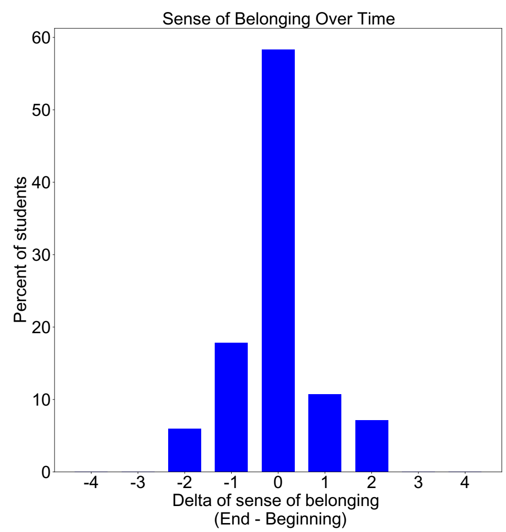

Figure 2: Histogram of the changes in individual students' responses to the question "Does your team help or hinder your feeling of belonging in computing?" between the two surveys. Positive numbers indicate a more positive perception of belonging at the end of the program.

ideas and opinions were heard at meetings; and feeling able to open up to the group about workload, computing-related struggles, and honest thoughts. For example, a student expressed the following sentiment:

> *My team never makes me feel marginalized or unwelcome in computer science. We all treat each other equally, with the respect that we deserve, so there is no feelings of a hostile or unwelcome environment among us. My group does a great job in making me feel comfortable and welcome in the field and project, and I try to reciprocate that feeling of belonging towards them.*
> -Man, majority race, non-transfer

This illustrates that students value the idea that they can safely express incorrect thoughts and doubts, which is an essential part of the learning (and research) process.

Of the 45 students who expressed a comfortable group environment, 15 students reported that their team had "no negative judgements," such as the following student (emphasis added):

> *My team helps my feeling of belonging in computing because they are open to all ideas and never doubt anyone's ability to acquire new skills and knowledge to help them grow in computing. They* ***never think any idea that I throw out is a dumb idea*** *and are always supportive of one another in learning more in our research in computing.*
> -Woman, majority race, non-transfer

And the following student:

> *While I may have been confused and challenged at times, they* ***never made me feel out of place****. They always valued my opinion even when I may have not had the same amount of experience as them. Knowing that I can work well within the team and make individual contribution heightens my feelings of belonging.*
> -Man, majority race, non-transfer

In this second quote, not only did this student report that he felt no negative judgements from his team in terms of feeling misplaced, he also reported feeling his opinion was valued. The sentiment of feeling valued through contributions was a shared one with 13 of the 45 students who reported a comfortable group environment.

However, while 45 students experienced feelings of comfort, 3 students reported their group environment felt *un*comfortable, such as the following student:

> *There are very large knowledge gaps between me and members of my team so I feel like an annoyance and I feel out of place when most things are being discussed. I can't ask questions because I feel like I'd be breaking the momentum of discussions and I'm not even sure if my questions are relevant. When I'm assigned work I'm not familiar with, my teammates would answer any questions I asked with plenty of detail, but I always feel like I should know the answers to the questions I'm asking already... I feel like I'm lagging too far behind my teammates which makes me feel like I might not be a good fit for computing.*
> -Woman, majority race, transfer

In this case, the student felt left out and unable to participate because of her perceived lack of knowledge relative to her team members. Interestingly, the behavior the student describes from her teammates is supportive ("my teammates would answer any questions I asked with plenty of detail"), yet the fact that the student had to ask the question and get the answer from her teammates was perceived by the student as a deficit, indicating that she did not belong.

This student's response also illustrates the more general tendency for students to compare their experiences and skills to those of their group, and this comparison surfaced a broad range of emotions for students. 19 students total (including the three that indicated that their group environment was uncomfortable) mentioned feeling behind their teammates. For two students, such as the one above, feeling a knowledge gap was perceived as a deficit, indicating that they did not belong. However, for more students, relative levels of knowledge surfaced neutral (9 students), mixed (5 students), or even positive emotions (3 students). For example, one student wrote:

> *My teammate is definitely a much better programmer than I am. This doesn't affect me because I'm still learning and forming good coding skills in the process.*
> -Man, marginalized race, non-transfer

This student views ERSP as a learning process, where different people are at different stages in the process, without judgement. Thus he places neither positive nor negative value on the idea that his teammate knows more than him.

The knowledge gap could also be viewed as positive, as in the following example:

> *I guess you could say [my team] helps [my feelings of belonging in computing] as I aspire to do as well as they do and so it makes me want to work harder and be better.*
> -Woman, majority race, non-transfer

Far from being discouraged, this student is inspired by her teammates, which motivates her to work harder.

Finally, some students' feelings about the knowledge gap were mixed:

> *I don't think they affect my feelings of belonging in computing because although they have more experience than I do and this sometimes makes me feel bad about myself, I also know that I am still very early on in CS and have a lot to learn so this does not discourage me.*
> -Woman, majority race, non-transfer

Like the student above, this student recognizes that learning is a process. However, this student admits that she is not always able to hold herself to a neutral feeling about her current stage relative to her group.

We hypothesized that women might be more likely to report a knowledge gap than men, as previous literature has shown that women are more likely to underestimate their abilities [21]. We found that the students who expressed feeling a knowledge gap was gender-balanced. Of the 19 students who reported instances of a knowledge gap, 10 were women (18% of the 55 total women) and 9 were men (18% of the 51 total men). However, when we examined the prevalence of the knowledge-gap phenomenon based on the gender composition of the groups, we found a trend. As shown in Figure 3, the percentage of women who expressed a knowledge

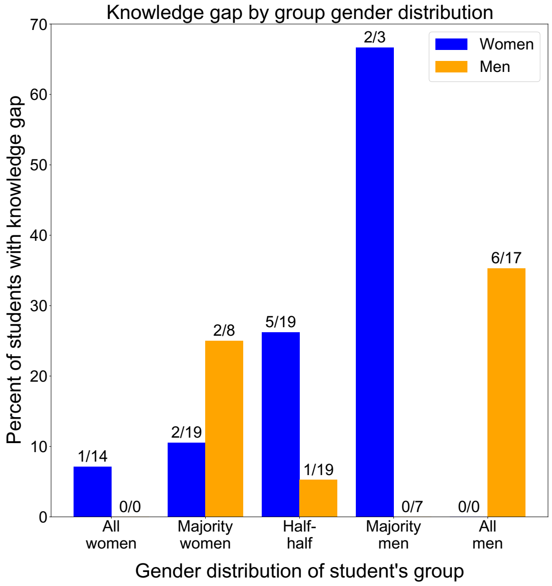

Figure 3: The proportion of students, by gender and group composition, who reported feeling a knowledge gap. For example, 5 out of 19 women students who were in gender-balanced groups expressed feeling a knowledge gap with their group, while 2 out of 3 women students in majority men groups reported feeling a knowledge gap.

gap tended to be higher in groups where women were less than the majority, while among men there is no clear pattern.

The following illustrates the potential reason behind the all-women and majority-women groups having lower overall instances of knowledge gaps:

> *My feeling of belonging in computing is very tied in with my identity as a woman, and being constantly surrounded with other women in CS changes my experience from last year. Another aspect that I notice in my group particularly, versus in the greater world of computing, is that my group members (and by extension, now I) are able to admit confusion or mistakes; in the CS community in general, saying incorrect things [is] a bit of a taboo.*
> -Woman, majority race, non-transfer

When surrounded by other women, this student felt that being uncertain or incorrect about something was more acceptable compared to within the broader community, where it would be perceived as a lack of knowledge.

We have focused on gender differences here because gender was the primary demographic identity expressed by participants in their open-ended responses, perhaps because ERSP was majority women. Exploring how the knowledge gap phenomenon varies across other demographic dimensions remains a topic for further exploration.

Table 4: Responses to the question “Does your team help or hinder your feelings of being supported?” at the two points in time.

Answer options	Beginning of ERSP	End of ERSP
They make me feel very supported	64.3% (54/84)	65.5% (55/84)
They make me feel somewhat supported	27.4% (23/84)	28.6% (24/84)
They don’t affect my feelings of being supported	6% (5/84)	4.8% (4/84)
They make me feel somewhat unsupported	2.4% (2/84)	1.2% (1/84)
They make me feel very unsupported	0% (0/84)	0% (0/84)

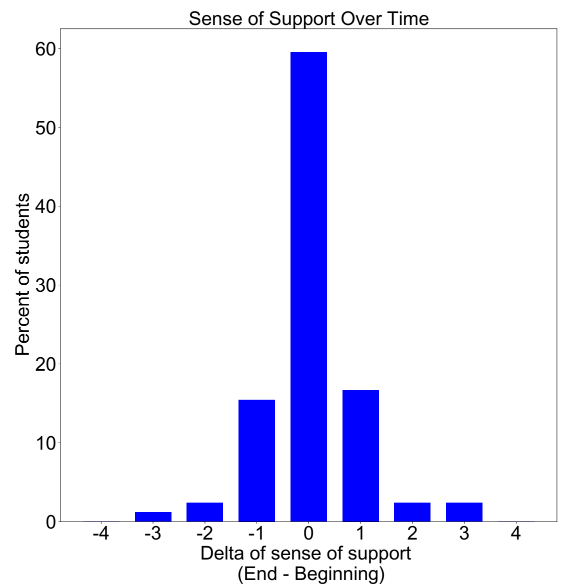

Figure 4: Histogram of the changes in individual students’ responses to the question “Does your team help or hinder your feelings of being supported?” between the two surveys. Positive numbers indicate a more positive perception of support at the end of the program.

5.2 Support and Group Environment

The majority of students stated that their groups made them feel ‘very supported’ (Table 4). Most changes in feelings of support from the beginning to the end of the program were small (Figure 4). Students’ responses to the question “In what ways does your team help or hinder your feelings of being supported?” revealed two central themes that spoke about how their perception of their group environment affected their feelings of support: common interests, struggles, and feelings; and a sense of (diverse) community.

32 students attributed their group environment's support to bonding over common feelings and struggles related to CS. For example, one student reported:

> *We just talk about how sometimes we are so lost in some of our classes and I guess it is reassuring that others are going through the same thing.*
> -Woman, marginalized race, non-transfer

This student appreciated knowing that she wasn't alone in her struggles. In some cases, a shared minority identity (being a woman) was an important factor in the shared experience, as the following responses illustrate:

> *My team is all women. Therefore, spending so much time with them makes me more comfortable with being a woman in computing: it doesn't seem as strange in comparison to a crowded lecture hall, where the major-wide percentage of women is clearer.*
> -Woman, majority race, non-transfer

> *I think that since we are an all-girls group, I felt very open about my feelings and the troubles I have in computing. Seeing reassurance from them really helped with my feeling of belonging.*
> -Woman, majority race, non-transfer

In these responses, the students seem to draw energy from being around others who face the same overall belonging struggles as they do.

While this sense of similar experience brought a strong sense of community and support to some, diversity was also an important part of support and community, as in the following quote:

> *My team helps me feel like I belong in computing because we all come from diverse backgrounds and we are being given the opportunity to work on exciting research in machine learning together. I can only imagine that, at other universities, students with our shared diverse backgrounds and majors may not be receiving these same opportunities to work with one another unfortunately. Our team is accepting of one another and we make sure that everyone feels like they are involved in the project.*
> -Man, marginalized race, transfer

To this student, the fact that students from different backgrounds got to work together—and did so in such an accepting and inclusive way—made him feel more connected to his group. It seems that both shared-identity and diverse-identity groups can bring feelings of support and belonging, but for different reasons.

ERSP groups also provided a significant amount of academic support, from the specific scope of ERSP and the research project (63 responses), to the broader context of academics beyond ERSP (45 responses, with 15 also receiving ERSP-specific support). The following quote exemplifies the research support teammates provided each other:

> *[Being open about confusion in the project] helps us sympathize with each other better and makes me feel like I'm less alone when I don't understand something. In my opinion, we're all also very willing to help each other understand... concepts. If one person has an understanding of something that the others don't, they are always willing to help the rest of us understand as well.*
> -Woman, majority race, non-transfer

This quote shows that in addition to receiving emotional support ("makes me feel like I'm less alone when I don't understand something"), the student also received important technical support that helped them learn and grow as a researcher.

Academic support beyond ERSP projects included support with other CS classes, hackathons, and internships. For example:

> *My partner seems to be doing quite well and has good opportunities. We usually talk about internships, jobs, classes, online tutorials and things like that. This makes me feel more personally involved as a developer. They also suggested that they're willing to help me with projects in the future, if they're related to code. I really appreciate that!*
> -Man, marginalized race, non-transfer

This student is using ERSP to get career development advice and support from a more-experienced member of their team.

We also compared the frequency with which different demographic groups (men vs. women, transfer vs. non-transfer, marginalized vs. majority racial groups) reported receiving help within and outside of ERSP. While most of the differences were small, we find that students from marginalized racial groups were statistically significantly less likely to report receiving help within ERSP than students from majority racial groups (10/26 (38%) marginalized and 53/80 (66%) majority, Chi-squared p-value=0.012), but slightly more likely than students from majority racial groups to report receiving support outside of ERSP (9/26 (35%) marginalized and 17/80 (21%) majority, Chi-squared $p = 0.169$). As these numbers are self-reports, we cannot know whether they represent differences in the actual support received or differences in how often students reported it in their open-ended responses. These results could indicate that ERSP provides a unique opportunity for students from marginalized racial groups to get support that might not be available to them in computing classroom contexts.

5.3 Summary

We found that students' relationships to their groups were complex, and shared a number of rich themes. Feeling comfortable expressing ideas, doubts and questions was related to a student's sense of belonging in a group. Yet, many students couldn't help but compare their abilities to those of their groupmates' (especially women in male-majority groups), which sometimes elicited negative self-perception, but more often was neutral or even positive. A shared experience was often cited when discussing group support, and students' identities relative to their groupmates' identities could increase the feeling and importance of this shared experience. Feelings of support were not limited to emotional support or support with research tasks; support beyond the research program was reported frequently indicating that the benefits of group work transcend students' specific projects.

Table 5: Responses to the question "To what extent do you feel that group members are contributing equally to the success of the project?" at the two points in time.

Answer options	Beginning of ERSP	End of ERSP
5	23.8% (20/84)	22.6% (19/84)
4	52.4% (44/84)	47.6% (40/84)
3	17.9% (15/84)	19% (16/84)
2	6% (5/84)	10.7% (9/84)
1	0% (0/84)	0% (0/84)

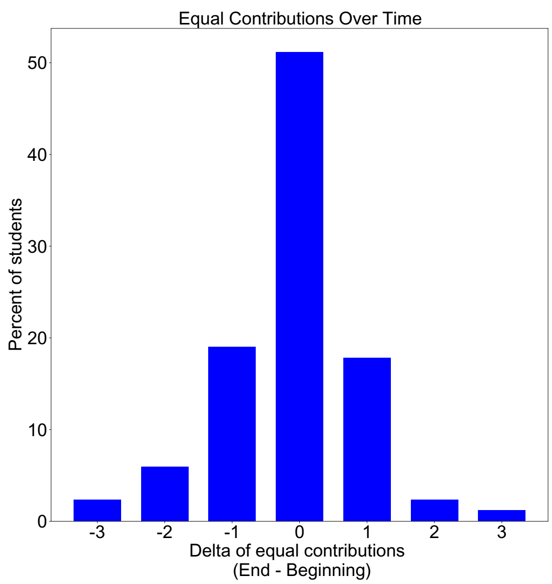

Figure 5: Histogram of the changes in individual students' responses to the question "To what extent do you feel that group members are contributing equally to the success of the project?" between the two surveys. Positive numbers indicate a more positive perception at the end of the program.

6 RESULTS: LOGISTICS

An emergent set of themes also arose around the logistics of working in a group. While the program provided suggestions for how groups should work together (Section 3.1), the specific division of labor and collaboration strategy was up to them. Students faced both successes and challenges in coordinating their group work. Surprisingly, only about half of the responses around this theme were in answer to the question "What suggestions do you have, if any, on what would make your team function better?" Mentions of logistical themes including the decision to separate work into individual tasks, the struggles and successes of coordinating meetings, and the general ability to effectively communicate appeared in responses across every open-ended question.

6.1 Division of Labor

As seen in Table 5, students ranked the contributions of their teammates at a 4 (out of 5) the most often, both at the beginning of the program and at the end. In many groups, the members of the group perceived the degree of contribution from team members similarly: of the 28 groups with Likert responses from at least two students, 15 groups had identical ratings across all group members at the beginning of ERSP. By the end of ERSP, 11 groups had identical ratings across all group members, with only 1 group displaying a standard deviation of over 1 point.

General contribution to the research was an important role in group function, as mentioned by students in their responses. We found 32 of 106 students that discussed how groups divided their work; 16 indicated an effective division of labor and 16 indicated an ineffective division of labor. Comments about effective division of labor did not always imply that work was divided exactly equally. Instead, some of these responses expressed a more nuanced division based on team members' individual situations, as in the following quotes taken from responses to ""In what ways does your team help or hinder your feelings of being supported?":

> *My group in general tries to be considerate about individuals schedules and abilities. We split tasks based on interest and skill, and understand that members may be able to do less when they have more tests or assignments.*
> -Woman, marginalized race, non-transfer

> *My group is really nice in terms of making accommodations. We all have points in the quarter where we are just too busy to do our normal amount [of] work, and we make sure to be cool about this and distribute work accordingly. No one is high-strung or over controlling, so we work together pretty smoothly.*
> -Woman, marginalized race, non-transfer

The above students spoke about a more dynamic collaborative effort, wherein collaboration was not measured by static contribution across the program, but rather contribution wherein members distribute responsibilities by taking into account students' personal lives and skill-set. We note here that students needed to be comfortable with communicating with each other and understanding each others' interests and importance of personal lives to be able to do this kind of collaboration.

Other students, however, did not have this kind of experience when it came to collaborating. 11 students mentioned that their team, in general, ineffectively divided the work, while five mentioned that dividing the work specifically into individual tasks had a negative impact on their experience. The following quote, taken from a response to "What suggestions do you have, if any, on what would have made your team function better?", illustrates this latter idea:

> *I think one suggestion would be a set time for getting group work done. At this point it has become 4 individual projects and it would be nice to be able to do this together!*
> -Man, marginalized race, transfer

This student feels that the independent nature of the division of tasks detracted from true collaboration and the student would have preferred more time working together as a group.

In response to "Does your team help or hinder your feeling of belonging in computing?", a student wrote:

> *I feel so uninvolved with this research that I do not feel that I am contributing to the computing aspect either. The main part of our [research] was already completed so now when I am adding little features I often do not know what certain components do. We don't ever code all together so it doesn't affect how I feel as a programmer.*
> -Woman, marginalized race, non-transfer

In this case the sequential and independent nature of the division of labor makes the student feel that she is not truly contributing to the project. Interestingly, she ties her emotions as a programmer to pair-programming or coding together, so the disconnect from her team members causes the student's feelings as a programmer to remain unchanged.

6.2 Scheduling of Meetings

We correctly anticipated that coordinating research meetings would be difficult for ERSP participants. Several students mentioned meeting scheduling in their responses to the open-ended survey questions about belonging and support.

Of the 15 students who mentioned scheduling and attendance of their group meetings as factors that affected how their group supports them, five students mentioned that teammates would miss meetings or it was difficult to schedule meetings in the first place. One student reported (emphasis added):

> *Two members on my team say they are too busy to meet some days, a couple times they have not responded to my messages and* ***left me hanging on a few meetings that they said they would come to.****...I really enjoyed working with them and I thought that these were all small issues that we could resolve internally.*
> -Woman, majority race, non-transfer

This student reported feeling "somewhat supported" by their team, and seems to view this support from two sides. Although her team members "left [her] hanging," because she "enjoy[s] working with them" she feels this is an issue the team can overcome.

Conversely, 10 students mentioned that they were able to schedule meetings or that teammates would regularly attend meetings. In at least one case, meeting regularity improved over the course of the program. One student reported in the first survey that in the future she wants "more meetings where everyone can attend." Then in the second survey she reported:

> *My team consistently meets on Fridays at 5pm. We update each other on what we are doing and try our best to give help.*
> -Woman, majority race, non-transfer

In response to the Likert scale question about group function, this student increased her answer from "Just OK" on the first survey to "Pretty Well" by the end of ERSP, which could in part be due to the students being able to find a consistent meeting time in their schedules.

6.3 Communication

Finally, communication was a common topic we saw in student responses to open-ended questions. Most of the time, communication was discussed as a positive. 21 students explicitly mentioned their team had good communication, with two of these students additionally attributing this to responsive teammates. Four students explicitly mentioned poor communication amongst group members, but stated that this was not a major obstacle and reported that their group still helped with individual tasks. One of these four students reported:

> *My team helps me when I am stuck on different bugs. However, we are not very communicative about the tasks that we are doing and ways that we can contribute.*
> -Woman, marginalized race, non-transfer

Another student reported:

> *There have been instances of protracted "radio silence", so to speak, and consecutive absences from meetings. I understand that people may be experiencing issues outside of [ERSP], and I would rather not comment on their behavior.*
> -Man, majority race, non-transfer

For this second student, this lack of communication was clearly an issue, but they appeared hesitant to speak negatively of teammates who did not communicate well, empathizing with their teammate's situation.

6.4 Summary

Logistics driving students' group work had a surprising impact on their evaluation of how their group affected their sense of support or belonging. Students gave their own insights into how dividing labor at times was successful (making accommodations based on relative availability, contributing to a sense of support) or was unsuccessful (feeling uninvolved with the group or project, with varying effects on the students). Others remarked on their research meeting experiences, with some citing difficulties with meeting scheduling or attendance (at times affecting their sense of support) and others remarking on the successes of their meetings (with varying effects on sense of support and belonging). Finally, students spoke about the communication between teammates, with some stating their teammates had strong communication skills and others stating that the poor communication present was not a major obstacle for their group and thus did not have a large impact on their sense of belonging or support.

7 DISCUSSION

In this section we summarize our results to answer our research questions outlined in Section 3, advise why and how future UREs should incorporate group work, and discuss the potential limitations of our study.

7.1 RQ1: How does working in a research group in this context affect students' sense of belonging and support in computing?

Groups provided a supportive environment through bonding over common feelings and, at times, bonding through a shared minority identity or recognizing the diversity of their teammates. Support went well beyond help with the research project; teammates provided each other academic support in their classes, career and internship advice, and most prominently, emotional support. The feeling of support seemed to be related to a feeling of trust that their teammates would show up and participate in the work. Some students reported feeling less support when their teammates missed meetings or posed difficulties with scheduling (Section 6.2).

Separately, students reported a sense of belonging being tied to their personal comfort within their group environment. This comfort came in the form of being able to ask questions, ask for help, admit to making mistakes, be open about opinions, workload, and feeling as though ideas and opinions are truly heard.

The tendency for participants to compare themselves to other students in their groups was common. For some students, this tendency made them feel that they were not able to ask questions or ask for help because they believed they lacked the knowledge or experience they perceived their teammates had. However, for other students, this difference was merely observed and did not affect or even had a positive effect of their group experience (Section 5.1).

Returning to our theoretical framework around belonging, we found that these stable research groups successfully provided a mechanism for students to find connection and belonging within a large university. Interestingly, while the context of the group experience (research) was fundamentally in line with the core culture of the university—perhaps suggesting that students would learn to adapt to this culture as suggested by Tinto [43]—in many cases students' sense of belonging seemed to stem from the ways in which their groups were apart from the dominant culture. Consistent with the findings of Hurtado and Carter [23], the fact that the group composition did not look like the typical composition of their CS courses was important, and provided a safe place for students to learn to navigate the dominant culture of not only their research but also their classes and career preparation.

7.2 RQ2: What are the successes and struggles of working in small groups in a computing URE?

Groups in ERSP seemed to function well, with most students reporting a successful division of labor and equal contributions from team members. Students valued working together, and expressed concern when they could not see how their work fit in with the rest of the team (Section 6.1). This finding echoes previous results around pair programming, which have found that disparate prior experience levels can negatively affect students' experiences with pair programming [12, 17, 25, 26]. Yet unlike in this previous work, in our study most groups seemed to navigate these imbalances well, perhaps due to the fact that the group relationship was sustained over a long period of time, or because of ERSP's strong mentoring structure, which helped groups work through issues such as these.

Further, meetings were a key component of successful group work. Not only was it important that students felt comfortable in their group meetings, but these meetings needed to happen on a regular basis. When teammates missed meetings, were difficult to schedule with, or were generally unresponsive, group dynamics and satisfaction broke down (Sections 6.2, 6.3).

7.3 RQ3: Do these experiences vary based on demographic factors and group composition?

Some experiences do appear to vary based on demographic factors. Consistent with Barker's findings [5], group composition seemed to be an important factor, especially for students who identify as women. They frequently linked group comfort to their shared sense of identity with their women teammates, which stood out as different from their "normal" CS experience. We also saw that women in all-women and majority-women groups were less likely to report that they felt a knowledge gap between themselves and their groups compared to women in gender balanced and majority-men groups. This finding could help explain why the CREU and DREU programs are so successful, as these programs also focus on building groups around shared identities, including shared gender identities. Other demographic differences were less prominent, but our results suggest that students from marginalized racial and ethnic groups might receive different kinds of support from their team than students from majority racial groups (Section 5.2).

7.4 Suggestions for Group-Based Research

Based on our results, we provide the following suggestions for running a successful group-based research program in computing.

- Group composition is important. Women students in particular value the comfort and support that come from working with other women. The same may be true for other marginalized identities, particularly if students have an opportunity to connect with their teammates around these identities.
- Help students manage the feelings that emerge when they compare themselves with their teammates. Remind students that each member comes from a unique background and each team members' relative knowledge is something to learn from, not feel discouraged by. Help students see that this tendency to compare (and come up lacking) is common, and allow them to bond over these common feelings. Remind students that the success of their group is dependent on their collective knowledge and experiences, not each student individually.
- Set an expectation of support beyond the research project. Communicating the expectation that teammates should support each other not only with their research, but also with their classes, careers, and personal lives will help all students both provide and take advantage of these supports.
- Ensure students work *together* and that each student sees their contribution to the larger project.
- Make meetings a priority. Establish a structure and expectation for regular meetings between team members outside of meetings with their advisor, and make sure these meetings happen.

Although we studied groups in the context of research, we believe many of these suggestions will generalize to group work in computing more generally.

7.5 Threats to Validity

Most of our threats to validity arise from the nature of qualitative research. First, as discussed in Section 3.4, this work can be biased by the experience of the researchers. Second, although we used formal coding processes to ensure that our codes would not be specific to any one researcher, there is a risk that they are not general enough that others would not be able to learn and apply our codes. Third, much of our analysis came after the coding process was finished, when we looked for patterns in the codes. It is possible that different trends would have stood out to different researchers. Fourth, our data comes from student self-reports, and it is difficult to know why students did or did not mention something as important. Using our approach, we can only conclude that a trend exists when enough students discuss it; we cannot assert that trends do not exist, or how widespread a pattern actually is.

It is also possible that these results will not generalize to other group-based research or group-based project settings. Our study was done on a single program at two similar universities. Future work is needed to see if the patterns we observed apply in other settings.

7.6 Impact of COVID

In total, all three of our cohorts experienced the pandemic during ERSP, with the 2019-2020 cohorts experiencing the pandemic and remote research at the end of the program and the 2020-2021 cohort experiencing the pandemic and remote research throughout the program. We see nothing notable in the responses that suggests there are any COVID-specific benefits or challenges for any of the cohorts.

8 CONCLUSION

The results presented help us understand how undergraduates experience working with a group in a computing research experience. While there is more to be studied about group work in computing research, we hope that these results will encourage others to adopt a group-based approach to their UREs to both improve the experience for students in these programs and to engage more early undergraduate students in computing research.

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