Exploring Team-Based Undergraduate Research to Expand Opportunities

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Abstract

For undergraduate students, research is a highly transformative and in-demand experience. It is also an especially important experiential marker for graduate school admissions in addition to being a valuable alternative work experience for those pursuing industry positions. Research is therefore popular with a wide variety of students. At institutions where graduate students advise mentees one-on-one, however, the number of mentors and their bandwidths directly limit the opportunities for undergraduate students to participate. To expand the availability of mentors, and open opportunities for undergraduate student research, we wanted to assess whether organizing undergraduate students into teams of 3-5 per research project with a high student to mentor ratio is an effective strategy. While the benefits of team-based instruction are not unknown to pedagogy, no study on its measurable effects with respect to undergraduate research has taken place. To address this, we surveyed students as well as mentors who participated in similarly organized research to study the 'cost-benefit' of this team-based mentorship strategy. Overall, creating team-based undergraduate research experiences lowers the per-student workload that mentors undergo while maintaining or improving the quality of the experience. This organizational strategy is worthwhile to adopt for programs and institutions of any size as teamwork between students is beneficial for meeting a wide range of educational objectives beyond increased access.

Keywords: Group Dynamics/Teams, Undergraduate Research, Student Outcomes

Introduction

Undergraduate research experiences are a common and critical service offered by academic institutions. These experiences come in all types from the federally funded NSF's Research Experience for Undergraduates (REU) programs [1], which are typically full-time during a summer term, to part-time and uncompensated research during the regular academic year. Regardless of funding or commitment, these experiences can not only be a student's first introduction to pursuing a graduate degree, but also serve as an important experience that builds critical skills [2], improves engagement in their field and department [3], and supports students despite challenging academic expectations [4], [5]. This support is critical, especially for under-represented students who routinely have lower retention within STEM, which undergraduate research has proven to be significantly effective at combating [6]–[10]. Because of this, undergraduate research experiences are widely beneficial concerning traditional and nontraditional metrics for student outcomes both in and out of the classroom [2], [11].

Arguably, the most important factor for students' success in a research experience is the quality of the mentorship they receive [10], [12]–[14]. This mentorship structure varies greatly between mentors, labs, and institutions. At primarily undergraduate institutions (PUIs), it is much more common to find direct relationships between faculty mentors and undergraduate students [15], [16], while larger universities primarily have graduate students help step in to fill the role of a mentor [10], [17]. For PUIs, it is often a necessity that faculty oversee several undergraduate students at the same time given the ratio of students interested in research to faculty. It is in these situations that a large degree of agency is given to more senior undergraduate students as part of a lab organizational framework, which has been described in literature across disciplines [18]–[21]. In contrast, larger universities with a robust graduate population more commonly employ one-on-one mentoring strategies with graduate students having no more than a few mentees at a time [22]. Faculty can have various levels of involvement in mentorship at these institutions resulting in a fluid mentee and faculty-graduate student triad relationship [23]. Graduate students in this relationship bring their own complex motivations and apprehensions towards mentoring [22]. It is seen both as an incredibly valuable professional and personal experience [24], while the time commitment is also acknowledged as a significant barrier for graduate student mentors [22].

Of the various soft skills that employers value from engineering graduates, effective teamwork and collaboration consistently rank among the most desirable [25], [26]. To meet this need, quintessential to engineering education, is the engineering capstone project that many senior engineering students take part in [27]–[29]. Efforts in the classroom to improve collaborative soft skills are numerous in engineering education [30], and many research labs have employed similar organizational structures for both productivity and student development [18]–[21]. Teaching and research institutions have their respective challenges associated with undergraduate research, but both can benefit from improving their student populations' access to undergraduate research opportunities.

Over the past two decades, the number of science and engineering (S&E) bachelor's degrees awarded in the United States has nearly doubled while the number of S&E doctoral degrees awarded increased only modestly [31]. These doctoral graduate students assume the majority of the mentorship responsibilities for undergraduate student research at larger universities [32], [33], thus decreasing graduate student populations will ultimately result in undergraduate students having decreased access to research opportunities. This issue is only expected to worsen in the coming years as funding continues to be uncertain for graduate student researchers [34]. Maintaining undergraduate access to research will therefore require having graduate student mentors oversee more mentees. With traditional one-on-one mentorship as it is typically practiced in collaboration with a faculty member, significantly increasing graduate student mentorship workloads is untenable and unpopular [13], [22]–[24], [32]. Many graduate student mentors cite some of their largest apprehensions towards mentorship are the impact it will have on their productivity or their decreased ability to mentor effectively when overworked [22]. Solving this challenge will require improvements in the efficiency of mentorship in undergraduate research such that mentors are able to oversee additional students without excessively increasing the workload that it demands.

To increase access to undergraduate research opportunities, organizational strategies that make better use of limited mentor resources, while still providing the same or better educational opportunities, are highly desirable. Herein, we described our experience employing a simple team-based strategy with a high student-to-mentor ratio that enables a research lab to support many more undergraduate students without significantly increasing the mentors' workload. We find that using a team-based method resulted in dramatic improvement in workload compared to an equal or even lesser number of individually mentored students. Additionally, we survey undergraduate and graduate students in our department and find no significant link between the self-reported quality of their experience and the number of students their mentor oversaw. Even for a low sample size, this finding suggests that teams of undergraduate student researchers have a similar experience to their peers mentored one-on-one and could be a viable strategy for continuing to provide undergraduate students access to high-quality research opportunities.

Methods

Survey

This study sought to investigate the impact that teamwork between mentees, and a high ratio of mentees to mentors, has on a mentee's self-rated outcomes of their research experience using Likert scale questions [35]. The full survey is listed in the appendix in Tables 1A-F. The study was submitted for IRB determination and was determined to be exempt by the University of Washington's Human Subjects Division (HSD) per classification as an educational test, survey, interview, or observation of public behavior. The survey was fully anonymous and voluntary, and quantitative and qualitative data from the survey was analyzed in aggregate.

The survey was disseminated to all undergraduate and graduate students belonging to the University of Washington's Department of Chemical Engineering, an R1 university in the United States of America. The survey took approximately 10-15 minutes to complete and was disseminated at the end of the Autumn quarter. A flow chart of the survey structure can be found in Figure 1. Of the 47 participants, 7 indicated they had never participated in undergraduate research in any capacity and were directed to the end of the survey. The remaining 40 participants were asked to answer questions based on their most recent experience of either being a mentee or a mentor during an undergraduate research experience. Graduate students that had participated in undergraduate research as a mentee but not as a mentor were only asked to answer questions about their most recent experience as a mentee. Undergraduate student participants were asked only about their most recent experience as a mentee. The majority of the participants answered questions about their most recent experience as an undergraduate student mentee (N=29). Of these students, 5 participants were graduate students with no mentorship experience that were asked to recall their most recent undergraduate research experience. The remaining participants (N=11) were identified as graduate students with mentorship experience and were asked questions regarding their experience as a mentor. Of the 11 mentors, 3 stated they had mentored a team of undergraduate students, defined as "…2 or more students who frequently collaborate with one another as they meet their research goals". The remaining 8 mentors had only mentored students one-on-one.

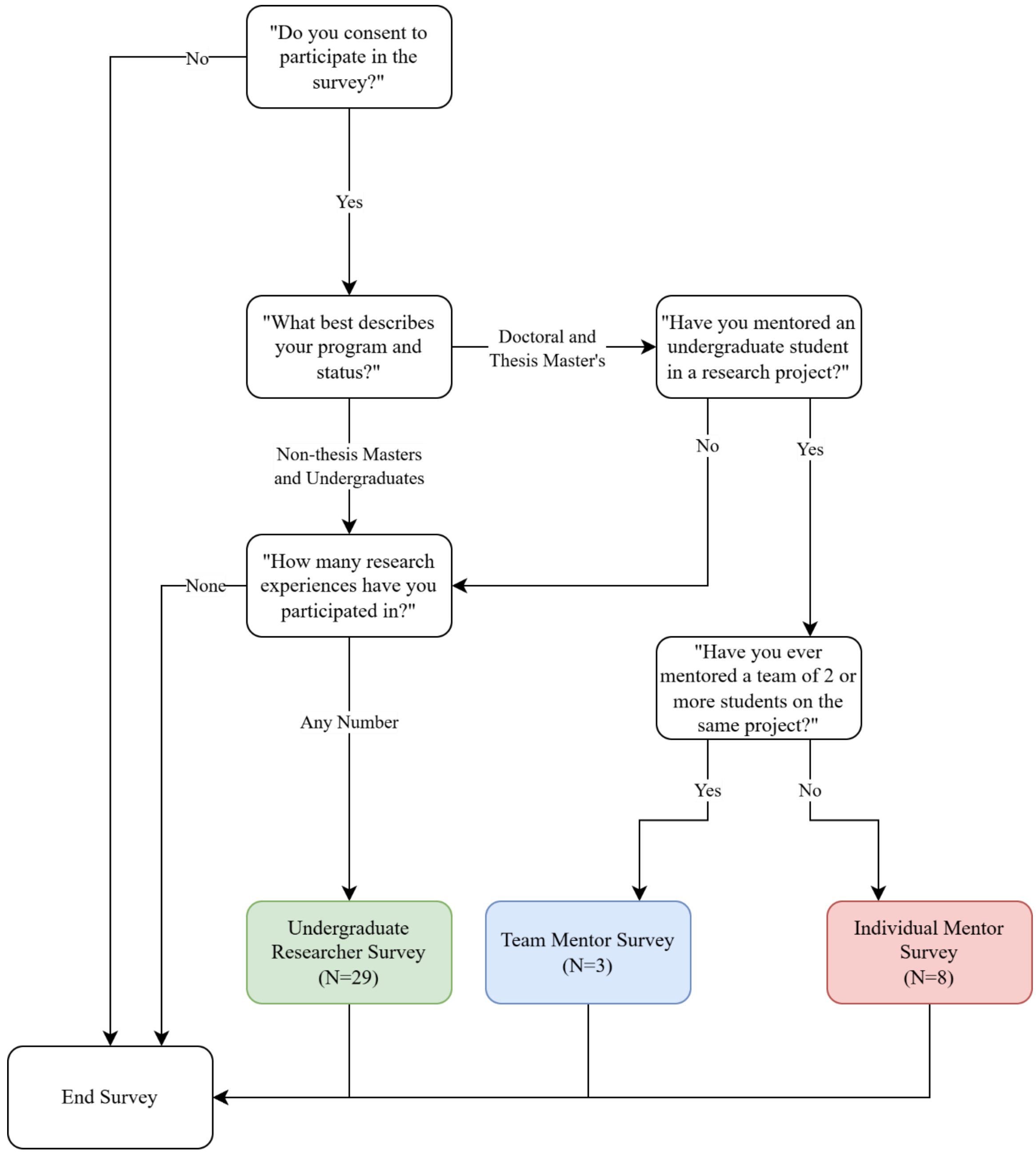

Figure 1: Survey flow chart. Participants began the survey with the question "Do you consent to participate in the survey?" Out of the 47 participants, 40 were identified as having engaged in undergraduate research as a mentor or mentee. The colored boxes indicate the number of participants (N) that participated in each survey.

Likert scale questions had participants rate their level of agreement for statements that fell into three broad categories: educational outcomes, personal and professional gains, and mentorship quality. The scale options in order were Strongly Disagree, Disagree, Neither Agree/Disagree, Agree, and Strongly Agree. The educational outcome questions sought to understand the mentees' perceived improvement in skills that are typically valued in the field of research, such as oral communication, written communication, designing and independently following a research direction, and reading comprehension of technical works. The personal and professional gains questions evaluated qualitative, identity-related, and professional or developmental outcomes rather than concrete research outputs. These items captured mentees' perceptions of belonging, autonomy in their work, enjoyment of research, self-confidence, and changes in interest or career priorities resulting from the experience. Finally, mentees were asked about the quality of the mentorship they received with questions centered around their mentor(s) effectiveness, level of communication, and investment towards them. These Likert scale questions can be found in the appendix in Table 1C.

Due to the incredibly varied and amorphous nature of teamwork and mentorship organization that can be found in undergraduate research [20], [36], [37], binary questions intending to identify mentees that worked on a team during their research experience were expected to be ineffective. Instead, mentees were asked general questions about how often they engaged with their peers and how many students their mentor had during their research experience. Questions such as "How often did you meet or work with your PEERS during your specific project?" and "How many of your peers did your mentor work with on your project?" were used to try to avoid misinterpretation by the participant when lines begin to blur of what constitutes a "team" of students. This framing also avoids a scenario where a student might formally have been on a team but would have rarely performed collaborative work with their peers.

Mentors were asked a shorter list of Likert scale questions meant to understand perceptions of student progress, mentoring dynamics, and the professional value of their mentoring role. These items assessed mentors' views on the extent to which their mentees developed research skills (e.g., communication, independence, engagement), as well as mentors' perceptions of the mentee's motivations and future research intentions. The questions also examined mentors' experiences of the mentoring relationship itself, including enjoyment, perceived burden or productivity costs, the quality of mentor-mentee connections formed, and the extent to which the experience contributed to their own professional development and growth as mentors. Finally, several items probed mentors' attitudes regarding individual versus team-based mentoring arrangements, aiming to understand how mentors evaluate student performance, learning, and manageability across the two mentoring structures.

It should be noted that some of the students that participated in the survey may have done so after participating in an intentionally organized undergraduate research experience that placed the students into teams to intentionally require teamwork. This organizational strategy is described later. The voluntary and anonymous nature of the survey means that this study does not directly interrogate the effectiveness of our specific mentorship organization approach.

Results

Mentee survey responders captured a range of research experiences

Of the mentee participants (N=29), 58.6% reported using she/her pronouns while 41.4% used he/him most frequently. The students were largely in their 3rd and 4th year, 44.8% and 31%, respectively. The vast majority were in research at the time of the survey (79.3%) and were participating in their first research experience (58.6%) or their second experience (34.5%). Every participant conducted their research in a university research lab and 82.8% were in a Chemical Engineering department. It was rare for participants to have participated in research during just the Summer (6.9%) as most participants had worked in both Summer and Autumn (41.4%) or Autumn only (51.7%). Financial compensation was also rare for participants. When asked to select all of the forms of compensation they received, 20.7% reported receiving a stipend for their work, 6.9% received housing, while 79.3% received course credit hours and 17.2% were uncompensated. When asked who they most frequently reported to, 86.2% stated they reported to graduate student mentors more frequently than a faculty member. Finally, when comparing their post-graduation plans before and after their research experience, 20.7% of participants reported switching their plans to involve graduate school.

Mentee satisfaction and sense of belonging did not correspond to frequency of mentor meeting, number of mentees their mentor oversaw, or frequency of peer interaction.

A significant portion of the mentee survey utilized Likert type questions [35]. Participants were asked their level of agreement to statements meant to probe their perceived educational outcomes, personal and professional gain, and the perceived quality of mentorship they received during their research experience. The full list of these questions can be found in the appendix in Table 1C. The responses to these Likert items were grouped by each multiple-choice question in Table 1B and 1C. Plotted as a bar plot, correlations could be identified between the responses to the multiple-choice questions and individual Likert items. In Figure 2, the Likert items are grouped with the multiple-choice question "How often did you meet or work with your MENTOR(S) during your specific project?". It was expected that mentees who worked less frequently with their mentors would have reported poorer outcomes in their research experience. However, in our population there were no such correlations. A large contributor to this likely is that only 3 participants reported meeting with their mentor less than 1-2 times a week; a more diverse population might have shown a stronger trend. Regardless, students who met with their mentors more frequently reported distributions of agreement to the Likert items "What was expected of me was clearly communicated" (Figure 2A), "I felt a greater sense of belonging in the scientific community after my experience" (Figure 2B), and "I became more confident in my ability to conduct a literature review" (Figure 2C). These Likert items were chosen out of the list in Table 1C to represent the distributions from the Likert items. These were chosen specifically because similar items are commonly used to assess the impact and quality of undergraduate research experiences in other surveys [38], [39]. Additionally, we identified similar results between these three selected Likert-demographic-question pairs and any of the other 777 combinations of every Likert item and every demographic question.

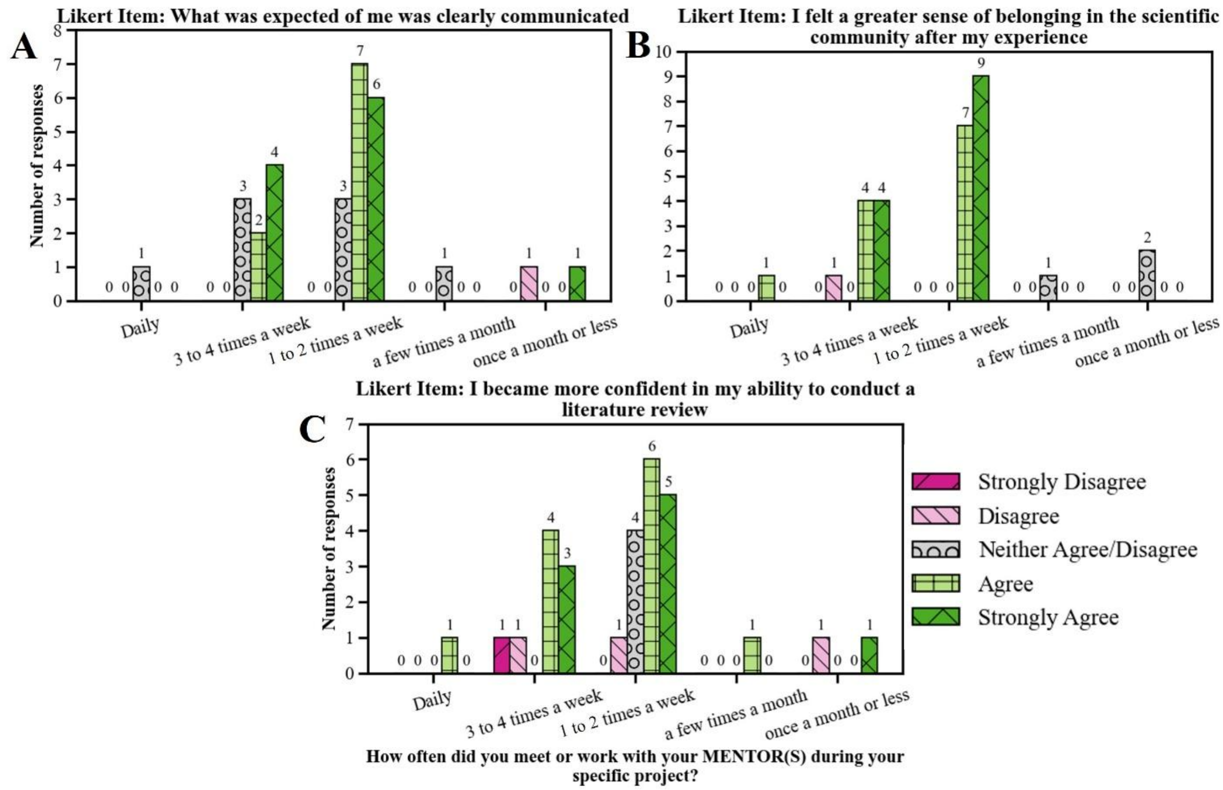

Figure 2. Mentee sentiment on research clarity and sense of belonging as a function of mentor meeting frequency. Bar plots of the number of Likert scale responses from Strongly Disagree to Strongly Agree of all mentees (N=29) sorted by a multiple-choice question about the mentee participant's frequency of working with their mentor. Likert items were chosen to exemplify common research assessments such as **A**) the communication of expectations by the participants' mentor, **B**) the participants' sense of belonging, and **C**) the participants' confidence in engaging in a common research task.

While it is, of course, unreasonable to conclude from the data in Figure 2 that a mentor should meet with their students as little as possible, it does show that there is little difference in our students' reported outcomes between a mentor being available to students 3-4 times a week compared to a mentor available only once or twice a week. The amount of time mentors spend with their students is important, but quality is evidently more important than quantity. Likewise, the number of students a mentor is assigned to also showed little to no correlation between the same three Likert items (**Figure** A-C). While not reported as a figure, the distribution of Likert responses to the questions "How many of your peers did your mentor work with on your project?" similarly had no strong correlations to any Likert items. Mentees reported that their mentors worked with a wide range of other students, from no other students to as many as 6 other mentees in total, with an average of 2.8 students per mentor. The mentees showed similar Likert response distributions regarding the communication from their mentors (**Figure** A) and their sense of belonging (**Figure** B). Some mentees advised by a mentor with fewer students, however, reported not being as confident at conducting a literature review as their peers (**Figure** C). Similar Likert items however did not show the same distributions, which may indicate this as an interesting outlier. Literature review is a time-consuming process for mentor and mentee, and an explanation for this trend might be that a mentor with fewer mentees is more inclined to conduct a literature review for their mentee than a mentor with more student projects to manage.

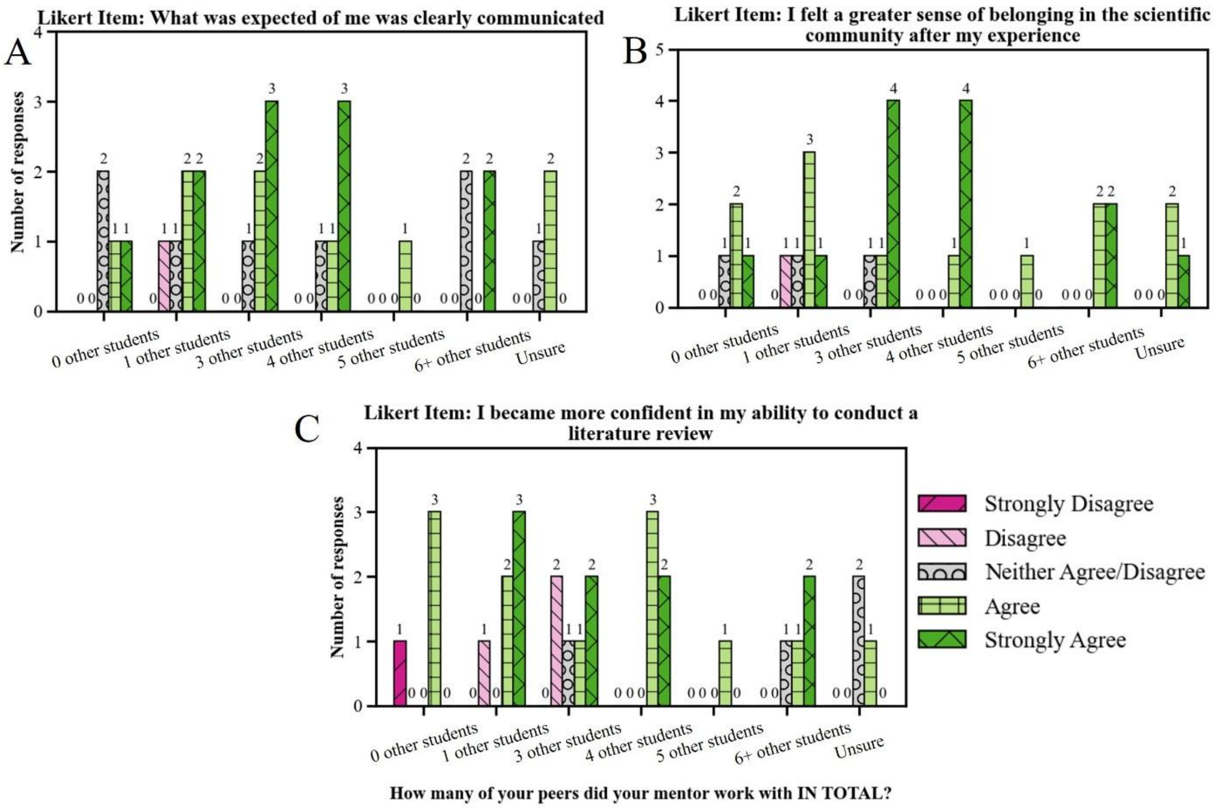

Figure 3. Mentee sentiment on research clarity, sense of belonging, and confidence in literature review as a function of number of mentees their mentor oversaw. Bar plots of the number of Likert scale responses from Strongly Disagree to Strongly Agree of all mentees (N=29) sorted by a multiple-choice question about how many mentees the participant's mentor oversaw in addition to themselves. Likert items were chosen to exemplify common research assessments such as **A)** the communication of expectations by the participants' mentor, **B)** the participants' sense of belonging, and **C)** the participants' confidence in engaging in a common research task.

On average, the number of students a mentor advised did not drastically affect the reported quality of the participants' research experience. Similarly, the amount that mentees engaged with their peers on their specific project showed equally little correlation between the other Likert items in appendix Table 1C. For the three representative Likert items, the distributions all trended towards agreement (Figure 4A-C). Interestingly though, the participants that answered with the least agreement to the Likert item "what was expected of me was clearly communicated" all reported they met with their peers once a month or less. Half of these participants answered with either a Disagree or a Neither Agree/Disagree. It was unexpected that the amount of peer support would affect a Likert item written to probe the quality of communication from the mentor. It is possible that having greater interaction with a mentee's peers would help fill in the gaps left by their mentor when it came to helping students develop a research direction or expectations.

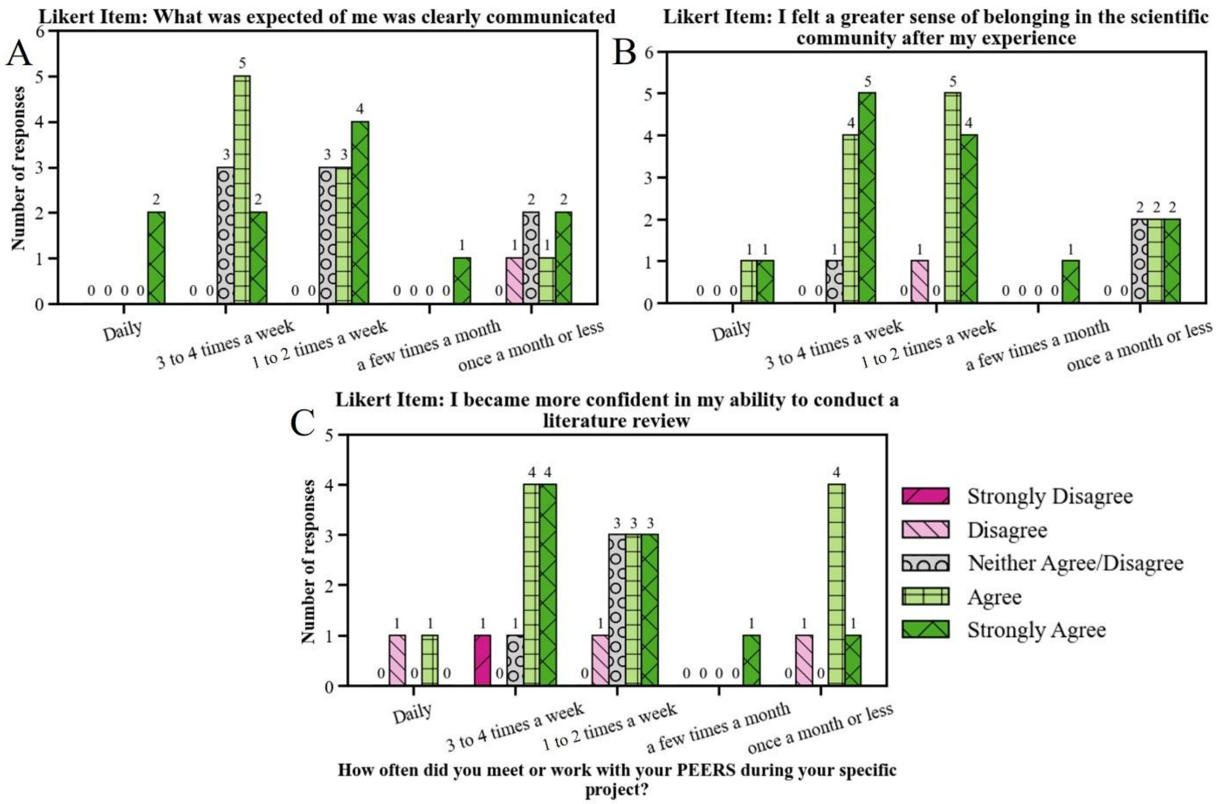

Figure 4. Mentee sentiment on research clarity, sense of belonging, and confidence in literature review as a function of frequency of peer interaction. Bar plots of the number of Likert scale responses from Strongly Disagree to Strongly Agree of all mentees (N=29) sorted by a multiple-choice question about how often the mentee participant worked with their peers during their research experience. Likert items were chosen to exemplify common research assessments such as **A**) the communication of expectations by the participants' mentor, **B**) the participants' sense of belonging, and **C**) the participants' confidence in engaging in a common research task.

The multiple-choice question in Figure 4A-C, "How often did you meet or work with your PEERS during your specific project?", was preferred in place of a more straightforward question such as "Were you part of a team in your most recent research experience?". Anecdotal interviews with other graduate student mentors and faculty within our department indicated that while research "teams" were present outside of our lab, they were often incredibly amorphous and fluid depending on the nature of the work being conducted. A student might be assigned to work on a team with a peer yet rarely interact with them and often meet with their mentor separately. A student might also not define their situation as team-like yet regularly share information with a peer and meet with a shared mentor at the same time. Because of this, multiple-choice questions, like those in Figure 2-4, were used to examine strong indicators of team-based research rather than relying on participant interpretation of what constitutes a team.

The indicators we questioned participants on were how frequently they work with their peers, how frequently they met with their mentors, and how many other mentees their mentor was assigned. Comparing these indicators to participant's Likert responses showed no significant trends between how participants were mentored and the educational outcomes, personal and professional gains, and mentorship quality that a participant reported. This leads us to conclude that a team-based organizational structure, one that assigns multiple mentees to a single project under the oversight of a single mentor, would be just as beneficial for undergraduate students as traditional one-on-one mentorship.

Mentee autonomy is correlated with mentor quality and team size

While the questions in Figure 2-4 did not demonstrate significant correlations, there was a surprising trend between the overall rating participants gave to their mentor and the degree of agency participant's felt they had with respect to their research. We asked mentees to rate their experience with their faculty mentors and their graduate student mentors along the following scale: Very Poor, Poor, Neutral, Good, Very Good. Participants gave their graduate student mentors a higher score on average with 96.1% rating their graduate student mentor as Good or Very Good, while 85.7% rated their faculty mentor as Good or Very Good. When grouped with the responses to the Likert item "I got to choose the techniques I used in my research" (Figure 5A and 5B) and "I got to choose the direction I took in my research" (Figure 5C and 5D) there was a clear positive trend. Participants that rated their mentors as Very Good agreed, on average, that they were given autonomy to choose their research direction and the techniques they used in the lab. Meanwhile, participants that rated their participants as Good or lower on average disagreed with the statement.

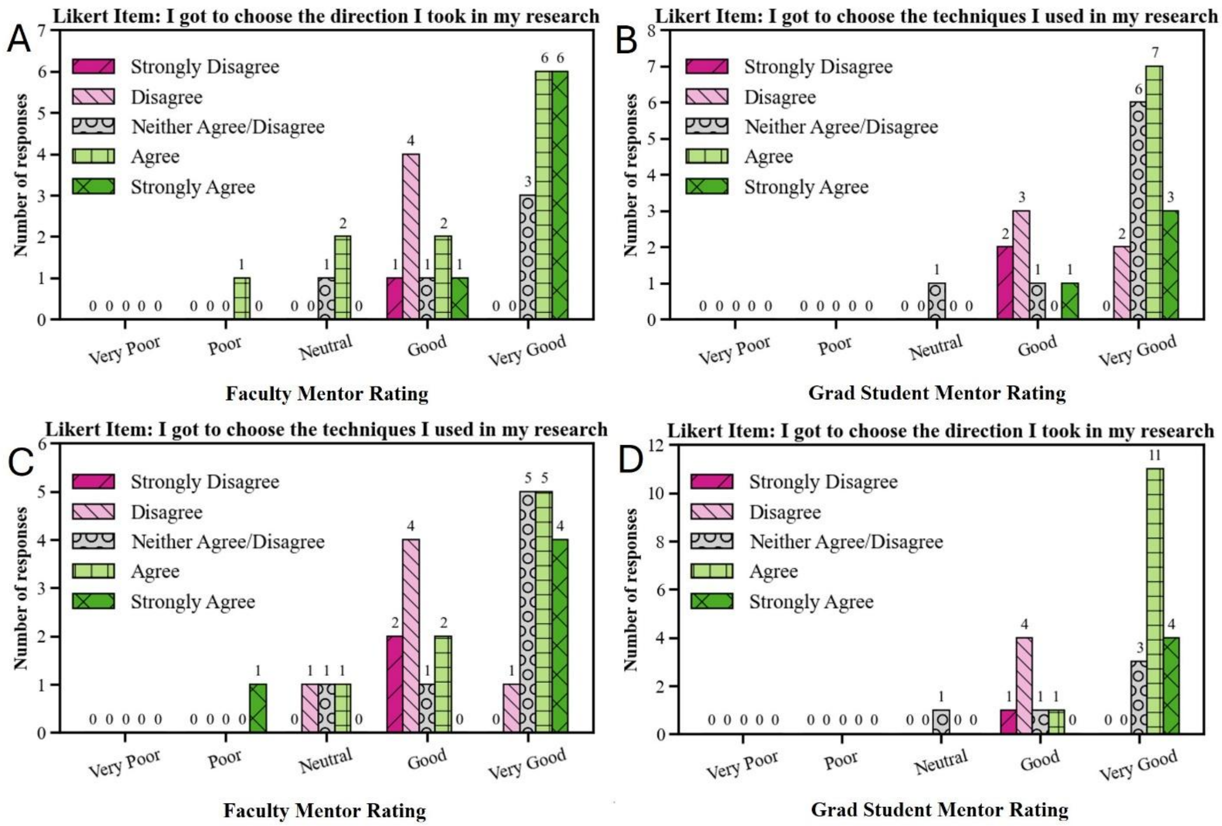

Figure 5. Mentee autonomy as a function of satisfaction with mentorship from graduate student and faculty mentors. Bar plots of the number of Likert scale responses from Strongly Disagree to Strongly Agree sorted by a multiple-choice question asking participants to rate their faculty and graduate student mentor(s). Likert items asked participants to rate their agreement with **A**) choosing the techniques they used in their research sorted with faculty mentor ratings, **B**) choosing the techniques they used in research sorted with graduate student mentor ratings, **C**) choosing the research direction with faculty mentor ratings, and **D**) choosing the research direction with graduate student mentor ratings.

The trends between the autonomy Likert items and select multiple-choice questions were noticeable. In addition to the positive trends in Figure 5, there was a noticeable negative trend between the same two Likert items and the multiple-choice question "How many of your peers did your mentor work with on your project?" where participants answered that they had less autonomy when their mentor worked with more students (Figure 6). Independence is undoubtedly an important skill and experiential marker in undergraduate researchers [40], and feelings of autonomy are tied to student's confidence and motivation [41]. It is possible that students advised as part of a team felt that they participated less in the team's direction than students working alone, which would not be surprising. However, since the surveyed population was smaller, it could also be that the students who said they had less autonomy were all advised by the same mentor.

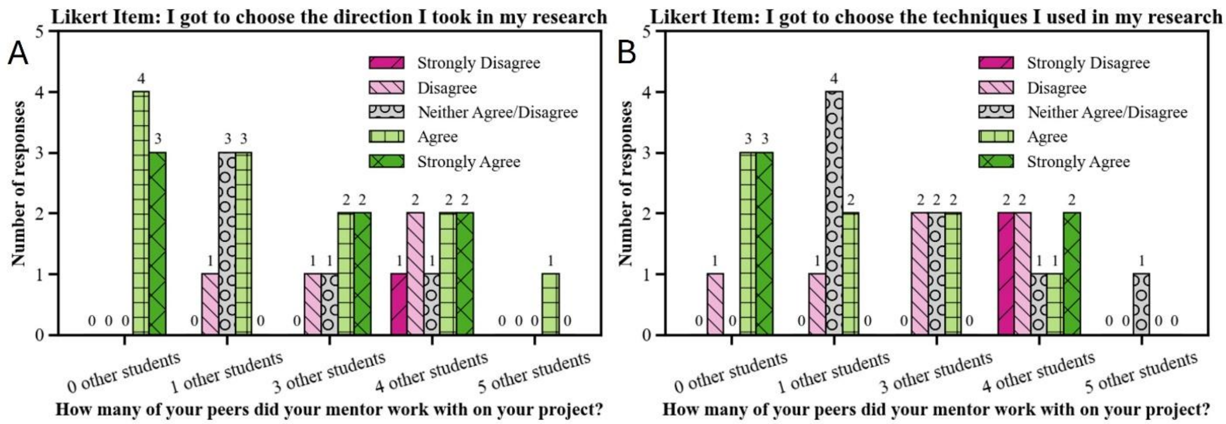

Figure 6. Mentee autonomy as a function of the number of peers assigned to the mentee's research project. Bar plots of the number of Likert scale responses from Strongly Disagree to Strongly Agree sorted by a multiple-choice question asking participants how many peers their mentor worked with on their research project. Likert items asked participants to rate their agreement with **A**) choosing the techniques they used in their research and **B**) choosing the research direction.

Graduate students who mentored teams preferred teams over individual mentorship experiences

It is undoubtedly important that if a team-based organization for undergraduate student research is followed that the mentees have an equal or better experience. Intrinsic to this is the quality of mentorship the students receive. At larger universities, this involves making sure the graduate student mentors are well supported and see the value of their labor. If graduate students did not prefer the team-based organization, then their performance as a mentor would suffer. Of the graduate students we surveyed, 11 stated that they had mentored at least one undergraduate student, and 3 of those stated that they had mentored a team of undergraduate students. The 11 mentors were asked a set of multiple-choice questions (appendix Table 1D), Likert scale items (appendix Table 1E), and optional open-ended response questions (appendix Table 1F). The Likert scale items in appendix Table 1E were given as-written to the one-on-one mentors while the team mentors had some of their questions worded to be specific to their experience mentoring a team for clarity.

From the survey, we saw that once graduate students were given the opportunity to mentor a team of students, they preferred it over individual mentorship. In Figure 7, the Likert responses for the two groups, team mentors and one-on-one mentors, were mapped to numbers (1 for Strongly Disagree to 5 for Strongly Agree) and averaged to be plotted in a box and whisker style plot. Individual mentors on average answered Neither Agree/Disagree to the Likert item "I would prefer if my student(s) were able to work together on a team" while the team mentors on average Agreed with the Likert item "I prefer working with students on a team". It is understandable that mentors who are likely used to one-on-one mentorship would be apprehensive about changing the structure they are used to, but once given the opportunity, the students we surveyed preferred it.

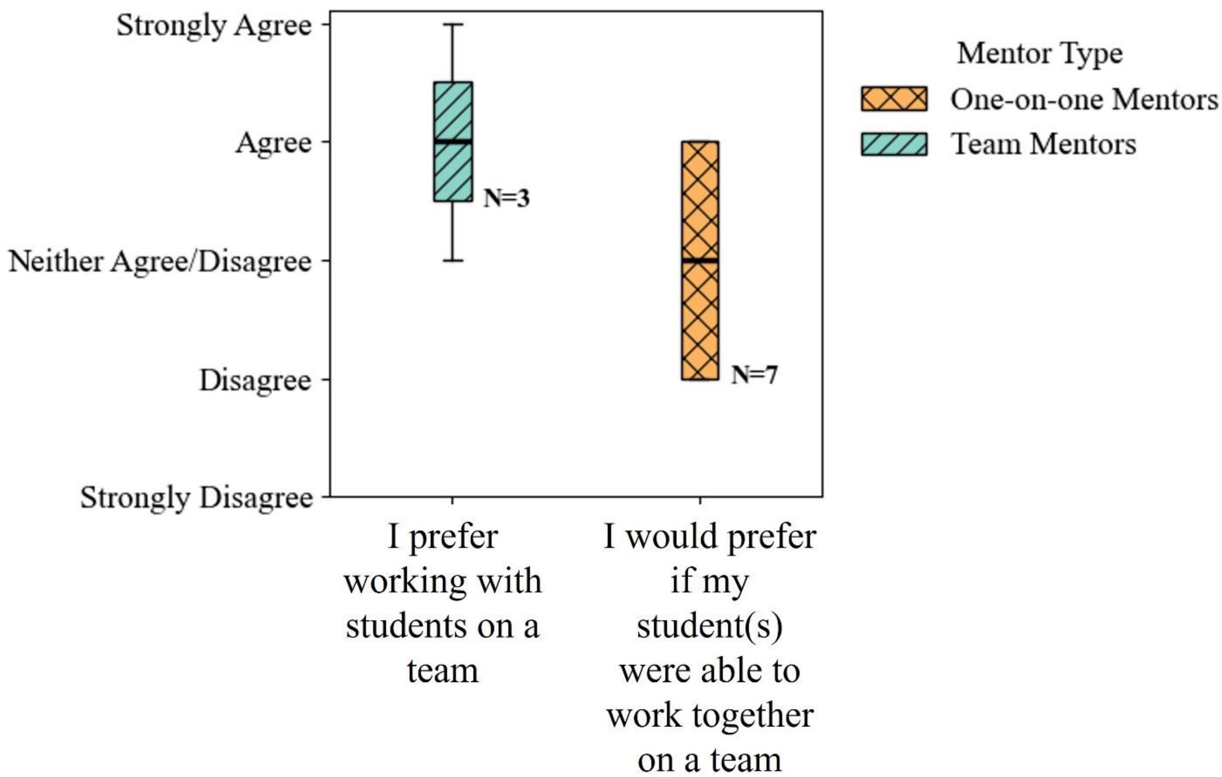

Figure 7. Graduate student mentor preference for team versus individual mentoring. Box and whisker plot of responses to a Likert item from mentors (N=11, 1 abstained) who oversaw student(s) one-on-one (orange) and on a team (blue-green). The label on the X-axis is the Likert item given to that individual group of mentors. The thick black line marks the median.

In addition to preferring to work with a team rather than individual students, once given the chance mentors also stated that they felt their students learned more and performed better when they worked as part of a team. In Figure 8, the averaged responses to the Likert items on student learning and performance given to team mentors and one-on-one mentors is compared. Both groups were given a Likert statement pertaining to their mentorship experience so as not to prompt mentors to speculate. Team mentors were asked their agreement with the statements "My student(s) learn more working as a team than when they work alone" and "My students perform better working as a team than working alone". The one-on-one mentors were asked inversely worded statements to pertain to their experience; "I believe that my student(s) learn more working alone than if they were on a team" and "I believe my student(s) would perform better alone than if they were on a team". When it comes to mentee learning, Figure 8A shows that the team mentors overwhelmingly agree that their students learn more when they work on a team. The individual mentors' results are spread widely with a small preference to disagreement with the statement that their students learn more alone. The separation between the two distributions indicates agreement between the two groups that students learn more when they work on a team.

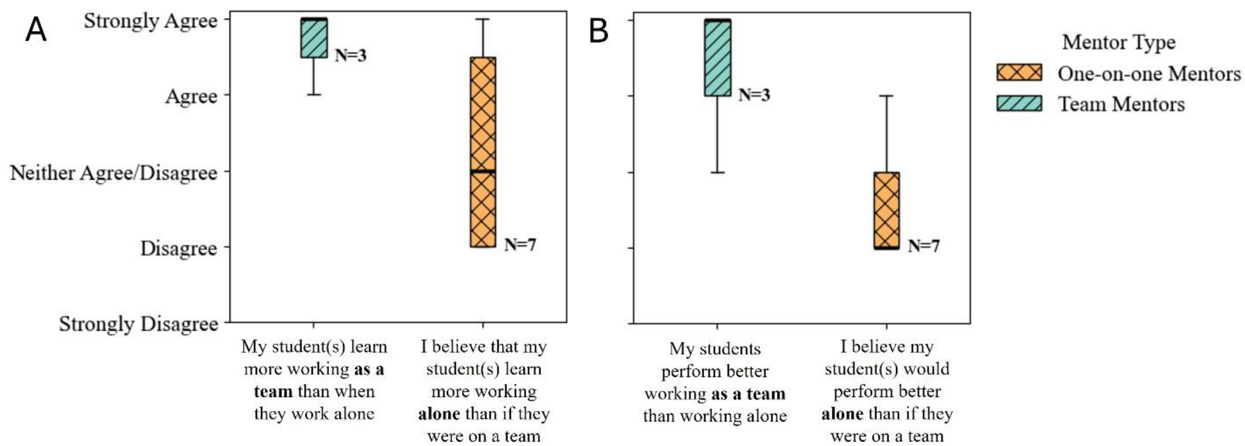

Figure 8. Graduate student mentor perception of student learning as team versus individual mentees. Box and whisker plot of responses to a Likert item from Mentors (N=10, 1 abstained) who oversaw student(s) one-on-one (orange) and on a team (blue-green). The label on the x-axis is the Likert item given to that individual group of mentors. **A**) Response to Likert type questions about mentee learning on alone and on a team and **B**) responses to Likert type questions about mentee performance. The questions asked to the one-on-one mentors are inverse from the questions asked to the team mentors, making separation equate to agreement. The black line marks the median response.

When asked about their students' performance alone and as a team, the team mentors and individual mentors agreed that they believed their students performed better working as a team than working individually (Figure 8B). The team mentors agreed with the statement that their students work better as a team, and the individual mentors disagreed with the statement that their students perform better alone. Together, these results show that team mentors are satisfied with their students' progress on a team and although the individual mentors don't have experience with a team, they are open to the idea that there can be intrinsic benefits to team-based mentorship.

Open-ended responses from mentors also gave insight into their motivations and apprehensions as it pertained to team-based mentoring. When asked about what they liked about one-on-one mentoring, responses from one-on-one mentors were not surprising. They appreciated how they could tailor the experience to meet their mentor, and how they could see their mentee develop more closely when they worked one-on-one. This individual tailoring was also related to concerns that mentees would suffer if a graduate student were unable to dedicate enough time to their mentorship. Some selected responses from the survey are included below.

> (To one-on-one mentors) What was something you liked about working with undergraduate students one-on-one?
>
> - *"I liked having time to spend working on one student's project/development at a time, I felt it could be much more effective in directing growth in certain areas"*
> - *"Working with students one-on-one is helpful to more directly see their individual growth as a researcher."*

- *"Working with them one-on-one allowed me to create a more tailored development plan with them and assign them tasks directly related to their goals. This kept them engaged with their tasks while pushing the project forward."*

(To one-on-one mentors) If you were given the opportunity to work with a team of undergraduate students, would you? Why or why not?

- *"I would consider it, but would likely decline. Our lab is too limited in resources and space and it would present a significant safety challenge. I also believe that the solution to students struggling to commit time and energy is to have them work directly with a graduate student on their own research rather than an independent/team project"*

"Maybe, if I had a project or task that would be good for a team to do. I feel like the work I have my undergrads do is typically a one person job."

Graduate student mentors also raised concerns about safety, lack of resources, and nature of the work as being a "*one person job*". In contrast, the team mentors felt that after their experience, that teams of students were actually safer in the lab, possibly due to having multiple people to support in the case of an emergency, and that students were more comfortable and less stressed performing lab work.

(To team mentors) Do you prefer working with teams of students or one-on-one with students? Why?

- *"Teams because it is less stressful for a new researcher."*
- *"Teams because it's safer and they feel more comfortable doing lab work"*

While the one-on-one mentors in our survey had apprehensions towards mentoring a team of students, the students with team experience were much more supportive. They answered with strong agreement that they felt their students performed better and learned more working on a team and wrote that they preferred teams since it was conducive to performing lab work. The mentees who experienced research where they worked with their peers frequently and were assigned to mentors who oversaw a larger number of students also showed no change in their perceived educational outcomes, personal and professional gains, or the quality of the mentorship they received. Instead, the autonomy they felt they had to choose their direction and techniques they used were more important to their experience as it relates to their overall rating of their mentor(s). Despite the small sample size, this together suggests that team-based undergraduate research opportunities are both supported by graduate student mentors after they experience it without negatively impacting undergraduate student outcomes.

Discussion

These results suggested to us that there was no significant dependence on mentorship structure in the undergraduate research experience. The frequency that students met with their peers or their mentor as part of their project, and the number of students a mentor supervised, showed no significant trend for any of the Likert items. Based on the mentee's responses, we also saw that mentees viewed mentors that gave them autonomy more favorably than those that didn't. We hypothesized, therefore, that a team-based organization where undergraduate students were supported both by their teammates and their graduate student mentor would both increase the available number of undergraduate research opportunities while retaining autonomy and optimizing a graduate student's time.

Description of team organization to facilitate team-based research projects

We employed the following strategy for organizing our undergraduate student researchers. It is very common for the authors' research lab to have many more undergraduate students interested in research than what could reasonably be handled by the small number of graduate students that are interested in mentorship. Importantly, the three research projects that each of the teams would be assigned to were defined by graduate student mentors in collaboration with their faculty PI well in advance of accepting students. These projects are characterized as very multi-faceted and require students to become familiar with common wet lab techniques and instruments, as well as open-source hardware and writing code in Python for lab-scale automation of sample preparation and material synthesis. A 1-page research description was written for each project as advertising to 2nd year undergraduate students in the Chemical Engineering department. Students were selected towards the end of Spring so that they could register for elective research credit hours in Autumn. In total, 14 undergraduate students expressed interest while 4 graduate students were available and interested in taking on students. All 14 students were accommodated by creating 3 teams, two teams of 5 students and one team of 4. A team of 5 was mentored by two graduate student mentors, while the rest were mentored by a single graduate student.

Students with interest were asked to complete a survey on CATME, a tool used for team-making and peer evaluation [42], [43], that evaluated their level of interest in the three projects, their familiarity with lab work and coding, and their availability. Prioritizing project interest and availability, students with complementary abilities and schedules were assigned to each team. Each team was mentored by the graduate student(s) that helped define the project and all teams were overseen by a single faculty PI. Graduate students met with their teams on an as-needed basis, and each team met with the faculty PI and graduate student mentor weekly for one hour. In the same document as the project descriptions, students also received the required online safety trainings from University of Washington's Environmental Health and Safety Department, learning objectives, expectations, and accommodations. The 'Expectations' that were given to students were that they enroll in 2-3 credit hours (4-6 hours of commitment), they be available for weekly meetings with their team and mentors, and that they produce a written report at the end of each quarter no more than 5 pages in length. Each team member was expected to contribute to the written report with their individual contributions that term. Students were also expected to complete a team contract following a rough template that they were free to alter.

Recommendations to develop successful team-based undergraduate research projects

Having finished a full Autumn term working with teams of 4 to 5 undergraduate students, we have been extremely impressed with the results. Anecdotally, mentors have had much less commitment compared to mentoring students individually on separate projects. In addition, students have been incredibly motivated by the team-oriented problem solving and have shown a great deal of camaraderie. To employ this organizational strategy, we identify several key factors that we believe have made our experience so successful. Most importantly, we had students apply to our lab by filling out a survey using the web-based team-making tool CATME [42], [43], and took an active role in team formation. Teams were formed prioritizing first their interest in the three projects, then their schedules, and finally their reported abilities in lab work and coding, among others. Without organizing students given their availability, the teams would be incredibly disjointed. Even so, scheduling is the most challenging aspect of having 5 students try and find a common time to work in lab.

Since the projects were defined early, we had the opportunity to tailor them so that they would be conducive to team-based research. A project with tasks that would be difficult to parallelize is not a project a team of students should be working on. The projects should involve having the students learn a mixture of skills and techniques, which we've found enable students with less confidence in certain areas to participate in their own niche at their own pace. We've found the projects in our lab to be well suited for this as they typically involve a mixture of wet lab work in the colloidal sciences, design and implementation of lab automation systems, and analysis of large datasets. These large projects are well suited for a team of 4-5 students to work on for as long as 1-2 years or until the students graduate. Since conducting safety training and onboarding multiple teams of students is so time consuming, our goal was always to retain as many students as possible throughout their entire undergraduate career. This way we hope to build up a pool of talented senior undergraduate students to help mentor more novice students in the future.

Finally, for mentors of larger teams of students, it is important that the students be given a realistic amount of autonomy rather than micromanaging their progress. We have found that our teams work their best when they are safely left to solve problems on their own without mentor involvement, promoting students to rely on one another rather than solely their mentor. Because of this, the project should be such that it would not interfere with a mentor's thesis work if it were to progress slowly or fail outright. By having the mentee's project be parallel to their mentor's thesis, rather than be a critical piece of it, it ensures that the mentor will have expertise in the subject area and still enable the students to learn independently at their own pace.

Conclusion

By surveying undergraduate and graduate students about their experiences in undergraduate research, we gained significant insight into effective ways to organize undergraduate student researchers. We find that the mentees that had research experiences with frequent peer interaction and mentors and that advised a larger number of students had similar outcomes compared to students that were advised more individually. All mentees had similar agreements with many different Likert outcomes relating to their educational development, personal and professional gains, and the quality of the mentorship they received. However, mentees who had stated they had more of their peers assigned to the same project as they felt they had less autonomy when it came to their research direction and choosing the techniques they used in lab. This autonomy also correlated positively with how they rated their mentor from Very Poor to Very Good. Together, this data demonstrates that team-based instruction is viable strategy for mentors to take, but should be intentionally designed and consider how students can be given autonomy when ready and appropriate. Mentors that had the opportunity to advise a team of students all agreed that their students learned more, were more productive, and that they preferred mentoring teams rather than one-on-one. We recommend that to effectively organize undergraduate students into research teams, the design of the projects should be tailor-made so that a team can break the work into parallel tasks. Also, it is critical that the assignment of students into the teams be intentional with respect to their research interests and schedules to be most effective. We find that team-based undergraduate research is a simple way for maintaining student access to research in the face of uncertainty by improving the efficiency of a lab's graduate student mentors.

Author Contributions

ZRW and LDP conceived of the study and developed team-based instruction. ZRW created the survey, analyzed data, created figures, and wrote and edited the manuscript. ANP, with LDP assisting, reviewed and edited the manuscript. ANP and LDP provided guidance throughout all stages of the study.

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Appendix

Table 1A. Consent

Question	Response Option(s)/Type
Do you consent to participate in this study by taking this anonymous survey?	• Yes • No

Table 1B. Multiple choice questions asked to all participants

Question	Response Option(s)/Type
What pronouns do you most regularly use?	• she/her • he/him • they/them • Prefer not to say • Other:
Which of the following best describes your current program and status in it?	• 1st year undergraduate • 2nd year undergraduate • 3rd year undergraduate • 4th (or higher) year undergraduate • Non thesis master's program • Thesis master's program • Doctoral Program

Table 1C. Multiple choice questions asked to all mentees

Question	Response Option(s)/Type
How many separate undergraduate research experiences have you participated in? Research experiences might be separated by a change in lab, field of study, or significant period of time.	• 1 • 2 • 3 • 4 or more • I have never participated in undergraduate research
When was your last undergraduate research experience?	• I am presently in research • 0-1 year ago (no longer in research) • 1-2 years ago (no longer in research) • 2-3 years ago (no longer in research) • 3-4 years ago (no longer in research) • More than 4 years ago
Where did your most recent research experience take place?	• University research lab • Medical institution • National/government lab • Other:

In which department were you affiliated with during your most recent research experience?	• Chemical Engineering • Chemistry • Materials Science and Engineering • Bioengineering • Other:
During what period did your undergraduate research take place? (select all that apply)	• During academic year (Fall, Winter, Spring) • Outside Academic year (Summer)
Approximately how many hours per week did you spend working in your most recent research experience? (Full time is 40 hours per week)	• 0-10 • 10-20 • 20-30 • 30-40 • 40+
Did you receive some form of compensation during your research experience from your department or institution in your most recent research experience? (Select all that apply)	• No compensation • Salary or stipend • Meal plan • Housing • Course credit hours
Answer the following questions about your most **recent or current** undergraduate research experience… How many GRADUATE STUDENT mentors regularly worked with or advised you on your project?	• 0 • 1 • 2 • 3 • 4+
How many FACULTY mentors (professor, staff scientist, or similar) regularly worked with and/or advised you on your project?	• 0 • 1 • 2 • 3 • 4+
Rate your experience with each category from very poor to very good, N/A means not applicable. • Grad student mentor(s) • Faculty mentor(s)	• Very poor • Poor • Neutral • Good • Very Good • N/A
Who did you report to most frequently?	• Grad student mentor(s) • Faculty mentor(s)
The following questions refer to your MENTOR(s) and your PEER(s). Your Mentor is the person who you report to who has technical expertise related to your project. Your Peers are people who have a similar level of experience as you in your project OR	• 0 other students • 1 other students • 2 other students • 3 other students • 4 other students • 5 other students

their own project. They may or may not work with you regularly, and they may or may not be your age. Answer the following questions about the mentor you reported to MOST FREQUENTLY; graduate student or faculty. • How many of your peers did your mentor work with on your project? • How many of your peers did your mentor work with IN TOTAL?	• 6 other students • Unsure
• How often did you work on your specific project? • How often did you meet or work with your PEERS during your specific project? • How often did you meet or work with your MENTOR(S) during your specific project?	• Daily • 3 to 4 times a week • 1-2 times a week • A few times a month • Once a month or less
• Before doing research, what was your post-graduate plan? • After your research experience, what was/is your post-graduation plan	• Pursuing a graduate degree • Getting a job in industry • Other:
If you did not return to your research experience, or are planning not to return, why? (Select all that apply)	• I plan to return • I graduated/left my program or institution • My graduate student graduated • My project ended/completed • My PI moved or left • I left the lab by choice because I don't enjoy research • I left the lab by choice because I had a bad experience • I left the lab by choice because I had a better opportunity • I left the lab because my research interests changed • I joined a new lab/am looking for a new lab
If you have any additional information, context, or comments you'd like to share about your research experience, please share it below. Please refrain from sharing identifiable or confidential information (optional).	Open-ended response

Table 1C. Likert scale questions asked to all mentees

Question	Response Option(s)/Type
Fill in the blank with how much you agree or disagree with the following statements as they pertain to your most recent (or current) undergraduate research experience (N/A means not applicable or does not apply). Educational goals questions • I understood my research project • I understood my research responsibilities • I made significant progress toward meeting the research goals of my project • The research experience improved my ability to work on independent research • The research experience improved my ability to work effectively as a team member • I became more confident in my ability to design a research project in my field • I became more confident in my ability to work on problems unfamiliar to me • I became more confident in my ability to conduct a literature review • I became more confident in my ability to present my research Qualitative goal questions • I felt a greater sense of belonging in the scientific community after my experience • I felt more prepared for my classes after my experience • I felt more prepared for my post-graduation plans after my experience • I felt isolated during my research experience • I felt like there was a good match between my interests and my project • I got to choose the techniques I used in my research	• Strongly Disagree • Disagree • Neither Agree/Disagree • Agree • Strongly Agree • N/A

• I got to choose the direction I took in my research • My research experience was enjoyable • I enjoy research • I want to continue doing research • Participating in industry research became a higher priority for me after my experience • Participating in academic research became a higher priority for me after my experience • After my research experience, I became less interested in research • I made valuable connections during my research experience • I am good at research • I am a good mentee Mentorship specific questions • I felt like I wasn't given enough direction to make progress • I felt scared to ask my mentor questions • I sought out support from people other than my mentor • My mentor(s) showed interest in my project • My mentor(s) was invested in the research I was/am doing • My mentor(s) was invested in my professional development • My mentor(s) did a good job advising me during my experience • My mentor(s) were instrumental in my project's progress • I felt sufficiently supported during my experience • What was expected of me was clearly communicated • I didn't rely on my mentor(s) very often • My research was an important part of my mentors thesis work	

Table 1D. Multiple choice questions asked to all mentors

Question	Response Option(s)/Type
Have you mentored an undergraduate student in a research project before?	• Yes • No
Which department do you belong to?	• Chemical Engineering • Chemistry • Materials Science and Engineering • Bioengineering • Other:
How many undergraduate students have you mentored in total?	• 0 • 1 … • 10 • 11+
How many of those undergraduate students were mentored one-on-one?	• All of my undergraduate students • 0 • 1 … • 10 • 11+
Sometimes, undergraduate student researchers work together as a team. A team may be 2 or more students who frequently collaborate with one another as they meet their research goals. How many of those undergraduate students were mentored as a team?	• All of my undergraduate students • 0 • 1 … • 10 • 11+
What is the largest team of students you have mentored?	• I have never mentored a team of students • 2 • 3 … • 7 • 8+
When was the last time you mentored an undergraduate student?	• Presently • 0-1 year ago (but not currently) • 1-2 years ago • 2-3 years ago • 3-4 years ago • More than 4 years ago

During what period was your most recent undergraduate research mentorship?	• During academic year (Fall, Winter, Spring) • Outside academic year (Summer)
How many hours a week do you typically spend working with your mentee(s) in total?	• 0-3 • 3-6 … • 12-15 • 15-20 • 20-25 • 25+
How many of the hours you spend a week working with your mentee(s) are valuable to you directly?	• 0-3 • 3-6 … • 12-15 • 15-20 • 20-25 • 25+

Table 1E. Likert scale questions asked to all mentors

Question	Response Option(s)/Type
Fill in the blank with how much you agree or disagree with the following statements as they pertain to your most recent experience mentoring undergraduate students one-on-one. N/A is not applicable. • I felt that my student(s) made significant progress in their research • My student(s) became better at oral communication after their experience • My student(s) became better at written communication after their experience • Mentoring undergraduate students slows down my own research productivity • Mentoring undergraduate students is an enjoyable experience • Mentoring undergraduate students is useful for my professional development • Mentoring undergraduate students is useful for the next stage of my career	• Strongly Disagree • Disagree • Neither Agree/Disagree • Agree • Strongly Agree • N/A

• I would gladly have my undergraduate student(s) continue working for me on a new project • I would gladly mentor other undergraduate student(s) in the future • My student(s) actively participated and were fully engaged. • My student(s) improved their ability to work independently over time • My students asked me questions frequently • My student(s) were able to work independently most of the time • My student(s) want to work in a research position after they graduate • I formed a valuable professional connection with my student(s) • My student(s) required a lot of guidance • I became a better mentor after this experience • I was/am a good mentor • I would prefer if my student(s) were able to work together on a team • I believe working with students one-on-one would be easier than working with the same number of students on a team • I believe my student(s) would perform better alone than if they were on a team • I believe that my student(s) learn more working alone than if they were on a team	

Table 1F. Open-ended questions asked to all mentors

Question	Response Option(s)/Type
Questions to one-on-one Mentors Please answer the following questions about your most recent experience mentoring an undergraduate student one-on-one.	Open-ended response

- What was something you liked about working with undergraduate students one-on-one? (optional) - What was something you disliked about working with undergraduate students one-on-one? (optional) - If you were given the opportunity to work with a team of undergraduate students, would you? Why or why not? (optional) - If you have any additional information, context, or comments you'd like to share about your research experience, please share it below. Please refrain from sharing identifiable or confidential information (optional).	
Questions to team Mentors Please answer the following questions about your most recent experience mentoring a team of undergraduate students. - What was something you LIKED about working with a team of undergraduate students? (optional) - What was something you DISLIKED about working with a team of undergraduate students? (optional) - Do you prefer working with teams of students or one-on-one with students? Why? (optional) - If you have any additional information, context, or comments you'd like to share about your research experience, please share it below. Please refrain from sharing identifiable or confidential information (optional).	Open-ended response