

Graduate student views of leadership and team structure in a self-guided instructional laboratory setting

Aaron Price¹, Kristin A. Oliver^{1,2}, Victoria Borish^{1,2,3}, C. A. Weidner⁴, Bethany R. Wilcox¹, and H.J. Lewandowski^{1,2}

¹*Department of Physics, University of Colorado, Boulder, Colorado 80309, USA*

²*JILA, National Institute of Standards and Technology and University of Colorado, Boulder, Colorado 80309, USA*

³*Department of Physics, Colorado School of Mines, Golden, CO 80401 USA and*

⁴*Quantum Engineering Technology Laboratories, H. H. Wills Physics Laboratory and
Department of Electrical and Electronic Engineering, University of Bristol, Bristol BS8 1FD, UK*

Effective collaboration is an essential skill for scientists, particularly in rapidly evolving, interdisciplinary fields such as quantum engineering. The Quantum Engineering Centre for Doctoral Training at the University of Bristol prepares PhD students to join this dynamic workforce through a combination of theoretical courses and team-based laboratory courses in their first year. In this study, we examine student views on teamwork within one of these lab courses, using a framework based on the Adaptive Instrument for Regulation of Emotions survey. We found that a lack of designated leadership roles and clear team structure led to specific challenges that students had to overcome. Furthermore, developing leadership skills was a primary teamwork goal for students, but they were often concerned that there would not be enough opportunities to attain this goal. This work can provide guidance to programs and instructors in developing more effective teamwork structures in laboratory courses.

I. INTRODUCTION

Teamwork is a crucial professional skill across scientific and engineering disciplines, including in the emerging quantum industry [1]. With 2025 designated the International Year of Quantum Science and Technology, investigating effective educational strategies to prepare a skilled quantum workforce, including in teamwork and collaboration is both timely and globally relevant. The importance of a well-trained quantum workforce is recognized in both the United Kingdom's and the United States' national quantum strategies [2, 3], and the US strategy, in particular, highlights the need for professional skills development. For many students, graduate school represents the final opportunity to develop these essential professional skills through structured coursework. Therefore, it is critical to understand how graduate students engage in team-based learning environments to better support the development of collaboration skills.

One program that was explicitly designed to address quantum workforce development goals was the Quantum Engineering Centre for Doctoral Training (QE-CDT) at the University of Bristol [4]. The QE-CDT engaged students in a cohort-based approach to doctoral education. The first year of the students' PhD education focused on a mix of theory and lab classes. The theory classes familiarized students with the current state of quantum engineering and quantum information science, while experimental courses included a team-based project (called the "Team Project") and individual research projects with professors. Students also engaged in a collaborative, cohort-wide project with the aim of developing something relevant to the quantum community (e.g., a podcast, review article, or game). Because of the QE-CDT's focus on collaborative projects, we chose to investigate student engagement with teamwork throughout the first-year Team Project at the QE-CDT.

Using a framework based on the Adaptive Instrument for Regulation of Emotions (AIRE) survey [5], we aim to address some student perspectives related to the following research questions:

1. What goals and expectations do students have for teamwork in the Team Project course?
2. What challenges do students face in achieving their teamwork-related goals?
3. What factors relate to students' ability to achieve their stated goals?

Although complete responses to these research questions are beyond the scope of this work, in this paper, we discuss one of the prominent themes that appeared in student responses for all three research questions: leadership and team organization.

II. BACKGROUND

A. Teamwork in instructional labs

The American Association of Physics Teachers established a series of guidelines for the creation of effective undergrad-

uate laboratories. Two of the areas of focus presented in these guidelines, "Designing Experiments" and "Communicating Physics," explicitly emphasize the need for teamwork in labs [6]. Although these guidelines are designed for undergraduate courses, the learning goals and, therefore, recommendations still have relevance to graduate courses.

Teamwork in undergraduate labs has a wide range of challenges in its implementation, but has also been found to benefit students. [5, 7–11]. Research on undergraduate labs found that some of the most common challenges faced by student teams, such as differences in goals, communication, commitment, and knowledge, were most often resolved by working together as a team [12]. Similar teamwork challenges were found in a "challenge-based course," where engineering and applied physics students reported that barriers to effective teamwork originated primarily from different knowledge levels [13]. Challenges in teamwork have also been found to arise from demographic differences, which have been found to affect the different roles that students take on, regardless of individual preferences [14, 15]. However, across STEM disciplines, undergraduate small-group work has been shown to lead to higher academic achievement, promote positive relationships between students and the discipline, and increase student persistence in STEM [10].

Because very little physics education research has been conducted at the graduate level, and almost none on graduate-level laboratory courses, we draw primarily on these studies of undergraduate courses. Although these studies focus largely on introductory courses, they consistently emphasize the importance of teaching professional skills such as teamwork. These goals remain highly relevant and could be extended to graduate-level instruction, including in quantum laboratory courses, to better support the development of teamwork skills for graduate students.

B. The AIRE survey

The Adaptive Instrument for Regulation of Emotions (AIRE) survey, developed by Järvenoja, Volet, and Järvelä, is an instrument that measures engagement in self-regulated and socially-regulated learning [5]. The goal of using the AIRE survey is to understand what situations students face while working with their team and how they view these situations. The first part of the survey explores students' specific goals with respect to teamwork for their current work. For example, it asks, "Apart from task completion, what other things have been important [within the context of teamwork goals] to you in this group exercise?" and it offers a series of possible answers such as "Get new ideas from the group." The second part of the survey then asks students to reflect on possible challenges they faced, offering similar possible answers. The final part of the survey explores how students resolved these challenges and prompts students with possible strategies they could have used in resolving these challenges.

The AIRE survey has been used before to analyze student engagement in teamwork in a large-enrollment introductory

physics lab [12]. In Ref. [12], the authors used a framework based on the AIRE survey to analyze a course-based undergraduate research experience to understand how students felt about the team aspect of the project. In this work, we use a framework based on the AIRE survey for both guiding the creation of our interview protocol and analyzing student responses from the Team Project course, rather than having students take the survey.

III. COURSE CONTEXT AND STUDY METHODS

The QE-CDT cohort included in this work was comprised of students from a diverse range of academic and professional backgrounds, including individuals with years of industry experience, as well as recent graduates from master's programs. During their initial year, students engaged closely with their cohort both inside and outside the classroom and had opportunities to receive mentorship from students in previous cohorts. Following this first year, students transitioned into their individual PhD research projects.

Our research focuses on the Team Project, a key component of the first-year experience in the QE-CDT. In this course, students were divided into small groups of three to four members and tasked with replicating a foundational experiment in quantum science, such as demonstrating a (non-loop-hole-free) violation of Bell's inequality [16, 17]. Each team was provided with an empty laboratory space and relevant literature to guide their work. Students were not given explicit direction on how to structure their teams or their time in the lab. Rather than being assessed on their exact experimental results, students were evaluated based on a journal-style article documenting the theory underlying their project, their approach, the experimental process, and their findings.

Our study focused on a single cohort from the QE-CDT, consisting of 12 first-year students. We conducted interviews with eight of these students, and each participant was interviewed twice: once prior to beginning the Team Project and again after its completion. All interviews were conducted remotely via Zoom by one of the authors, and audio was recorded for use in analysis. During these interviews, we employed a two-stage questioning strategy based on the AIRE survey. In the first stage, students responded to open-ended questions based on AIRE survey items. In the second stage, we presented the same questions along with the predefined answer options from the AIRE survey. The interviews were transcribed using Otter.ai [18]. Starting with an *a priori* codebook based on the AIRE survey, we conducted a thematic analysis of the data similar to Ref. [12]. This was followed by an emergent coding process to capture unanticipated themes and insights beyond the scope of the original framework.

The data presented in this work come from student responses to four questions regarding their perception of teamwork during the project. The first question we analyzed, which was asked during the pre-interviews, was:

1. What are your goals with respect to teamwork for this project?

The other questions we analyzed, which were asked during the post-interviews, are:

2. What are some challenges with respect to teamwork that you faced?
3. How did you deal with the challenges you mentioned?
4. What goals with respect to teamwork were you able to accomplish?

To ensure the reliability of our qualitative analysis, two authors conducted inter-rater reliability checks using Cohen's kappa, a chance-corrected measure of agreement between coders [19]. According to established benchmarks, a kappa value between 0.61 and 0.80 indicates substantial agreement, while values between 0.81 and 1.00 indicate almost perfect agreement [20]. We computed Cohen's kappa for three components of our analysis: for goals stated before the course, for the challenges and regulations students used, and finally for the goals students attained. Following collaborative resolution of disagreements, the final kappa values were 0.75, 0.85, and 0.86, respectively. These results demonstrate a high level of consistency between coders, indicating that our analysis is reliable.

IV. RESULTS AND DISCUSSION

Our analysis revealed several main goals that students had with respect to their teamwork within the course (shown in Tab. I). The three most common goals centered around positively interacting with the team through mutual learning, supporting one another, and socializing. Many students also had the goal of "having a good time" more generally. Another common goal that did not align with this theme was that many students wanted to develop leadership skills. We did not define leadership for the students during the interviews or ask them to provide their definition of leadership. Here, we focus explicitly on how leadership and team structure appeared within students' experiences of teamwork within the Team Project, however, other common goals identified in Tab. I will be addressed in future work.

TABLE I. Number of students who identified each statement as a goal for the Team Project or a goal that they attained through the Team Project. Students are counted if they responded that the statement was a goal either prompted or unprompted.

Goal Statement	# of students stated goal	# of students attained goal
Not let the group down	8	4
Learn as much as possible from others	8	6
Make new friends, socialize with others	7	7
Practice leadership skills	6	2
Have a good time, enjoy the experience	6	4

Prior to beginning the Team Project, many expressed concern about whether they would have meaningful opportunities to practice leadership, despite identifying leadership development as a key personal goal. Throughout the project, students encountered challenges that they attributed to a lack of team structure. In post-project interviews, several students

reported that they were ultimately unable to meet their goal of gaining leadership experience, reinforcing the impact of informal or undefined team organization on their learning outcomes.

A. Leadership goals pre-course

Before engaging in the Team Project, one of the most common goals from the AIRE survey that students cited was “Take the opportunity to practice my leadership skills,” with six out of eight students reporting it as a goal. However, while students stated this as a goal, they also expressed concern over whether there would be opportunities to achieve this goal. After being prompted with possible answers from the AIRE survey, one student, Deven, said,

“I am keen to practice my leadership skills, but I also don’t know how you implement- like how you practice leadership skills in something that’s meant to be kind of like a- an equal peer thing. So it’s actually- it’s something I really want to- I want to develop that skill, but I’m not sure whether- whether it’s something I can necessarily say is something I would get to do on this project or not.” (*Take the opportunity to practice my leadership skills*)

This student expressed concern about their ability to take on a leadership role within a team of their peers. This suggests the presence of a pre-existing conception that teams of peers do not necessarily need a leader or that choosing a leader among students with equivalent qualifications may be difficult. Another student, Addison, offered insight into the possible source of the challenges of creating structure among a group, stating:

“It’d be good if I could practice that [leadership]. But I think it’s difficult at the start, because I’ve got less experience than a couple of the others. So it feels like they’re naturally going to take on that role at the start. But, yeah, maybe once I’ve got more competent, I’d like to do that.” (*Take the opportunity to practice my leadership skills*)

Both Addison and Deven discussed a shared concern about their legitimacy or authority to assume leadership roles in the Team Project. Deven expressed apprehension about taking on a leadership role among peers with similar levels of experience, while Addison questioned whether they had sufficient experience to justify stepping into a leadership position. In both cases, students’ preconceived notions about who is qualified to lead within a group were not challenged by the structure of the Team Project, which did not specify formal mechanisms for assigning or supporting leadership roles.

B. Challenges and regulations related to leadership

Some teams encountered specific challenges that stemmed directly from this lack of defined leadership. When asked

about the challenges that their teams faced, one student, Drew, said,

“The fact there wasn’t really clear leadership role and the fact that that kind of sometimes cause, like, maybe one person wants to go another way and another person wants to go a different way and there wasn’t a clear way of [deciding].” (*Our ideas about what we should do were not the same*)

Another student, Quinn, also discussed a difficulty in making decisions; when asked about challenges they had faced, they said,

“I think maybe in decision making and organizational and planning skills, so decision making in the sense that because we- we three, once familiar with the subject matter, a lot of the things we are sort of- a lot of decisions were made without hierarchy, in the sense that we’re all equally clueless. So it was difficult to say something like, yeah, I think this should be done, with certainty.” (*We didn’t have a clearly organized team structure; emergent*)

These students identify another possible consequence of the lack of a formal decision-making structure. At the start of the project, many students entered with preconceived notions about who should assume leadership, which was often based on perceived authority or prior experience. However, once work on the project began and those perceived differences began to even out, students found themselves without clear direction. This illustrates the challenges that can arise when teams face a complex task without an established framework to guide decision-making and coordinate efforts.

While most teams identified the absence of leadership as a challenge, those with a clear leader described it as a crucial factor in successfully navigating obstacles. A student from this team, Jordan, said,

“One person particularly was definitely more of, like, a team leader kind of character and [they are] very good at, like, asking some of the quieter people, you know, what their opinions are if even if they’re not necessarily wanting to, like, come forth with information in the first place. So [they’d] be quite good at asking, like, oh, what do you think about this? Do you agree with this?... That’s probably the main way it happened, just making sure everyone was heard, and so the louder people didn’t speak over some of the quieter people.” (*We accepted that group members were different and we had to organize our work accordingly*)

This team appeared to avoid the challenges experienced by others thanks to the presence of a leader who effectively

guided their efforts. Notably, the leader in this group was not stated to have experience beyond that of their peers, indicating that groups of peers can successfully identify a leader among a group with relatively equivalent levels of technical experience. Several students from other teams reported that the absence of a clear hierarchy led to difficulties in determining direction and making decisive choices. In contrast, Jordan did not report facing these issues, highlighting the potential benefits of having a designated and capable team leader to facilitate coordination and decision-making.

C. Student perception of success in practicing leadership

After completing their Team Project, only one of the six students who reported at the beginning that they wanted to “Take the opportunity to practice my leadership skills” said they were able to achieve this goal in their project. Furthermore, four of the six students reported that there was a lack of opportunity for this practice. During the post-interview, when asked about attaining their goal of practicing leadership, Deven said,

“I wanted a chance to practice leadership skills but I think because there’s no, like, assigned leader in, in this it would feel weird to kind of go, oh, I’m gonna just tell everyone what to do or whatever. And it’s a collaboration at the end of the day...” (*Not have the opportunity to practice my leadership skills; emergent*)

In this statement, Deven appears to retain the same views on leadership that they held at the beginning of the project. The fact that all members of the team were peers still seems to present a barrier to stepping into a leadership role. For Deven, the absence of a formally designated leadership position within the Team Project may have reinforced their hesitation to take on such a role. A similar continuation of initial beliefs about leadership can be observed in Addison’s response to the same prompt. They said,

“And I don’t think I did get to take the opportunity to practice my leadership skills. Yeah, I think for similar reasons, because I went into it not knowing as much as the other two, it quite naturally became that those two were, like, the leaders in the group. So there wasn’t much chance to.” (*Not have the opportunity to practice my leadership skills; emergent*)

At the start of the project, Addison expressed concern about whether they had the authority to take on a leadership role. This sentiment persisted through to the end of the project, suggesting that Addison carried this mindset throughout and ultimately deferred to others to lead. For both Addison and Deven, perceived barriers to practicing leadership remained during the project. As a result, these students did not fully

engage with the leadership opportunities they had hoped to pursue.

V. CONCLUSIONS

Using a framework based on the AIRE survey to examine the role that teamwork plays in a graduate-level lab course, we identified some common themes around student experiences with leadership. One theme we found was how students perceived opportunities to practice leadership and the role that leadership played in the perceived success of the team.

Students entering this lab course expressed a desire to practice their leadership skills in their teams; however, we found that there exist possible obstacles based on students’ perceptions of leadership, whether or not these perceptions were actually accurate. For one student, this obstacle seemed to be the perception that it is difficult to establish a leader within a team composed of peers. For another student, this obstacle seemed to be their perceived lack of authority on the subject. For both of these students, these obstacles persisted throughout the project and were reported as reasons they did not practice leadership. These results were consistent with previous research that showed differences in students’ understanding of the task and their prior knowledge were barriers to participating in effective teamwork [12, 13].

We also found that the lack of a leader on a team could lead to students encountering challenges. On teams that did not have an established leader, students reported challenges that originated from a lack of authority, like struggling to decide among possible solutions. For the team that did have a leader, students reported the leader as being one of the primary ways they resolved challenges together as a team and made sure everyone’s voice was heard.

Our analysis revealed the nuanced ways students perceive leadership and how the presence of a leader can shape their experience of the project. These findings suggest that when designing team-based courses, instructors should consider incorporating scaffolding to support explicit discussions around team organization and leadership roles. Such scaffolding could help students navigate group dynamics, while still preserving opportunities for agency and self-directed organization. This opens the door for future research into which types of interventions are most effective in graduate-level settings. More broadly, our study highlights the need for further investigation into the specific leadership skills required in students’ future careers and how graduate programs can intentionally integrate the development of these skills into their curricula.

VI. ACKNOWLEDGMENTS

We would like to thank the PER group at the University of Colorado Boulder for their continued guidance and feedback. We would also like to thank the students at the QE-CDT for sharing their experiences and the instructors for supporting this project. This work was supported by the Undergraduate Research Opportunities Program at CU Boulder and the National Science Foundation QLCI Award OMA 2016244.

-
- [1] C. D. Aiello, D. D. Awschalom, H. Bernien, T. Brower, K. R. Brown, T. A. Brun, J. R. Caram, E. Chitambar, R. Di Felice, K. M. Edmonds, M. F. J. Fox, S. Haas, A. W. Holleitner, E. R. Hudson, J. H. Hunt, R. Joynt, S. Koziol, M. Larsen, H. J. Lewandowski, D. T. McClure, J. Palsberg, G. Passante, K. L. Pudenz, C. J. K. Richardson, J. L. Rosenberg, R. S. Ross, M. Saffman, M. Singh, D. W. Steuerman, C. Stark, J. Thijssen, A. N. Vamivakas, J. D. Whitfield, and B. M. Zwickl, Achieving a quantum smart workforce, [Quantum Science and Technology](#) **6**, 030501 (2021).
- [2] Department for Science, Innovation and Technology, [National quantum strategy](#) (2023).
- [3] National Quantum Coordination Office, [Quantum information science and technology workforce development: A national strategic plan](#) (2022).
- [4] [Quantum engineering centre for doctoral training | university of bristol](#) (2025).
- [5] H. Järvenoja, S. Volet, and S. Järvelä, Regulation of emotions in socially challenging learning situations: an instrument to measure the adaptive and social nature of the regulation process, [Educational Psychology](#) **33**, 31 (2013).
- [6] J. Kozminski, H. Lewandowski, N. Beverly, S. Lindaas, D. Deardorff, A. Reagan, R. Dietz, R. Tagg, M. Eblen-Zayas, J. Williams, R. Hobbs, and B. Zwickl, [Aapt recommendations for the undergraduate physics laboratory curriculum subcommittee membership](#) (2014).
- [7] M. Laal and S. M. Ghodsi, Benefits of collaborative learning, [Procedia-social and behavioral sciences](#) **31**, 486 (2012), publisher: Elsevier.
- [8] D. W. Johnson, R. T. Johnson, and K. A. Smith, Cooperative learning: Improving university instruction by basing practice on validated theory, [Journal on Excellence in University Teaching](#) **25**, 1 (2014), publisher: Citeseer.
- [9] D. W. Johnson and R. T. Johnson, An Educational Psychology Success Story: Social Interdependence Theory and Cooperative Learning, [Educational Researcher](#) **38**, 365 (2009), _eprint: <https://doi.org/10.3102/0013189X09339057>.
- [10] L. Springer, M. E. Stanne, and S. S. Donovan, Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis, [Review of Educational Research](#) **69**, 21 (1999).
- [11] S. Tannenbaum, G. Fernández Castillo, and E. Salas, How to overcome the nine most common teamwork barriers, [Organizational Dynamics](#) **52**, 101006 (2023).
- [12] A. Werth, K. Oliver, C. G. West, and H. Lewandowski, Assessing student engagement with teamwork in an online, large-enrollment course-based undergraduate research experience in physics, [Physical Review Physics Education Research](#) **18**, 10.1103/physrevphyseducres.18.020128 (2022).
- [13] C. Mesutoglu, D. Bayram-Jacobs, J. Vennix, A. Limburg, and B. Pepin, Exploring multidisciplinary teamwork of applied physics and engineering students in a challenge-based learning course, [Research in Science & Technological Education](#) **42**, 1 (2022).
- [14] M. Dew, E. Hunt, V. Perera, J. Perry, G. Ponti, and A. Loveridge, Group dynamics in inquiry-based labs: Gender inequities and the efficacy of partner agreements, [Physical Review Physics Education Research](#) **20**, 10.1103/physrevphyseducres.20.010121 (2024).
- [15] D. Doucette, R. Clark, and C. Singh, Hermione and the secretary: how gendered task division in introductory physics labs can disrupt equitable learning, [European Journal of Physics](#) **41**, 035702 (2020).
- [16] J. F. Clauser, M. A. Horne, A. Shimony, and R. A. Holt, Proposed experiment to test local hidden-variable theories, [Phys. Rev. Lett.](#) **23**, 880 (1969).
- [17] G. Weihs, T. Jennewein, C. Simon, H. Weinfurter, and A. Zeilinger, Violation of bell's inequality under strict einstein locality conditions, [Phys. Rev. Lett.](#) **81**, 5039 (1998).
- [18] [Otter.ai - Automatic Notes for Events](#).
- [19] J. Cohen, A coefficient of agreement for nominal scales, [Educational and Psychological Measurement](#) **20**, 37 (1960).
- [20] L. J. Richard and G. G. Koch, The measurement of observer agreement for categorical data, [Biometrics](#) **33**, 159 (1977).