

Taking on a manager role can support women's physics lab identity development

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Prior research has indicated that students in the undergraduate physics lab divide work inequitably with regard to gender. In this work, we further probed women's experiences in lab group work, focusing on women who take on managerial and leadership roles in the lab. We interviewed and surveyed women enrolled in a sophomore-level project-based lab course, drawing on a practice-linked identity framework to characterize their opportunities for engagement and identity development within the course. Although we observed some gender inequities in group work, we also found that taking on a manager role had a positive impact on many women's development of physics lab identity. Our results suggest that instructors should take into account women's individual experiences and preferences for particular roles when structuring equitable group work.

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I. INTRODUCTION

The inequities present in women's experiences of physics education have been well documented. Compared to men, women in physics face sexual harassment [1–3], lower perceived and received recognition of their physics competence [4–7], lower self-efficacy [8–12], and lower sense of belonging [13–16]. These inequities can have a significant negative impact on women's development of physics identity and persistence in pursuing physics degrees and careers [14,15,17,18].

Gender inequities are particularly concerning in laboratory instruction, which is one of the only opportunities for students to learn experimental skills and develop their identities as experimental physicists. Research has consistently found that lab groups divide up lab tasks unequally, with men more frequently working hands-on with the experimental apparatus and women more likely to take notes or perform other organizational and logistical tasks [19–23]. Although some work has suggested that this dynamic arises due to women's lower confidence working with experimental equipment [24,25], other research has suggested that women and men share similar preferences for what tasks they take on in the lab [26], implying that men's preferences receive more weight in group division of roles. Consequently, this inequitable division of lab tasks

can negatively impact women's self-efficacy and identity development [23].

One lab role that may contribute significantly to this inequity in identity development is the role of group manager or leader. Doucette *et al.* identified a gendered mode of physics lab work division in which a woman takes on a managerial role and disproportionate amount of work for a lab group (“Hermione”) because her group mates do not contribute (“Slackers”) [23]. This inequity can lead to the Hermione spending most of her time delegating tasks and admonishing her group mates to contribute or cursorily completing all the work herself. In either case, the result is that she cannot engage deeply with the experiment or physics at hand. Even in situations where a woman does not spend most of her time on managerial tasks, being the primary manager for her group may nevertheless dominate her perception of her role in the lab [27], further limiting her identification with physics.

Beyond limiting women's engagement with physics in the lab, taking on leadership roles can negatively impact their interactions with their group mates. Research has found that students prefer their lab groups not to have a single consistent leader, expressing concern that a student in this role will boss everyone around or otherwise “take over” [26]. This negative attitude toward leaders in group work may be especially salient in contexts where women are in this role. In general, men more often take on general leadership roles and are seen as skillful leaders [28]. As a result, women leaders must navigate a difficult balance in which they cannot be too feminine and collaborative but also cannot too forcefully take charge [29–31]. For example, a study of group-work dynamics in a ninth-grade math classroom [32] found that students were resistant to the

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leadership of a girl in their group, classifying her as “bossy.” The group positioned a boy as “smart” when he moved into a leadership position in the group, however, even though both students engaged in similar dialogue within this position. The result of this interaction led the rejected girl leader to disengage from group work as the semester progressed, limiting her opportunities for learning and engagement with her peers.

Much of the literature on group work in the classroom has focused on how a student in a leadership or managerial role can influence their group’s learning experience [26,33–38]. Comparatively little work, however, has probed how taking on a leadership or managerial role impacts the student in that role, particularly in a lab context. With this paper we aim to expand upon Doucette *et al.*’s [23] findings to explore the range of experiences women can have as managers and leaders in the physics lab, focusing on the experiences of women in a sophomore-level project-based physics lab course. In particular, we focus on the following research questions:

1. How do students describe and distinguish manager and leader roles in a project-based physics lab?
2. How does taking on a managerial or leadership role influence women’s opportunities for identity development in the physics lab?

II. FRAMEWORK

We draw on Nasir and Hand’s practice-linked identity framework [39] to understand how women’s managerial and leadership roles influence their opportunities for identity development, engagement, and learning (see Fig. 1). This framework recognizes learning as inextricably

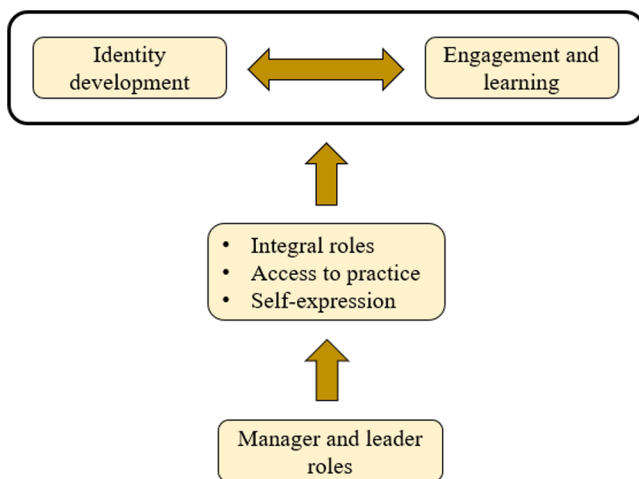


FIG. 1. Nasir and Hand’s practice-linked identity framework [39], adapted to our research context. The manager and leader roles that women take up can positively or negatively influence their identity development, engagement, and learning in the physics lab. This influence is mediated through three key factors: taking up integral roles in the lab, access to knowledge of the practice as a whole, and opportunities for self-expression.

linked to identity development and expression within the learning environment [40], where *practice-linked* identities are the “identities that people come to take on, construct, and embrace that are linked to participation in particular social and cultural practices” [39] (p. 147). As students develop a practice-linked identity, they must negotiate between their global, stable sense of self and the identities available for them to take on within a given learning environment or practice [41]. The opportunities for engagement afforded to students influence their development of practice-linked identities, and students’ practice-linked identities, in turn, influence how they engage and learn. Nasir and Hand argue that for a student’s practice-linked identity to enhance engagement and learning, and for a student’s engagement to enhance identity development, their opportunities for engagement within the learning environment must include the following:

1. Access to roles that are integral to the practice they are engaging in,
2. Access to the practice as a whole with opportunities to construct knowledge, and
3. Opportunities for self-expression.

Here we outline the significance of each of these criteria in the practice of instructional physics labs and identify ways in which each criterion might manifest in the lab, with particular attention to how gender and managerial or leadership roles relate to each.

A. Access to roles

For students to develop an identity that is central to a particular practice, they must take on roles that are central to that practice. They must take on responsibility for mastering their role and making essential contributions to the practice as a whole [39].

In the context of physics, there have been many calls for laboratory courses to develop students’ technical and practical scientific skills, such as data analysis and instrumentation [42–44]. Thus, we would expect that for students to take on an integral role within the practice of the physics lab (particularly one with these goals), they must have access to roles that engage with these skills (i.e., analyzing data and handling the equipment) [45]. Unfortunately, studies indicate that women are more likely to take on roles such as writing notes or managing the group, while men are more likely to work with the experimental apparatus and perform data analysis [19–23,25]. This inequity suggests that women, particularly those in managerial roles, may face barriers to taking on integral roles in the lab.

Engaging with skills that constitute an integral role, however, does not necessarily imply that a student must always be touching the experimental apparatus or sitting at the computer performing data analysis. Indeed, students can be cognitively engaged with an activity even if they themselves are not directly performing the activity [46].

For example, in a study of an introductory physics lab course focused on data analysis in which students worked in pairs throughout the semester, individual time spent on the computer during lab sessions was not correlated with scores on the postcourse data analysis assessment [19]. That is, even though some students spent less time analyzing data on the computer than their partners, their learning was not disadvantaged by their collaboration.

To illustrate how students might take on an integral role even if they are not primarily responsible for a hands-on task, we draw on the ICAP framework [46,47]. This framework categorizes student cognitive engagement on a spectrum from most to least engaged: Interactive, Constructive, Active, Passive. Passive engagement involves receiving information but not necessarily engaging more deeply with it, such as a student listening to a lecture. Active engagement, in contrast, involves a student directly working with objects involved with learning, such as setting up an experimental apparatus or using a computer for data analysis. When constructively engaging, a student generates new knowledge or applications of what they are learning, for example, designing an experimental apparatus rather than simply following a prescribed set of directions to set up an experiment. Finally, interactive engagement involves students constructing knowledge with others, be they peers, instructors, or a computer tutor. ICAP recognizes that students do not learn best by passively receiving knowledge from their teachers but instead are “responsible, active agent[s] in [the] knowledge acquisition process” [48] (p. 352).

Thus, watching another student perform data analysis or set up an experimental apparatus likely does not constitute an integral role, as it involves only passive engagement. However, *constructively* engaging with these processes, for example, directing the student sitting at the computer to take a particular step in the data analysis process, can constitute an integral role in the experiment, even if the role does not involve direct *active* engagement with the relevant equipment. Being a group manager or leader can be an integral role so long as it involves either *actively* taking on other roles and/or *constructively* engaging with other aspects of the experiment. On the other hand, if the group manager or leader must spend all her time admonishing her group members to contribute rather than engaging with the experiment herself, as described by Doucette *et al.* [23], then this responsibility will impede her identity development and engagement in the physics lab.

B. Access to the broader practice and opportunities for knowledge construction

Students must also understand the broader context of a given practice and have opportunities to construct knowledge within that practice to support their identity development [39]. When students work in groups to design and conduct an experiment in the physics lab, however, they

typically divide the necessary tasks [22,23]. This means that each student cannot possibly participate in every minute detail of every aspect of the experiment. Instead, group members must collaborate by working on separate pieces of the experiment while also ensuring that those pieces contribute to a cohesive whole. Thus, group interactions are crucial for students to develop an understanding of how their role fits into the broader context of their group’s experiment alongside their group-mates’ contributions.

In the ICAP framework, group collaboration (interaction) constitutes the highest level of student engagement and leads to the highest learning outcomes [49]. Research on students in K-12 robotics competitions and university engineering projects, for example, showed that groups produce the highest quality products when all group members contribute equally to discussion and are highly collaborative [50,51]. Individual students similarly demonstrated the largest learning gains when working in high-collaboration groups in a math class [52].

For this collaboration to foster maximal engagement, all group members must be involved in knowledge construction—putting these pieces together and understanding how their individual contributions fit in. Unfortunately, students and teachers may struggle to structure group work in a way that fosters productive, constructive collaboration [46,53,54], thus impeding the learning improvements associated with interactive engagement [49,52,55]. Of particular concern in the lab is unequal opportunity for engagement for different group members. Students who make more constructive statements in group discussions and who spend more time explaining to their peers tend to learn more from group work [49,51]. In the lab, therefore, each student must have the opportunity to contribute constructively to discussions about the overall experiment to foster their understanding of the practice of experimental physics.

Thus, the nature of a manager or leader’s contributions to discussion can significantly support or hinder her understanding of the experiment and contextualization of her role. If she has the opportunity to offer insights to the group based on her own role in the experiment, this will deepen her engagement and identity development. In contrast, if she must focus primarily on keeping her group members motivated and on-task in discussions, she will miss out on important opportunities for engaging with the broader experiment and, consequently, miss out on developing her physics lab identity.

C. Self-expression

Students must also have opportunities for self-expression within their roles to maximize their engagement and their identity development. How students engage with science in the classroom is impacted by the acceptable identities for them to take on there, as well as the consequences of those identities on students’ lives outside science [56–59].

Numerous studies have described the impact of affording more agency to students of all ages who do not see science as compatible with their identities. For these students, getting to define their own roles within a science context can dramatically increase their engagement with science [60–64]. For example, Basu *et al.* described how two ninth-grade physics students, Neil and Donya, greatly increased their personal identification with physics when given the opportunity to design their own projects [62]. Neil, who had previously considered himself a “dumb student,” completed a complex robotics project and began to consider robotics as a possible career path that would allow him to help soldiers, such as his cousin. Donya, whose goal was to become a lawyer, developed a lesson that engaged her fellow students in a debate about scientific principles. For both students, being able to connect physics to other aspects of their identity, namely Neil’s personal connection to the military and Donya’s career aspirations, greatly enhanced their learning experience and their self-identification with physics.

In contrast, when students’ opportunities for self-expression are limited or when the roles available to them directly conflict with other aspects of their identity, their engagement with science is hindered [56,65–68]. For example, one study on the experiences of women of color who have persisted in science describes a Latina woman’s experience of this disconnect between science classes and her identity as a political activist [56]. She did not take AP science classes in high school because she valued her political activism and science classes offered no opportunities for her to engage in similar work. In contrast to the students in Basu *et al.*’s work, because she was not afforded opportunities for this type of self-expression within science classes, she chose not to engage with science at that time.

Furthermore, all roles that exist within an academic environment may not be accessible to all students, and barriers to taking on a desirable role can negatively influence students’ engagement [32,56,69]. This is complicated by the fact that developing a science identity, especially in the physics lab, is inherently gendered [25,70]. Science teachers may devalue girls who demonstrate problem solving or hands-on skills but do not fit into a “good student” or social role [71,72]. Within the physics lab, an identity compatible with femininity is likely to focus on organizational, analytical, and collaborative skills [73], in opposition to tinkering and manual work, which are often seen as inherently masculine [74–76]. Although students tend to view physics as gender neutral, they may still consider identification with physics as incompatible with traditionally feminine traits, such as attention to fashion and personal appearance [77,78]. As a result, many women either choose not to express these aspects of their identity in physics contexts [2,3,78] or explicitly define their physics identity as a rejection of these traits [73,77–79]. Thus, women must navigate the complexity of performing their gender as they attempt to bring their identities into the physics lab.

We therefore considered in this work the gendered nature of women’s experiences in the physics lab and how this influences the roles they take up and their opportunities for self-expression. For some women in the physics lab, being a manager or leader may be a beneficial mode of engagement and identity development, as it allows them to use their collaborative and organizational skills in a context where they might otherwise be devalued for being feminine. Other women managers or leaders may feel forced into taking on this role because others see it as compatible with their gender identity, even though they themselves do not see it as part of their personal identity.

D. Summary

In this paper, we characterize women managers’ and leaders’ engagement in the physics lab and their practice-linked identities. Nasir and Hand’s framework [39] indicates that for women managers and leaders to effectively engage, learn, and develop practice-linked identities in the physics lab, these women must take on integral roles, understand and construct knowledge related to the experiment, and have opportunities for self-expression in the lab context. Accordingly, we investigated whether these women’s managerial roles allowed them to take on and/or engage constructively with other roles tied to experimental skills (integral role) and participate fully in group discussion about the experiment (understand and construct knowledge related to the experiment). We also investigated whether these women viewed managerial skills and responsibilities as compatible with their sense of self (self-expression) or whether being a manager conflicted with other aspects of their identity that they would have preferred to bring into the lab.

III. METHODS

We studied undergraduate students at Cornell University enrolled in a calculus-based course on waves and thermal physics. This course was the third semester of the honors-level introductory physics sequence and was made up primarily of physics majors (84% of students). The remaining students were either engineering students or majoring in other STEM fields. Women made up 23% of the students in the course. Most students were either White (60%) or Asian or Asian American (35%). Owing to the COVID-19 pandemic, the course lectures and discussion sections met online.

The laboratory component was separate from the content of the lecture portion of the course. This lab was the culmination of a three-semester sequence that emphasizes experimental skills (see, for example, Refs. [80–85]) and supports students’ agency to design and conduct experiments [86]. Students work in groups of two to four on a semester-long project, where they choose a topic, design and execute an experiment, and present their work in a

poster session at the end of the semester. For each lab session, each group submits an electronic notebook detailing their progress to be graded. During the semester described in this paper, students attended two-hour lab sessions approximately weekly, with at most one person per group in the physical lab space at a time and the other group members attending via Zoom. Some groups were comprised of students who were fully remote for the semester and these groups conducted their experiments from home.

We collected data through surveys and interviews. At the start of the semester, students filled out a closed-response pre-course survey about their attitudes and preferences for laboratory group work. The questions asked students about what roles they prefer to take on in the lab, how they prefer to divide and/or share roles, and their preferred group leadership structure (see Ref. [26] for more details). A similar post-course survey was administered at the end of the semester. Students received course credit for filling out both surveys.

Students also completed an open-response group work survey as a homework assignment for the course. This midsemester survey asked each student to reflect on their current group work experience and on their own contributions to their group's project. Questions on this survey included the following:

- What do you feel are your group's greatest strengths?
- What are ways your group could improve?
- What do you feel like are your greatest strengths as a group member?
- What group work skills would you like to work on?
- In your lab group, how do you negotiate leadership?
- How do you think groups *should* negotiate leadership in physics labs?
- In your group, how do you decide who will take on which role or who will perform which task?
- How do you think groups should divide and assign roles or tasks in physics labs?

During the semester following this lab course, we conducted semistructured interviews with women in the course to gain a more in-depth understanding of their group work experiences. These interviews focused on the same themes as the surveys, prompting the interviewees to define the manager and leader roles, describe their role preferences and experiences, group work dynamics, and managing or leadership preferences and experiences. Several questions were tailored to the interviewees' specific survey responses, asking them to elaborate on their previous answers. We also asked interviewees to reflect back on how their lab experience influenced their broader perceptions of and interest in physics research. We conducted pilot interviews with two undergraduate students who had previously taken the course and made only minor changes to the protocol based on these pilots.

We recruited participants via email and invited all students who reported their gender as "female" on the

surveys to participate (14 in total). Five women agreed to be interviewed. Each interview was conducted with an individual student participant via a Zoom meeting, which was recorded. One researcher conducted the interview while another took notes. Each interview lasted approximately 45 min and participants were compensated for their time with a \$20 Amazon gift card. Afterward, two researchers transcribed the interviews.

We focused our analysis on seven students: the five interviewees (Audrey, Valerie, Lillian, Maya, and Phoebe) plus two other women who were members of the interviewees' groups (Lucy and Melanie). These women's self-reported racial identities included Pakistani, Hispanic or Latinx, Asian or Asian American, and White. Their majors included physics, engineering physics, materials science, computer science, and mechanical engineering. All seven women were in project groups that were either majority women or had equal numbers of men and women.

Two researchers analyzed the survey responses and interview transcripts. First, each researcher individually read through the transcripts and survey responses for each interviewee and her group mates several times to become acquainted with the data, writing a brief summary of each student's experience. Each researcher then individually returned to the data several more times with a specific focus in each pass (access to integral roles, access to the practice, self-expression, and defining or taking up managing and leading). The researcher identified places in the transcripts and surveys where students attended to each theme and compiled a set of comprehensive notes characterizing students' experiences and perceptions of each theme. All of the authors met to discuss these notes and synthesize between the two researchers. Afterward, a single researcher continued to iteratively refine the analysis based on frequent discussions with the other authors.

IV. RESULTS

Here we report on women's perceptions of and experiences in manager and leadership roles through the lens of the practice-linked identity framework. All names are pseudonyms that are currently popular names in the United States. These pseudonyms reflect students' gender identity but do not reflect their race/ethnicity, as we could not include this information while preserving students' anonymity. Where necessary, we have also masked identifying details in the quotations below.

A. Definitions and interviewee classifications

To answer our first research question, we describe here our interviewees' distinct and overlapping definitions of manager and leadership roles (see Fig. 2). We also compare these definitions to the interviewees' descriptions of their own roles in the lab and classify them as managers or leaders of their groups (see Table I).



FIG. 2. Characteristics of the manager and leader roles, as defined by the interviewees. The leader role includes all of the characteristics of the manager role, as well as additional ones.

1. The manager: Organizing logistics and organizing people

When describing the responsibilities of a manager, the interviewees focused on two main themes: organizing project logistics and organizing group members. Organizing project logistics included tasks like keeping track of deadlines and the experiment timeline. Lillian reported,

“Each lab session I think I was probably the one to set up our Google Doc and say, ‘Oh yeah, this is what we are doing today,’ because in Gradescope [course management system] there was a part that said, ‘You need to write each time what each person does,’ and then so I guess wanted to make sure we hit that... I’d say zooming out and looking at the timeline and I think we all did that, but I always made sure that we did do that and then I guess just looking at the timeline and then Gradescope requirements was, and then deciding what we’re going to do throughout the week, if anything.”

Valerie and Maya also discussed project logistics as a key part of a manager’s responsibilities. Valerie described a manager as *“a checklist person ... someone who is in*

TABLE I. The leader and manager categorizations of our interviewees and their group members. Women who are not interviewees but were also group managers are included in italics beneath their interviewee group member.

Student	Classification
Valerie	Manager
Phoebe	Manager
Lillian	Manager
<i>Lucy</i>	<i>Manager</i>
Maya	...
<i>Melanie</i>	<i>Manager</i>
Audrey	Leader

charge of organizational tasks,” while Maya focused on deadline management: *“the person who is initiating any sort of ‘Oh, hey, we need to get this done,’ or ‘Hey, this deadline’s coming up.’”*

Organizing group members involved keeping tabs on other students’ progress and potentially intervening to steer group members back on track. Phoebe described this aspect of managing:

“I guess to manage the group you would check in to see what everyone’s doing, obviously, and then maybe not tell people what to do but make suggestions based on where everyone’s at, what would be a good direction to move in. Just to manage the group progress, not the group itself but where the group is going and what everyone is able to accomplish.”

Valerie and Audrey similarly described managing people as a key part of the role. Like Phoebe, Valerie focused on having an overview of group members’ progress: *“Just making sure everyone is on track and getting to the point that we want to be at when a lab report is due.”* Audrey more bluntly described providing organizational help to group members who might struggle without guidance:

“Some people, I think, need more concrete deadlines and coherent deadlines to work with the rest of the team ... [the manager is] making sure that everyone’s on track working at a similar pace. So, just checking in with people, I guess, is what managing is about.”

Overall, the interviewees described the manager as responsible for ensuring the group met deadlines and finished an appropriate amount of work by keeping track of what everyone is working on. Notably, none of the women indicated that the manager would tell anyone what to do, simply that they would gently nudge group members to keep the project on track.

2. The leader: Managing and taking charge

Interviewees’ descriptions of group leaders overlapped significantly with their definitions of the group manager (Fig. 2). Several of the women described logistical and people-management tasks that were similar to those they described for the manager. For example, Phoebe reported

“They [the leader] also check in with everyone else to make sure that, like I said before, overall progress and then everyone staying on track. So I guess the leader would be the manager of the group’s progress that I was talking about before.”

The women also mentioned other responsibilities focused on people managing that went beyond the role of the manager. For example, Lillian described the leader’s

role in fostering group rapport: *“I guess feeling comfortable with each other too, I think that would be a thing for the leader to establish.”* Audrey similarly discussed the leader’s role in motivating the group: *“I think trying to find the fun in the unfun things is important for a leader as well. ‘Cause a lot of times a bad mood of one party member is gonna influence the whole party, so I guess making sure that people look on the bright side of things.”*

What most significantly distinguished the leader role from the manager was the women’s attitudes toward it. Four of the five interviewees expressed concern that a group leader would make all of the decisions and boss everyone around, which they would dislike. Valerie described her previous negative experience with a bossy group mate:

“I have been in group lab experiences before where there was one person who was in charge and they just told everyone the microtasks to do, and it felt very removed from the actual process of learning something new about the course material, and I generally disliked that process.”

Audrey similarly commented on the detrimental effect a bossy leader could have on the group’s learning:

“I think that it’s really weird when there are power dynamics, and I think that if everyone’s not brainstorming on the same level and doing work on the same level that you’re not getting the most out of your group, and I think like every decision should be made with the group.”

Lillian put it most succinctly, expressing the view that a leader should avoid making the group *“like a tyranny.”*

Thus, while the interviewees saw the group manager as beneficial to the group, keeping others on track and making sure deadlines are met, they did not see leaders as consistently beneficial additions to the group. Although several of the women described ways in which the leader can be helpful to the group, such as by supporting group rapport and motivation, they also expressed concern that leaders might try to make all the decisions and boss everyone else around. Overall, our interviewees saw leaders as more likely to cause harm than to provide help.

3. Our interviewees’ classifications

Based on these descriptions, we classified each of our interviewees as a manager or leader based on her role within her group, as summarized in Table I. All five interviewees reported that their group had at least one person who took on a managerial or leadership role throughout the project.

Two of the interviewees, Valerie and Phoebe, described taking on the role of group manager themselves. Valerie reported that her lab partner had not previously taken a lab course, so she *“ended up ... managing progress and*

checking in and making sure [they] were at where [they] wanted to be.” Phoebe similarly described checking in on her group via Zoom because many students had to work remotely: *“... keeping the group focused because it’s just hard to know what everyone is doing when everyone is on Zoom so I found it helpful sometimes to touch base in the middle of the session and just check in on what everyone was doing.”* Because both Valerie and Phoebe took responsibility for keeping track of their group members’ progress, we classified them as managers.

Two of the interviewees, Lillian and Maya, reported that another member of their group acted as a manager. Lillian described how she and Lucy shared managing responsibilities for their group: *“I think it might have been Lucy and I who were working around the logistics side.”* Maya, who herself did not take on a managerial or leadership role, reported that when her group required a manager, Melanie took on that responsibility: *“I think Melanie before the lab was due was reaching out a lot like, ‘Oh, we should FaceTime because this deadline is coming up’ so I guess in that sense she was helping manage our progress.”* As Lillian, Lucy, and Melanie all took on responsibility for organizing their groups’ logistics, we also classified them as managers.

Audrey alone described her role as being the leader. In reflecting on her group in the middle of the semester, she reported that she was responsible for motivating the group and pushing the project forward: *“I think I have stepped forward to get some momentum for our group, but my partners don’t seem to be interested in moving forward.”* When we interviewed her during the next semester, she also indicated that she had been the primary decision maker for her group, saying *“I think at some points there were just times where someone had to make an executive decision. When everyone was like ‘Yeah?’ about everything, someone just has to say ‘Yes.’”* In facilitating and organizing her group, Audrey took on responsibilities beyond those of the women classified as managers. As a result, based on her role as the primary motivator and decision maker for her group, we classified Audrey as a leader.

B. Access to roles

To address our second research question, we describe how these women’s roles as managers or leaders influenced their opportunities for engagement and identity development in the physics lab. We first explore the managers’ and leaders’ access to integral roles.

1. Managing as an integral role

We found evidence that being a manager can enhance the importance of a student’s role within a group. Phoebe, who worked collaboratively on a simulation, reported that a large part of her responsibilities also focused on writing up the lab notes and creating the final presentation for the group: *“then she [other group member] did more of the*

simulation part so I did more of the presentation and lab notes part.” As described by Doucette *et al.*, being phased out of working on the simulation into being primarily responsible for writing notes could have sidelined Phoebe from having an integral role in the group [23]. Phoebe, however, saw her role quite differently. She described managing the group as a way to “*check in to see what everyone’s doing... and then maybe not tell people what to do but make suggestions based on where everyone’s at, what would be a good direction to move in.*” And she saw taking notes as part of this process:

“It was easy to see what everyone was doing and stay updated with all the stuff that was going on and then keeping the group focused because it’s just hard to know what everyone is doing when everyone is on Zoom, so I found it helpful sometimes to touch base in the middle of the session and were just check in on what everyone was doing.”

Phoebe viewed her role not as a passive observer who recorded what happened but rather as an active participant who had the best view of the big picture. By checking in with her group members and offering suggestions, she could take on an integral role in the group by contributing to other aspects of the experiment. Moreover, discussing other group members’ roles with them and then synthesizing that information into the lab notes would have given Phoebe an opportunity to constructively engage with other aspects of the experiment, enhancing her engagement with the experiment overall [46,47]. Although Phoebe herself never interacted directly with the experimental setup or the data analysis process, her role as manager and note taker allowed her to engage with other aspects of the experiment and was in itself an integral role.

2. Access to nonmanaging roles

All of the women managers also reported that they had access to integral roles that were not directly connected to their managerial responsibilities. Owing to the hybrid format of the course, many of the remote students did not have access to the physical lab space. However, all the women managers who had access to the physical experiment shared in working with the apparatus and collecting data. Lillian and Maya indicated that their lab groups rotated which person went into the lab (only one student was allowed to be in-person in the lab at a time). Maya reported, “*I’d say we went almost on a cyclical rotation, like I think Melanie went first, I went next, and then after that ended we just went through the same thing.*” Lillian told us that this rotation gave her sufficient access to the experiment to be satisfied with her participation: “*I think I was pretty happy with what I had done because I’m pretty sure it was a full two and a half hours or something in the lab, ... and so I think I was satisfied with my one time in the*

lab.” Valerie, who along with her partner was doing the project remotely, similarly reported that both of them had shared in the experimental design and data collection: “*I guess we both had to handle the apparatus since we had to collect data separately, so I ended up doing some of [that].*” In addition, Valerie took on the role of data analyst, another key aspect of the project.

The women managers who were working remotely and did not have access to the experimental setup also constructed integral roles for themselves outside of their managerial responsibilities. Phoebe described how she and another of the remote students took on an integral role even though they did not have access to the experimental setup: “*Then that left the other two of us and so we worked on the simulation together.*” Because their group needed to understand the theory behind their experiment, the simulation was an integral part of their project. In her reflections during the semester, Lucy similarly described taking on the role of data analyst, which could be done remotely: “*I can’t access the physical circuit, so I’ve been messing around with the simulator to test my data analysis programs.*” Even without access to the physical experiment, both Lucy and Phoebe were able to take on integral roles in addition to their managerial work.

3. Factors impeding taking on an integral role

In contrast to the women in manager roles, Audrey felt that she was prevented from taking on an integral role while being the group leader. Audrey worked directly with the experimental apparatus: “*I did a lot of data gathering and I’d go into lab sometimes.*” She did not feel, however, that this role was significant enough for her to fully contribute to the project. The nature of her group’s experiment meant that gathering and processing data was simple and took a relatively short time. The bulk of the work was instead in the data analysis process. Audrey reported that one of her group members worked through the data analysis by himself and excluded the other two from the process:

“It just feels a little wrong to say oh, well Adam was very clutch in the fact that he did most of the programming and Python analysis, and so he’s really what kept the project alive and gave us anything to work with. But at the same time, because he wasn’t willing to teach Abigail and I anything, we weren’t able to help out in that respect.”

Here Audrey highlighted that the data analysis process was the piece of the experiment most critical for producing a presentable result. Because the data analysis was such a large part of the project, Audrey was frustrated that she had been excluded from it and consequently felt her role in the experiment was not as important as she would have liked.

Audrey also felt limited by her leadership role in the group. Her group had difficulty making decisions, so she

took on responsibility for pushing the project forward while trying not to be tyrannical:

“I think I figured out with each of my groupmates ways to get them to make the decisions, which sounds very manipulative, but I promise is not. But basically if by not giving any input aside from ‘Here are some pros and cons to this option. What do you think?’ and really forcing them to make a decision, we were sort of able to let everyone feel like they were contributing.”

Even though Audrey was heavily involved in every decision her group made, she saw her role as trying to give her group mates agency to take on a key role in making decisions, rather than an integral role as primary decision-maker. Moreover, the effort she felt she had to put into people-managing limited her ability to negotiate access to the data analysis aspects of the lab: *“I would have liked to participate more in the data analysis... but I didn’t want to mess too much with the flow, so I stepped away from that.”* Audrey attempted to be a fair and effective leader by prioritizing her group mates’ participation in decision making and the group’s overall progress. As a result, she missed out on securing a desirable integral role for herself. Adam’s exclusion of Audrey from data analysis, exacerbated by Audrey’s role as group leader, prevented Audrey from having full access to integral roles in her group’s project.

Beyond her response to Adam’s gatekeeping, Audrey also saw the leadership role as limiting her participation in the science aspects of a project: *“I would say if the group doesn’t have that strong presence of someone that can delegate well, that I can, I guess step up to that and do it, but I also prefer the more sciency part, so if that’s an option I’d rather do that.”* Audrey saw herself as a competent and effective leader, but she also saw this role as limiting her engagement with the science of the project.

4. Summary

Most of the women we studied took on integral roles in their groups beyond their managerial or leadership responsibilities. Those who had access to the lab and experimental apparatus tended to share this role equally among all group members. Even the women managers who were studying remotely and did not have access to the physical experiment took on other integral roles, such as developing simulations and performing data analysis. For one woman, the manager role itself constituted an integral role that allowed her increased access to the overall experiment.

Audrey, however, did not have access to a desirable integral role in her group’s project. Adam’s exclusion of her from the data analysis, exacerbated by the responsibilities she took on as group leader, limited her participation in the experiment.

C. Access to the broader practice and opportunities for knowledge construction

According to the framework, students must also understand and construct knowledge related to the broader context of the physics experiment. Here we examine managers’ and leaders’ opportunities to develop this understanding and construct knowledge, with particular attention to how their role as manager or leader impacts these opportunities.

1. Managing and leading as understanding the experiment

Taking on a manager or leader role can aid students in understanding the overall experiment. Both Valerie and Phoebe described managing as enhancing their understanding of their experiments. Valerie focused on her managerial role not as an integral role in itself but rather as an opportunity for her to better understand the experiment, in conjunction with note taking:

“Writing up the lab report and managing what everyone is up to is my overview way of being able to tell what we’re actually doing and making progress with and what the overarching goal is. So I generally enjoy lab experiences more when I can tell where we’re going and what we’re trying to achieve. Which is helpful for, I think, learning.”

Valerie saw managing as personally beneficial to her and her own learning, not just as a way to keep the group on track. By managing her group, she was better able to understand the experiment as a whole.

For Phoebe, too, managing the group, in conjunction with writing notes, allowed her a greater understanding of the overall experiment and her group’s progress:

“It was easy to see what everyone was doing and stay updated with all the stuff that was going on... It’s just hard to know what everyone is doing when everyone is on Zoom, so I found it helpful sometimes to touch base in the middle of the session and check in on what everyone was doing.”

Checking in with her group regularly as a manager and note taker also gave Phoebe the opportunity to ask her group members for clarification when she did not understand some part of the experiment: *“If I had a question about the experimental setup, I would just ask the person who was in the lab, or if I had a question about data analysis, I would just ask the person who was writing the computer software program.”* For both Phoebe and Valerie, being a group manager and note taker was beneficial to their overall understanding of the experiment.

Audrey’s role as group leader also allowed her greater understanding of the experiment, as it gave her a prominent position in group discussions. She reported making most of

the decisions for her group, saying, “*It was very indecisive at first and so I was like, ‘Okay, how ‘bout we do this?’ And then they give me like, ‘Eh, no I don’t want to do that.’ And I’m like, ‘Then propose an alternative. Otherwise we’re doing this.’*” When she wanted her group members to help her make decisions, she pushed them to make a decision by laying out the pros and cons of each option: “*Basically, by not giving any input aside from ‘Oh, here are some pros and cons to this option. What do you think?’ and really forcing them to make a decision.*” Because Audrey was thinking deeply about all decisions the group made, either by making them herself or by thinking through the consequences of them for her group members, she took an active role in constructing knowledge about her group’s experiment. What limited Audrey’s identity development and engagement was not a lack of opportunity to construct knowledge and develop an understanding of the experiment but other barriers to taking on a desirable role (see Sec. IV B 3).

2. Nonhierarchical group discussions to construct knowledge about the experiment

Group discussion is a key context in which students can develop an understanding of the experiment as a whole and construct knowledge. According to the ICAP framework, students will learn more in group discussion if they are contributing ideas (constructive) and building off other students’ ideas (interactive) [46,47]. Thus, for group discussion to help students understand their group’s experiment more broadly, they must have opportunities to contribute to group discussion. Here we describe the ways in which women had a voice in group discussions irrespective of their role as a manager.

Many of the women reported having a voice in group discussions. Valerie, Phoebe, and Maya described their group discussions as giving everyone an opportunity to contribute. Valerie described her discussions with her partner as the two of them building off each other’s ideas:

“We didn’t have a very clear decision-making process. It was largely, ‘Oh, I have this idea’ or ‘Oh I have this other idea’ and we built off each other, not really in a way where either of us was taking the leader roles, just bouncing ideas off each other.”

From Valerie’s description, both she and her partner had the opportunity to construct knowledge as both of them were contributing ideas throughout the project to further develop their experiment.

Phoebe similarly explained that everyone in her group participated in discussions to develop their experiment throughout the project:

“At the beginning [of each session] we all liked to figure out what we wanted to accomplish during the lab session... And then at the end it was good to catch

up and see what everyone did and then reevaluate where we were for the next lab session.”

For Phoebe’s group, these beginning- and end-of-session discussions likely allowed everyone in the group to better understand how the experiment was going and how their work for the day fit into the overall long-term project.

In Maya’s group, opportunities to contribute ideas were somewhat more limited. She reported,

“In the beginning it was definitely just a lot of different ideas being thrown around and that felt pretty equal. But then once we decided on what was happening, I think the person who initially came up with the idea had far more further ideas down the line as to what we would do. But then sometimes we would add in aspects of other ideas to our actual lab.”

Although the person who had come up with the agreed-upon idea for the experiment contributed more to the discussions throughout the project, Maya indicated that others were able to add on other ideas to the experiment. These contributions suggest that the other group members were able to construct knowledge that developed the experiment. Overall, Valerie, Maya, and Phoebe indicated that everyone in their groups had opportunities to develop their understanding of the experiment and contribute new ideas and directions to their experiment.

3. Factors impeding understanding and constructing knowledge about the broader experiment

For Lillian’s group, discussions did not necessarily enhance understanding of the experiment or provide opportunities for knowledge construction for all group members. Lillian reflected,

“A lot of it was going around in circles, everyone saying their thoughts and then more of a discussion between—I feel like it was not always discussion between all of us. I feel like usually only two or three people knew what was being talked about at a time cause I think at one point one of us was confused, so that was probably like two or three people talking at a time.”

Lillian indicated that although all group members had some opportunity to engage in discussions, oftentimes several of them were confused and unable to engage constructively. She described how this impacted her experience working in the lab specifically: “*I’m pretty sure it was a full two and a half hours or something in the lab, and then I was also not as confident in what I could do further because I kept getting confused as to what we were actually doing further.*” Lillian had the opportunity to work directly with the experimental apparatus, an integral role for the experiment. However, she struggled to understand the experiment well enough to identify the next steps she should

take when conducting the experiment, which limited her ability to engage effectively with the experimental apparatus.

Lillian reported that all three women in her group similarly struggled to understand the experiment:

“Leo was the one who had prior experience with this topic. So he had more background information than the rest of us... I think I resonated more with Lucy and Laura in being slightly lost in a lot of the stages of the lab... And so that was one thing that I remember is just bonding over not really knowing what’s going on but also trying to figure it out together with them.”

Because Leo, the sole man in the group, was the one who had chosen the topic, he took on the role of expert within their group. Lillian described, *“The three girls would always ask Leo like, ‘Oh, so is this what this actually means?’”* Previous research on group work has suggested that while answering questions in a group can enhance learning and engagement, only asking and never answering questions leads to worse learning outcomes [51]. This group discussion structure, in which Leo was always answering questions and the three women were always asking the questions, likely fostered increased engagement for Leo at the expense of the other group members.

Notably, Lillian did not suggest that being the group’s manager impeded her ability to understand the experiment, as three of the four group members struggled to understand the experiment. Although this inequity in access to group discussion and understanding the experiment is concerning, it is not tied to Lillian taking on the role of group manager.

4. Summary

Most of the women we studied had opportunities to develop an understanding of their overall experiments and construct knowledge within the broader context of their groups’ projects. Most of the interviewees indicated that everyone in their groups had opportunities to contribute constructively to group discussions. Two of the interviewees highlighted that their role as a manager and note taker actually increased their access to additional aspects of the experiment and allowed them to understand the overall project better than they might have otherwise.

Lillian alone described significant barriers to her understanding of the overall experiment and opportunities to construct knowledge. Because Leo chose a project topic his group mates did not understand particularly well, Lillian and the other group members struggled to contribute constructively to group discussion. This inequity, however, was not linked to Lillian’s role as a manager, as it similarly impacted other nonmanagers in the group.

D. Self-expression

Students must also have opportunities for self-expression within their practice-linked identities in the lab. Here we

describe the ways in which a manager or leader role can increase or inhibit self-expression.

1. Managing as a form of self-expression

Some of the women we interviewed described their personal sense of self as including being a “manager-type” person. Access to the manager role allowed these women to bring this aspect of their identity into the lab and to feel that these managerial skills were valuable in an experimental physics context.

Valerie, Lillian, and Phoebe all reported that they enjoyed taking on a managerial role within their groups: when asked to identify the roles they preferred to take on in the postsemester survey, all three included managing the group. They also saw their managerial skills as important assets they brought to their projects. In response to the question “What do you feel are your greatest strengths as a group member?” on the reflective midsemester survey, all three highlighted their managerial skills. Valerie wrote, *“I think I’m very organised, and I make sure that the group stays on track with the tasks and schedule for the week.”* Lillian and Phoebe similarly focused on organizing the group’s schedule and tasks to keep everyone on track. Lillian wrote, *“I can organize our plans, tasks, and results in a logical fashion that is clear and well-presented,”* while Phoebe explained, *“I offer suggestions on how we can streamline our process or work more effectively.”* Lillian further discussed this aspect of her identity in her interview. When discussing why she took on a managerial role, she said, *“It might have been Lucy and I who were working around the logistics side because, I’m not really sure. I think that was just more in our nature, I guess, to make sure we get things done.”* Lillian described being a manager and keeping track of logistics as an aspect of her sense of self. Because she had an inclination for the logistical aspects of the group project, taking on a managerial role allowed her to bring this aspect of her identity into the lab. Being group managers allowed Valerie, Phoebe, and Lillian to productively draw on their organizational and logistical personal strengths within a physics lab context.

2. Opportunities for other forms of self-expression

In some groups women ended up taking on a manager role because external factors pushed them into the role. Even when women were pushed into the role of manager, however, they could still maintain other aspects of self-expression and identity in the lab. Lucy and Valerie became group managers due to factors outside their control, but both of them were still able to maintain their identities as data-analysis-type people.

Lucy took on a managerial role within her group, even though she did not express any particular interest in taking on a managerial role. In the pre-semester survey, she indicated that she preferred to work with the experimental apparatus and perform data analysis when working in the

lab. According to Lillian, however, she and Lucy shared the responsibility for managing their group: *“I think it might have been Lucy and I who were working around the logistics side.”* Because we were unable to interview Lucy, we cannot be certain why she took on a managerial role. However, based on her midsemester reflections, we can conclude that her work helping manage her group did not impede her identity growth as a data-analysis person. As described in Sec. IV B 2, Lucy took charge of data analysis for her group. She identified this work as her greatest strength in lab work and as a significant aspect of her sense of self:

“I think my greatest strengths are my data analysis skills. I have done some data analysis for a research group at Cornell and have interned at [a tech company] doing similar work, so I think my programming/data analysis skills are relatively decent. I also in general really love programming :).”

Although Lucy did take up some managerial responsibilities within her group, she also was able to express her love of programming and data analysis within her role in the project.

Valerie, too, found opportunities to express her sense of herself as a programmer in her group while taking on a managerial role. She reported taking on a managerial role partly to compensate for her partner’s lack of lab experience and punctuality: *“This is not at all a reflection on him, but ... some of it was me bringing him up to speed... Sometimes he would miss the calls.”* In spite of taking on this responsibility, Valerie was able to draw on her interest in computational physics within the lab. She described data analysis as a significant aspect of her personal identity:

“With regards to data analysis, I’m pretty interested in the field generally, so that’s probably why I ticked that off [on the survey]. I’m doing numerical computing computational physics research right now, so it’s up my alley. So it’s what I’m familiar with and what I enjoy doing.”

In addition to her prior experience with computational physics, Valerie also discussed her computational skills as a key part of her future plans:

“I’m maybe hoping to go to graduate school, question mark? And I’m definitely at least very interested in computational physics and astronomy in general. I think planetary science is really, really interesting, and I’m hoping to explore the field further maybe if the job market permits.”

Overall, programming and computational skills were an important part of Valerie’s physics and research identity, and it would have been important for her to have the

opportunity to further develop and express this aspect of her identity. Valerie did indeed find opportunities to develop this aspect of her identity in the context of her project. She described how her work on data analysis in Python for this project impacted her general confidence in computational physics:

“[It] definitely helped me gain a lot more familiarity with using Python in general, in all of the Python modules, especially Matplotlib, which has been really helpful in the astrophysics that I’m doing... it’s given me a lot of familiarity with the tools that I’m using for my research. And I’m not sure it changes my perspective but definitely changes my confidence level with regards to tackling computational tasks.”

Even though Valerie took on a managerial role to keep her partner organized, she still was able to develop her computational physics identity in the lab by working with Python and gaining confidence in her programming skills.

Notably, Valerie also discussed her managerial skills and valued this aspect of her identity. In her role in her project, she was able to express both the managerial and computational aspects of her identity, developing both. For both Lucy and Valerie, taking on a managerial role did not inhibit their expression or development of their identity as programmers in the physics lab.

3. Leading as an impediment to self-expression

For the women we have discussed so far, being a manager was, at best, an opportunity for self-expression they might not have otherwise had or, at worst, not a barrier to other avenues of self-expression. However, even for those who see themselves as naturally good at managing or leading, bringing this aspect of their identities into the lab may not foster a positive learning experience. For Audrey, acting as the leader of her group negatively impacted her opportunities for identity development.

Audrey identified managing her group as a role she preferred to take on in the pre-semester survey. In the interview, she explained this preference in terms of seeing herself as good at leading and organizing:

“I also understand in sort of a weird way that I’m good at managerial things. I mean that’s why I’m [an officer] of [a STEM-focused club]. Not because I know a lot about [science] but because I know how to run a club. And organize things. And so I would say if the group doesn’t have that strong presence of someone that can delegate well, that I can, I guess, step up to that and do it.”

In her project group, then, she took on a leadership role because she felt the group could not make progress otherwise. In her midsemester reflection, she commented, *“I think I have stepped forward to get some momentum for*

our group, but my partners don't seem to be interested in moving forward." In her interview, she similarly told us, "I think at some points there were just times where someone had to make an executive decision. When everyone was like 'Yeah?' about everything, someone just has to say 'Yes.' Audrey saw that her group could benefit from someone taking on a leadership role, so she took on this role because she knew she could do it effectively. In this way, her experience was similar to Valerie's, in that Valerie took on a managerial role because her partner would struggle to complete the lab otherwise.

Unlike Valerie, however, Audrey had a very negative outlook on this role. She reported that she did not want to hold that kind of power within her group:

"That's why I guess I was kind of frustrated in the beginning because I didn't want to have to be the person who said 'Yes' when everyone else was saying 'Yeah?' Because I don't like forcing on other people my ideas, I guess, and so I try to avoid that feeling at all costs."

Although Audrey saw herself as good at leading, she did not like feeling that she was forcing everyone else to do things her way. Being the group leader negatively impacted Audrey's experience in the lab because it did not align with her personal preferences for engaging with her peers.

4. Summary

Overall, the existence of manager roles generally had a positive or neutral impact on women's opportunities for self-expression in the lab. Several of the women identified their organizational and logistical skills as strengths they brought to their projects and enjoyed taking on managerial roles as a way to use these skills. Being a group manager also did not necessarily restrict other forms of self-expression, as two of the women managers described ways in which they were able

to draw on and develop their identities as programmers within their projects.

Audrey's role as group leader, however, did restrict her opportunities for self-expression. Although she considered herself highly skilled at managing and leading a group, she disliked forcing her ideas on others or telling her group mates what to do. By becoming her group's leader, Audrey took on an identity within the lab that she was uncomfortable with and that inhibited her engagement and identity development.

V. DISCUSSION

In this work we explored women's views of and experiences in manager and leader roles in a project-based physics lab. We used a practice-linked identity framework to identify how taking on these roles influenced women's access to integral roles, access to the broader practice and opportunities for knowledge construction, and opportunities for self-expression. These results are summarized in Table II. Here we first synthesize these results across the three axes of the framework and then discuss implications for instruction and future work.

A. Synthesis of results

Our interviewees expressed concerns about having a group leader, indicating that leaders can take over and tell everyone else what to do. This result agrees with prior findings that students are mistrustful of leaders in the physics lab [26] and that women tend not to want to take charge of a group, preferring to collaborate with peers as equals [87]. This attitude was reflected in Audrey's negative experience as her group's leader. Although she worked to foster equity within her lab group, she felt uncomfortable being in a position of power over her group mates due to the perception that group leaders tend to take over and boss others around [26]. Moreover, she felt that

TABLE II. Summary of women's experiences in the project lab course, emphasizing the impact of the manager role on women's practice-linked identity development.

	Integral roles	Access to practice	Self-expression
Managing as beneficial for identity development	Managing can be an integral role.	Managing and leading can enhance understanding of the overall experiment.	Women may self-identify as managers.
Managing as neutral for identity development	Managers can take on other integral roles.	Managers are not restricted from constructing knowledge in group discussion.	Being a manager does not prevent women from expressing other aspects of their identity.
Other impediments to identity development	Gatekeeping by group members and being the group leader can restrict access to desirable integral roles.	A topic that is understood only by a single group member can restrict others' understanding of the overall experiment and opportunities for knowledge construction.	Being the group leader can be incompatible with a student's personal values and collaboration style.

taking on the leadership role limited her opportunities to engage with the physics in her group's project, negatively impacting her identity development. Audrey's experience was commensurate with the Hermione archetype identified by Doucette *et al.* [23], limiting her identity development because she did not view her leadership role as part of doing physics [23,88].

In contrast, our interviewees generally viewed having a group manager as beneficial for group logistics and keeping people organized. Furthermore, being a manager was largely beneficial to the women who took on the role, in contrast to previous findings [23,27]. The women managers indicated that this role enabled them to develop a broader understanding of their groups' experiments, with Phoebe characterizing the combination of managing and taking notes as a key role in itself. The women managers also indicated that they had the same access to knowledge construction within group discussions as their nonmanager peers. For Valerie, Lillian, and Phoebe, moreover, being a manager allowed them to construct an "analytical physics student" identity [89] within the lab that better aligned with their sense of self than tinkering with the experimental apparatus. This contrasts Doucette *et al.*'s [23] findings, in which managing and note-taking prevented women from constructing knowledge within the broader practice of experimental physics or from having a key role in the lab, limiting their identity development. For women managers who viewed other aspects of lab work as strongly aligned with their sense of self, such as data analysis for Lucy and Valerie, taking on the manager role did not impede their development of physics lab identities focused on data analysis. This again contrasts prior findings that taking on a nontechnical role limits women's identity development in a lab or project setting [23,27].

There are several aspects of instruction that may help explain why women had a positive or neutral experience in managerial roles in this lab course but not in the Hermione role within Doucette *et al.*'s study [23]. One key difference is in the course structure. Doucette *et al.* studied students in a first-semester introductory lab course in which students had little prior physics lab experience. In contrast, our project-based lab course was the culmination of a three-semester sequence of introductory lab courses designed to support students' agency to design and conduct experiments [86]. As a result, students' prior lab experience likely influenced their views of roles in the lab. The semester-long project structure may also have contributed to the importance attributed to the manager role. Because each week's work built on previous weeks, groups had to maintain an extended plan for getting their work done and keeping track of previous progress [90], work that the manager contributed to the group. It remains an open question whether women similarly benefit from taking on a manager role in other lab course contexts.

The COVID-19 pandemic may also have affected these students' experiences. During the semester in which the study participants were enrolled in the project-based lab course, lab groups met remotely and could only have a single student work in the in-person lab space at a time. This disrupted structure led groups to engage in more explicit negotiations of roles, setting up equal rotations of who would go into the lab, in contrast to the implicit role negotiation more common in usual in-person labs [22,26,91]. As a result, the women had increased access to handling the experimental apparatus independently from their group members, which other work has suggested can enhance learning [34,92]. The remote nature of the work may also have enhanced the perceived importance of the manager role. With students never working in the same physical location, it would be more difficult to maintain group communication and coordination, making the manager role particularly important and potentially more valued by all group members.

Finally, four of the five groups we studied had at least two women in them (as identified by the interviewees). Prior work has argued that not isolating minoritized students, such as women, in group work can foster more equitable interactions [92–94] and that the Hermione archetype tends to lead to the greatest inequity in mixed-gender partnerships [23]. Thus, not being isolated may have helped managers gain more access to other aspects of the experiment beyond their managing role.

B. Recommendations for instruction and future work

Our results indicate that women taking on managerial roles does not have to lead to inequity within group work. For some women, being the group manager consistently can, in fact, be beneficial to their learning and identity development, even if this distribution of labor may appear inequitable to the instructor [26]. As a result, putting in place rigid structure for group work to prevent unequal distribution of tasks, such as requiring students to rotate and/or share all roles [23,92,93], may be unnecessary [26]. Nevertheless, encouraging groups to explicitly negotiate role assignment, as the pandemic conditions and other course structures required students to do in this project lab course, may help promote equitable distribution of work [91] and prevent women in manager and leader roles from being excluded from other key aspects of the experimental process.

Simply encouraging students to explicitly negotiate role assignment, however, is likely insufficient to ensure equitable group work, and the instructor must still monitor group equity. In this study we observed inequity arise when a single student monopolized a desirable role for the entire semester (Adam in Audrey's group), when some group members were unable to fully engage in group discussions (the women in Lillian's group), and when a woman was forced to take on a leadership role to ensure her group made

progress (Audrey), similar to the Hermione archetype [23]. From outside observation, it may be difficult to distinguish these issues from a woman acting consistently as group manager in a way that is beneficial to her experience in the lab. One possible way to probe the equity of students' group work would be to have students periodically write reflections on their group dynamics, which would enable the instructor to determine whether the students perceive inequities within their group dynamics and to intervene appropriately. Future work should evaluate how instructors can best structure lab group work to foster equitable interactions without being overly prescriptive and while attending to students' self-expression.

While the women in this study saw their managerial contributions as valuable to their projects, other work has suggested that students may not recognize managing as contributing to doing physics [23,88]. These attitudes may be damaging to women's physics identity development if women managers and leaders are not seen as physicists by their peers or themselves [5,17]. This issue may be particularly salient for women in leadership roles, like Audrey, who may be seen as bossing everyone around [26]. Given that leaders have the potential to increase their groups' equity [33], instructors should reframe the leader as the person who ensures "everyone's voice is heard" [26] and place value on manager and leader roles as important roles in the physics lab to ensure that women receive recognition from their peers.

VI. CONCLUSION

We have expanded on prior work studying women in manager and leader roles within the undergraduate physics lab [23], adding nuance to our understanding of these roles. Although we observed similar inequitable group dynamics to Doucette *et al.*'s [23] Hermione archetype, we also found that taking on a managerial role can be beneficial for women working on a semester-long project. These results suggest that instructors should be careful in structuring group work to ensure women are not harmfully forced into leader roles while also leaving space for women to consistently take on roles commensurate with their sense of self, such as managing the group. Although this paper cannot conclusively identify what structures would be best, future work should test instructional interventions for group work, particularly the extent to which explicit role assignment, sharing, and/or rotation impacts women's experiences in the lab.

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