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Centering and marginalization in introductory university physics classrooms

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Introduction: Research-based instructional strategies in physics promote active participation in collaborative activities as a primary means for students to construct understanding. Discussions of physics content are also negotiations of social relations.

Methods: Video analysis of small-group collaborative learning activities in introductory physics classrooms at three different universities, using situated learning theory analyses that include a critical consciousness lens.

Results: Students' ability to actively participate in sensemaking may be limited by their peripheral or marginalized position. Some people seem to be centered (or marginalized) for reasons other than the strength of their physics reasoning, and some people's contributions are elevated (or neglected) for reasons other than their scientific merit.

Discussion: Some of the behavioral patterns that we observe typify racialized and gendered interactions that are common in broader U.S. society.

KEYWORDS

physics, classroom and school based research, situated learning and legitimate peripheral participation, critical analyses, interaction analysis

Introduction

Research-based instructional strategies in physics promote active participation in collaborative activities as a primary means for students to construct understanding (Crouch and Mazur, 2001; Brewe, 2008; Shaffer and McDermott, 2012). This emphasis is in line with situated learning theory (SLT), a family of approaches in which learning is indicated by a student's increasing centrality in a community (Lave, 1991; Lave and Wenger, 1991; Wenger, 1998). Centrality is indicated by the extent to which everyone in a group orients to a specific person, either physically (by looking at them or turning their body in their direction) or discursively (by responding to what they say or do). People in a central position have access to full participation in the activity; in a small-group collaborative physics activity, for example, they start discussions, conduct experiments, write on the board, or decide when a question has been answered. Others, whose position is more peripheral, may be physically located on the margins of the activity or may participate less fully in it. In addition to indicating learning, movement from periphery to center is also associated with identity development: as participants move toward full participation in a physics activity, they increasingly identify as physics students (Lave, 1991; Lave and Wenger, 1991; Wenger, 1998). Overall, this family of approaches contrasts with approaches in which learning is seen as an individual cognitive achievement and knowledge is a psychological or volitional reality of an individual.

In a study of small-group collaborative learning activities in introductory physics classrooms at three different universities, we observe that discussions of physics content are also negotiations of social relations and that full participation is often limited by how students are situated within these social relations. These relations impact which students are centered (and their contributions are valued whether or not they reflect the learning of physics concepts in a cognitive sense) and which students are marginalized (and their contributions are neglected even when their physics content may be worthwhile). Our analysis demonstrates that the sensemaking activity (participation) of small collaborative groups is influenced by the situated social relations: students' ability to actively participate in sensemaking may be limited by their peripheral or marginalized position. This work is part of a larger effort to become conscious of how centering and marginalization shape the way physics is taught and learned.

Theoretical framework

Situated learning theories define learning in terms of the practices of a community (Lave, 1991; Lave and Wenger, 1991; Wenger, 1998). In a situated learning perspective, learners move from legitimate peripheral participation (participation in relatively simple yet necessary tasks) into more central positions as they are acculturated through knowledge acquisition and identity development (Lave, 1991; Lave and Wenger, 1991; Wenger, 1998; Contu and Willmott, 2003; Curnow and Chan, 2016). SLT is often used to describe learning in the community or the workplace, but also provides a framework for analyzing school learning (Haneda, 2006; Esmonde and Booker, 2016). SLT's emphasis on centrality aligns with common values in physics education research: in both perspectives, a key component of learning is increasingly engaged participation in learning activities (e.g., starting discussions, conducting experiments, writing on the board, deciding when a question has been answered). In physics classrooms as in other contexts, an SLT perspective would typically presume that a participant's mastery of the situated practices, knowledge, and skills of the community determines centrality and sustains the practices of the community (Lave, 1991; Lave and Wenger, 1991; Wenger, 1998).

Critical theories seek to make explicit the implicit assumptions of normativity and homogeneity, and the power relations that instantiate them (Esmonde and Booker, 2016). SLT has been criticized by critical scholars such as Esmonde and Booker for paying little attention to the power relationships that are negotiated in communities of practice, for not considering race, gender, or other sociocultural identities to be barriers to participation, and for treating students who remain peripheral as failing to identify as expert learners, regardless of sociocultural identity (Contu and Willmott, 2003; Curnow and Chan, 2016; Esmonde and Booker, 2016). Critical scholars have pointed out that power relationships are key to learning in the SLT model because access to the cultural system, and its associated identity development, is determined by those positioned at the center (Contu and Willmott, 2003; Bang and Vossoughi, 2016; Curnow and Chan, 2016; Esmonde and Booker, 2016). Power relationships are not static, but negotiated (Esmonde and Booker, 2016): power is (or is not) shared by the expert with the novice in a legitimate negotiation of shared identity (Contu and Willmott, 2003; Haneda, 2006). Some SLT analyses assume that those at the margins are engaged in legitimate peripheral participation and can naturally move towards the center as they learn. Critical theories point out that social relations often keep others at the margins and prevent them from moving towards the center. Identifying peripheral participation and marginalization requires a thorough understanding of communities of practice as historically embedded within racial and gendered contexts of power and social relations (Hughes et al., 2013; Curnow and Chan, 2016). Thus, while situated learning theories contrast being naturally and legitimately centered with legitimate peripheral participation, critical theories contrast being centered as a result of social relations with being marginalized and prevented from moving towards the center.

Critiques of SLT argue that full participation within a community of practice, such as a classroom, creates inequitable opportunities when power relationships are negotiated based on sociocultural identity (Hughes et al., 2013; Barthelemy et al., 2016; Esmonde and Booker, 2016; Gonsalves et al., 2016). An understanding of the physics classroom as a culturally hierarchical community is historically and inherently informed by students' social identities of race and gender, which acts as an barrier to sensemaking that prevents full participation: e.g., in the community of practice of a physics classroom, a woman of color may be questioned because her social identity does not conform to prevalent images of the "ordinary" white male physicist (Ong, 2005; Ong et al., 2011; Rosa and Mensah, 2016; Hyater-Adams et al., 2019; Prescod-Weinstein, 2019). Social relations ascribed by the broader sociocultural context may not value the membership of diverse others, in which case the learning of those diverse others will be limited (Haneda, 2006). For example, in a year-long ethnographic study of female Japanese graduate students in a Canadian university, students negotiated and constructed identity in an attempt to gain a more central position in the academic community of practice: the movement to a more central position required negotiating pre-existing social relations, but the students did not always get access to necessary cultural resources (Haneda, 2006). Full participation may not be accessible to all students regardless of the learner's willingness to participate. In such circumstances, historic social relations are structurally reinforced in the collaborative learning process. In such circumstances, structural inequities and epistemological hierarchy are reinforced (Bang and Vossoughi, 2016; Esmonde and Booker, 2016).

In physics, which has among the lowest representation of women, gender-diverse people, and people of color of any academic discipline [Sax et al., 2016; National Center for Education Statistics (NCES), 2023], theories of learning need to address the situated social relations that can hinder full participation. Without a critical lens to account for the situatedness of race, gender, or even patriarchy within the power relations, physics education research risks reproducing structural inequities (Gosztyla et al., 2021; Robertson and Hairston, 2022; Russo-Tait, 2022; Waight et al., 2022; Robertson et al., 2023). Acculturation with no assessment of the power relationship, or attention to sociocultural identities, ensures learning as identity construction is a type of colonization (Bang and Vossoughi, 2016; Esmonde and Booker, 2016).

In this study, we analyze physics learning interactions using an SLT approach that redefines the idea of legitimate peripheral participation as situated marginalization by including a critical consciousness lens (Freire and Macedo, 2000; Contu and Willmott, 2003; Curnow and Chan, 2016; Esmonde and Booker, 2016; Hyater-Adams et al., 2018, 2019). We characterize interactions among students in terms of centering and marginalization. Our analysis demonstrates that the sensemaking activity of small collaborative

groups can be hindered by these social relations: the illegitimate centering of some students and marginalization of others reinforces structural inequity in physics. This work is part of a larger effort to become conscious of how centering and marginalization shape the way physics is taught and learned.

Methods

Data collection

We video recorded 1–2 weeks of introductory physics classes at three different universities in the Western United States, totaling approximately 10–20 h of video for each site. These three universities constitute a variety of institutional types: two public and one private, ranging from 3,000 to 30,000 undergraduate students. Two are Minority Serving Institutions (Office of Diversity, Inclusion, and Civil Rights, n.d.). The project team and the study site selected the classes to be videotaped by mutual agreement, with attention to classes that feature (1) frequent or in-depth interactions among students and between students and instructors and (2) racial, ethnic, or gender diversity. Video recording was conducted either by members of the project team or by a faculty member for that university, and focused on small-group interactions when possible.

From the body of video data for each site, the project selected sequences of events in which centering and/or marginalization was visibly sustained or contested. Evidence of centrality comes from discourse and physical activity: e.g., who does the talking, who gets attention, who handles the equipment (Kendon, 1990; Goodwin, 2000; Derry et al., 2010; Engle et al., 2014). Such interactions, when they occur repeatedly, consistently, or in a sustained manner over time, indicate that someone is being sustained in a central position. We also selected episodes in which centrality was contested: when an otherwise peripheral participant tried to gain the floor (Engle et al., 2014), contribute knowledge, or direct the group's activity. Five to eight episodes were selected from each of the three universities.

To inform and triangulate the analysis of selected classroom video episodes, the project conducted 2–3 stimulated recall interviews (Calderhead, 1981; Lyle, 2003; Dempsey, 2010) per site, in which faculty or students who appear in a classroom video episode offer their perspective on those specific events. Stimulated recall interviews have a substantial history in research on teaching (Calderhead, 1981) as well as in ethnography (Dempsey, 2010) and cognitive studies (Lyle, 2003). For stimulated recall interviews, the project developed a unique protocol for each interview, since each recording presented a unique set of events to explore with the interviewee (Dempsey, 2010). Questions common to each protocol included the following: "(1) Do you remember this event? Please describe what happened, from your perspective. (2) What do you think this event means? How does it seem to you now?" The interview protocol also included the question, "Are there any aspects of your identity that you think matter for your physics learning experience?" None of the participants were explicitly asked to identify their gender, race, ethnicity, or other aspects of social identity, and few did so. (Both interviewers present as white women, which may influence what interviewees choose to discuss). Therefore, our description of participants' race, ethnicity, or gender in the following analysis may not accurately represent how they would describe themselves. It is likely that the students in our analysis also did not know how their peers would prefer to be described (since this is not often a topic of discussion in collaborative groups in physics), and interacted with each other based on their perceptions of others' sociocultural identity rather than on how those others would have identified themselves.

Not all of the episodes in the study are represented in what follows: for this paper, we selected the episodes for which no instructor was present, to focus attention on student interactions. These episodes come from two of the three universities in the study. Other episodes are informing analyses of instructor behavior (Robertson and Hairston, 2022).

Analytic methods

The episodes described below are cases of centering and marginalization in introductory university physics classrooms. Our analysis presumes that interactions between participants in physics classes are shaped by both unique local influences and general societal ones. With Erickson, we take the position that local discourse practices are situated in the social and historical circumstances in which they occur (Erickson, 2004). Though social actors in any particular situation are responding to their present circumstances – where they are located, who else is there, what they are trying to accomplish – they are also constructed by the world that exists prior to their responding to that situation, which includes gender, race, and ethnicity, among other influences. As Erickson says, "Economy, history, and the distribution of power within society provide what we do in face-to-face interaction with sets of constraints and enablements which we encounter as structures of local affordance" (Erickson, 2004). Alternatively, as Marx states, "Humans make their own history, but not just as they please; they do not make it in circumstances chosen by themselves" (Marx, 2013). Students in a physics class, for example, may be negotiating in the moment how they will solve a physics problem together, but that negotiation will take place in a situation in which the male students have typically been taught that they are intellectually superior to the female students (Komarovsky, 1973; Connell, 2005); the white students have generally had better access to educational advantages than the students of color (Woodson, 2006; Banks and Banks, 2015); black female students have never had another black female physics student in class with them (Ong et al., 2011; Rosa and Mensah, 2016); and white culture is considered normative (Bonilla-Silva, 2006). These influences from beyond the classroom constitute a social "gravitational field," with a "weight" of history that constrains the kinds of interactions that can take place.

Erickson insists that a responsible analysis must not succumb to either voluntarism on the one hand or determinism on the other: the tension must be sustained between the assertions that (1) "the conduct of talk in local social interaction as it occurs in real time is unique, crafted by local social actors for the specific situation of its use in the moment of its uttering," and (2) "the conduct of talk in local social interaction is profoundly influenced by processes that occur beyond the temporal and spatial horizon of the immediate occasion of the interaction" (Erickson, 2004). The connection between unique local influences is found by identifying the "antecedent conditions that provide local social actors with particular constraints and affordances in a particular local occasion" of interaction (Erickson, 2004). In a critical SLT perspective, the racialized and gendered conditions of

American society are these antecedent conditions. Race and other aspects of social identity do not determine behavior: the fact that a physics student is Black does not rule how that person behaves, or how we interpret their behavior. However, insofar as race and other aspects of social identity are strong factors in American society, they influence the interactions we analyze, and contribute to our analysis of these interactions. They are factors, though not determinative. In each of our analyses below, we first offer evidence of centering and marginalization from an SLT perspective without attending to social identity; then demonstrate the way that students in the episode participate in centering and marginalization; and finally consider race and gender as contributing factors to those patterns of behavior.

Our analytic focus is on patterns of behavior within a particular group, especially on implicit norms in which we see students participating. For example, we see some students participating in norms of dominant behavior such as controlling access to the equipment, making unilateral decisions, and ignoring or dismissing the contributions of other group members. We see such norms as ever present, socially constructed patterns that any person can participate in, regardless of race, gender, or other social identity. At the same time, we recognize that norms of dominant behavior tend to be more strongly socialized for certain groups, especially white men (Komarovsky, 1973; Mahalik et al., 2003; Connell, 2005). Individual people's participation in such norms is shaped by their social context. However, it is possible for individuals to contest or decline patterns of behavior in which some people dominate others. In the examples we share below, we will highlight moments when participants either reinforce or contest norms of dominant behavior.

Cases of centering and marginalization

Four cases of centering and marginalization are described below. For each case, we first provide general background information; then describe the interactions among participants; then analyze the interactions in SLT terms (centering and marginalization); and finally conduct a critical analysis, considering how race and gender constrain learning opportunities.

Case 1: equipment access

The following episode takes place in an introductory physics class at a small private university in the western United States. The class uses evidence-based practices including tutorials [2] to support small-group collaborative activities. The project videotaped 2 weeks in the middle of the autumn quarter course in mechanics, recording two out of six groups four times a week, for one to 2 h each class session.

In the following episode, students are working on a tutorial activity about acceleration in one dimension. The students, pseudonymed Andy, Bill, Cindy, and Dan, sit together for each class session (see Figure 1). Andy, Bill, and Dan present as white men and Cindy presents as a white woman. These four students sat together for every class session we recorded. Overall, the positioning for this group is highly stable: the same individuals are centered or marginalized to approximately the same extent in all of the class sessions observed for the study. In SLT terms, the legitimate peripheral participants are kept at the periphery, and thus reified as novices.

Episode: acceleration

In this episode, Andy, Bill, Cindy, and Dan are predicting how the acceleration of a cart on a ramp will change when they change the mass of the cart. The cart, ramp, and motion sensor are set up at their table so that they can run experiments to test their predictions. Andy asks if the weight of the cart is 700 g, and Bill says it is 0.8 kg. Bill sets up the cart, Dan starts the motion detector, and Cindy stops the cart. Andy states that the acceleration would decrease when the mass is decreased, according to Newton's Second Law (in which he presumes, incorrectly, that the net force is constant):

1. Andy: So the mass of the base cart is 700 grams, right?
2. Bill: Uh, it's about 0.8 kilograms.

[12 s in which Bill arranges the equipment]

3. Bill: You ready to test our prediction?
4. Dan: Oh, yeah, sure.
5. Andy: Wouldn't the acceleration decrease?
6. Dan: We do not have enough significant figures.
7. Cindy: Yah.
8. Andy: F = ma… Why would acceleration increase? Acceleration should decrease. F = ma so assuming that force is constant.

Amidst some talk about running the experiment, Bill responds to Andy with, "Oh. Right. No. The acceleration should not do anything. Thank you," seeming to agree with Andy, while also seeming to state that the acceleration would stay the same (which is not what Andy said). Andy next says, "Acceleration is still just due to gravity," now seeming to agree with Bill that the acceleration of the cart is independent of its mass.

Once Dan has finished assisting with the experiment, he and Cindy do not attend to Andy and Bill's interchange. Instead, they focus on a graph on the computer screen, which likely represents the output of the motion sensor. Dan has the mouse and manipulates the graph, appearing unsatisfied with the result. Cindy makes a technical suggestion ("Put a highlighter on it"), and then says "Hello?," suggesting she feels Dan is not listening to her. She requests the mouse by wiggling her fingers. Dan throws up his hands, releasing the mouse to her, and she uses the mouse to make an adjustment to the graph (see Figure 2). As Cindy gains the mouse, Andy and Bill look down at their papers and write.

Analysis

This episode shows several behavioral patterns that we observe to be typical for this group over the two-week period of video recording. One student, Bill, is centered: he directs the group's action (such as deciding when to run the experiment) and makes intellectual decisions for the group (what the mass of the cart is, and whether the acceleration is independent of mass). In a stimulated recall interview, Andy affirms Bill's centering as typical: he says, "Usually I deferred to his opinions and his reasoning because it was usually right." Andy described this episode as unusual in that Andy made a bid to correct Bill's reasoning; Andy says he "phrased it hesitantly because [Bill is] really smart, he's in his third year doing a master's in physics, just retaking this class because he transferred," suggesting that Bill has

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FIGURE 1
Clockwise from bottom left: Andy, Bill, Cindy, and Dan. Image is altered for confidentiality.

FIGURE 2
Cindy reaches for the mouse.

unusually high expertise for an introductory physics class.[1] Andy adds that "usually when I ask something like that, about half the time I'm probably wrong, if I'm trying to correct him, because he's really good at physics." In other words, Bill is centered partly because other students attribute academic merit to him. In this episode, Andy makes a bid to move toward the center (by "trying to correct" Bill), but perceives this action as unusual (thus he "phrased it hesitantly"). In the end, Bill's centralized position is sustained: Andy's contribution is absorbed and changed into a different statement made by Bill.

Dan appears close to the center occupied by Bill in this episode: he carries out Bill's suggestion to run the experiment, and he takes the lead in manipulating the graphical output of the motion sensor (he initially holds the mouse). Cindy makes a bid to move toward the center by making a technical suggestion about how to manipulate the graph ("Put a highlighter on it"), but her move is ignored. Cindy's "Hello?" shows her own recognition that she is on the periphery of the action: that others are not listening to her, and that if she is going to be heard, she needs to take more action. She does so by requesting the mouse. Her move is treated as unusual (Dan throws up his hands to release the mouse to her, as if doing so was a major event). None of the

1 Andy is mistaken about Bill's status; no one with a master's degree in physics would be in this introductory physics class.

other group members attend to her manipulation of the graph. In an interview, Andy described Cindy's low profile as typical for their group: he says Cindy is "usually a little more quiet. She and Dan are good friends and she mostly defers to what he says."

Overall, two students in this group are centered: primarily Bill, and secondarily Dan. In this episode, Andy and Cindy both make bids for centrality: these moves are seen as non-normative (Andy describes his move as rare, and Dan throws up his hands), and do not disrupt the overall structure of the group. Situated learning theory would likely pose Bill and Dan as being more expert-like and having a secure identity as physics learners, as evidenced by their central positions. Physics education research would tend to see Bill and Dan as successful learners in that they are actively engaged with the material: they are "hands-on," they direct action, they are visibly engaged in the instructional activities, they share their ideas, and they pursue answers to physics questions. Andy and Cindy, meanwhile, might be understood by SLT to be legitimate peripheral participants in the group: they engage in simpler, lower-risk tasks, such as asking about the mass of the cart or making suggestions about the computer display. Overall, SLT and PER would tend to judge Bill and Dan as more successful learners than Andy and Cindy, in this episode.

Missing from the above analysis is the critical perspective that to move to the center in a group is to negotiate power, sometimes inequitably. Norms of dominant behavior in groups include control, independence, and decisiveness (Komarovsky, 1973; Mahalik et al., 2003; Connell, 2005). Bill and Dan display these characteristics: they control the equipment, act independently, and make decisions for the group. Andy does not participate as much in these dominant behaviors: he defers to Bill and is "hesitant" to question Bill's decisions (about the mass of the cart, the timing of the experiment, and the group's prediction). Bill's decisionmaking has the effect of marginalizing Andy: Andy's suggestions are not taken up by the team, and are even rendered less visible by Bill's discourse (e.g., when Bill reframes Andy's prediction as something other than what Andy said). In other words, the centering of Bill produces the marginalization of Andy.

Bill, Dan, and Andy all present as white men, a sociocultural identity that is greatly overrepresented in physics at all levels [National Center for Education Statistics (NCES), 2023] and that is associated with the earlier-named dominant behaviors in a physics context (Harding, 1991; Traweek, 1992; Gonsalves et al., 2016). In displaying norms of control, independence, and decisiveness, Bill and Dan are participating in norms that are strongly reinforced for white men in American society. However, Bill's and Dan's social identities do not determine behavior: Andy presents as having a similar social identity (although we do not know how he identifies), but does not participate in norms of white masculinity to the same extent.

Meanwhile, on the other side of the table, Dan and Cindy's interaction typifies some patterns of gendered interaction in physics, including men getting more attention and more access to equipment (Ong et al., 2011; Danielsson, 2012; Barthelemy et al., 2016; Gonsalves et al., 2016; Doucette and Singh, 2020; Herrera et al., 2020). For example, Dan's possession of the mouse makes the mouse initially inaccessible to Cindy. When Cindy obtains the mouse, she does not gain the group's attention: at that moment, Andy and Bill look away from the computer display, down to their individual worksheets. This marginalization, though contested (e.g., by Cindy obtaining the mouse), is not significantly disrupted during this episode. Overall, Cindy, like Andy, is not only on the periphery, but kept to the periphery with behavioral patterns that, to some extent, typify racialized and gendered interactions.

Case 2: peer characterization

The second case of centering and marginalization that we will describe takes place in the same introductory physics class as the first, at a small private university in the western United States. In the following episodes, students are working on a sequence of tutorial activities about forces and Newton's laws of motion. As many as six students sit at this table, pseudonymed Nick, Kevin, Tashi, Richard, Damien, and Pierce. Nick, Tashi, and Kevin present as men of color, and Tashi identifies as being an immigrant from a South Asian country. Richard, Damien, and Pierce present as white men. Over the 5 days of class that were videotaped for this study,[2] a different combination of students attended almost every day. Even on days when the same combination of students is present, they sit in different places at the table. Overall, the positioning for this group is somewhat stable, with the same students being centered and marginalized most of the time, but there is a notable exception on 1 day in which the students who are typically centered did not come to class. Pierce typically dominated conversations when he was present, but Kevin explained in an interview that Pierce does not usually come to class on Thursday because he attends a different lab session. This made the dynamics of who was centered different on Thursdays than on other days.

Episode: yayy

At the start of this episode, which took place on a Thursday, Kevin and Nick are working together to draw the free-body diagram for a magnet and an iron rod that are attached magnetically and suspended from a string (Figure 3). Tashi arrives and is visibly welcomed by Kevin. The three of them proceed to collaborate on the task.

1. Kevin: Yayyy… What up dude?
2. Tashi: What's going on
3. Kevin: We got the magnet, iron rod whatever, string,
4. Nick: We're supposed to draw a free-body diagram for the magnet and the rod.
5. Tashi: Tension, weight? weight?
6. Nick: We're not sure if there's a normal force. Just cause there's tension force. Is that it?
7. Tashi: Yeah, and magnetic force.
8. Nick: For the rod
9. Kevin: So we had to draw here
10. Tashi: I mean for the magnet is off this
11. Kevin: So they are both exerting magnetic force on each other
12. Tashi: Yeah
13. Kevin: Yeah okay that makes sense. Okay. We could have magnet force pointing down, against
14. Nick: Wait. Would that be added to weight though?

2 We videotaped two Thursdays, two Fridays, and a Monday; the class also meets on Wednesday, but technical difficulties prevented recording both Wednesdays as well as one Monday.

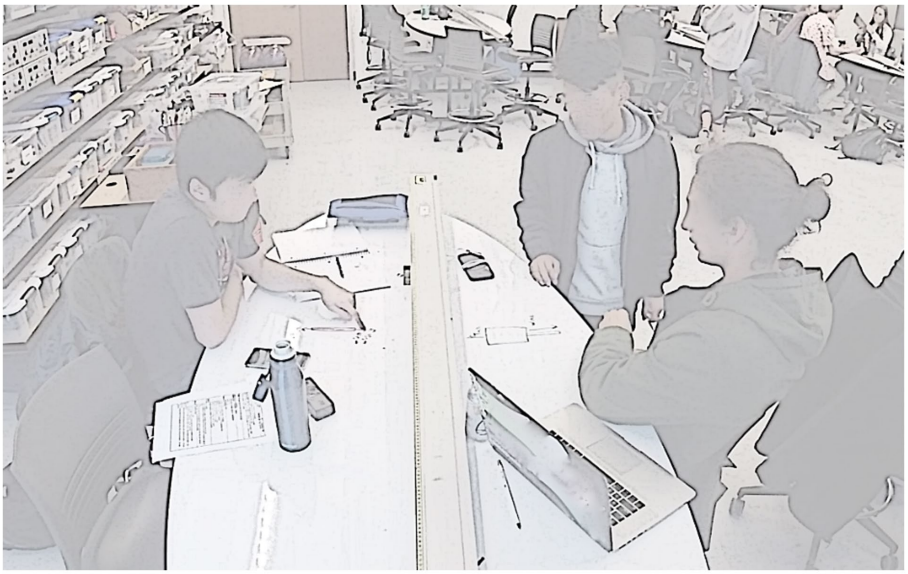

FIGURE 3
Clockwise from left: Kevin, Tashi, and Nick.

15. Tashi: I think it's a magnetic force. It's very small though
16. Kevin: Isn't it like opposite, so they attract, right? Actually no never mind.

This general format of interaction continues for some time: all three students participate in the collaboration. Nick and Kevin ask Tashi questions (such as "Is that it?"), with an air of consulting him on the answers they are generating. Tashi answers their questions and adds substance of his own ("Yeah, and magnetic force"), which seems to prompt Nick and Kevin to improve their free-body diagram ("So they are both exerting magnetic force on each other"). About an hour later, Richard arrives; Kevin greets him, but he is not visibly invited into the general discussion. Damien and Pierce do not come to class that day.

Episode: high school

The second episode with this group takes place on the following day. All six students are present (Figure 4). Damien and Pierce discuss how to find the magnitudes of the forces exerted on a pair of blocks that are pushed horizontally by a hand. Kevin is sitting between Damien and Pierce and attends to the discussion. Nick, Tashi, and Richard are not engaged with Damien, Kevin, and Pierce: Nick is working on his laptop, Tashi is on his phone, and Richard is looking away from the table.

1. Damien: How do you find the pushing force?
2. Pierce: If you look at your diagram, the pushing force from the hand has to be equal to the frictional force, plus the normal force of B on A. That normal force is just the exact same as the frictional force on this.
3. Damien: Ah. I see.
4. Kevin: Isn't that a pair?
5. Pierce: Sorry, this is a different diagram, but. So, because of those pairs, the pushing force must be the sum of the two frictional forces. Which makes sense because if you combined it all into one system, the friction on the entire system must equal the pushing force.
6. Damien: So the weight, so the normal for the weight force for B is 25.
7. Pierce: Yes.
8. Damien: So then the normal force would be 25.
9. Pierce: Yeah.
10. Damien: And that means… the friction force must be 5 N.
11. Pierce: Yes. And it'll be 10 N for the other, so the pushing force in total should be 10 N plus 5 N.

At this point, Richard asks how they know how to do this problem:

12. Richard: How are you guys doing this?
13. Damien: Pierce explained it to me a few minutes ago.
14. Pierce: What?
15. Richard: When did you learn this?
16. Pierce: I took physics in high school. And I have a pretty good memory. It's also just like, you can – I knew that it was, you can do this kind of reasoning where you say, okay what's this, it must be equal to this plus this. But this right here is a force pair with this. And this must be equal to this because this is not accelerating. And then you go oh, so it's just the sum of the two friction forces.
17. Richard: Where did you get this formula?
18. Pierce: The formula for like the static friction? Or the kinetic friction?

During this part of the conversation, Richard and Pierce are in direct conversation, with Damien and Kevin attending. Nick remains on his laptop and Tashi remains on his phone. Overall, this episode represents a very different format of interaction than the one in which only Tashi, Nick, and Kevin are present: Pierce is explaining physics

FIGURE 4
Clockwise from left: Nick, Tashi, Richard, Damien, Kevin, and Pierce.

concepts, mainly to Damien, with others participating marginally or not at all.

Episode: night before

The third episode with this group takes place a week after the second episode. Class has not started yet and students are still coming in and unpacking their bags. Five of the students in this group, Tashi, Damien, Richard, Kevin, and Nick, have arrived. They are all still settling in and Nick is still unpacking his bag. Pierce has not yet arrived (he arrives shortly after this episode ends). The students are sitting in a different configuration than in previous classes (Figure 5), with Damien sitting in the center of the table, orienting towards Tashi and Nick.

1. Tashi: What was the first question. I might just do it in a scratch program
2. Nick: Gotta get this done
3. Damien: Did you lose the first sheet?
4. Nick: No
5. Damien: Because this was definitely not easy. It took me a good amount of my last night.
6. Nick: I do not understand it.
7. Kevin: The first two pages are pretty easy
8. Nick: We have to do this too, right?
9. Damien: When did we talk about that? That question is so whack. I did not -- I got some [inaudible].
10. Nick: I think we can turn it in some free time
11. Damien: I think, you can definitely turn it in until 8 pm tonight.
12. Tashi: Really
13. Kevin: It's not even 8 pm, it's like, as long as you get it in before he comes in the next day.
14. Nick: Oh really? it just sits in the box?
15. Kevin: Yeah, in his mailbox.
16. Damien: Now you guys can procrastinate even more than usual. Guys, what if, let me just throw an idea out there. What if you guys just had your homework done the night before?
17. Kevin: Yeah well we did systems design though.
18. Damien: What a concept
19. Nick: Systems design
20. Kevin: We did systems design though
21. Damien: What if you just plan your time accordingly
22. Nick: I turned it in, I turned it in, yeah, at 9:57.
23. Kevin: I literally did that until 10 o'clock. And then after 10, starting to work on math and physics, until 12
24. Nick: I like barely touched it
25. Kevin: And then after that I did like the first two pages

During this discussion, Damien is turned towards Tashi and Nick, and appears to be engaging mostly with them, turning towards Kevin occasionally when Kevin speaks. Richard is mostly looking at the board, and none of the other students engage with him.

Analysis

The behaviors that these students exhibit in the first episode (Yayy) are in marked contrast to those in the second and third episodes (High School and Night Before), which are more typical of the classes we recorded. In the first episode, Nick, Kevin, and Tashi all contribute to the construction of the free-body diagram, consulting among each other fluidly. To the extent that someone is centered, it is Tashi: Kevin and Nick turn to him for assistance with the task both physically and figuratively (they orient their bodies to him and they ask for his contributions). This episode is more consistent with a classic SLT analysis, in which Tashi moves towards the center due to his expertise and other students' understanding that he can help them, Tashi does not strongly solicit others' attention to him; his responses are brief, and function to keep Nick and Kevin going in their own

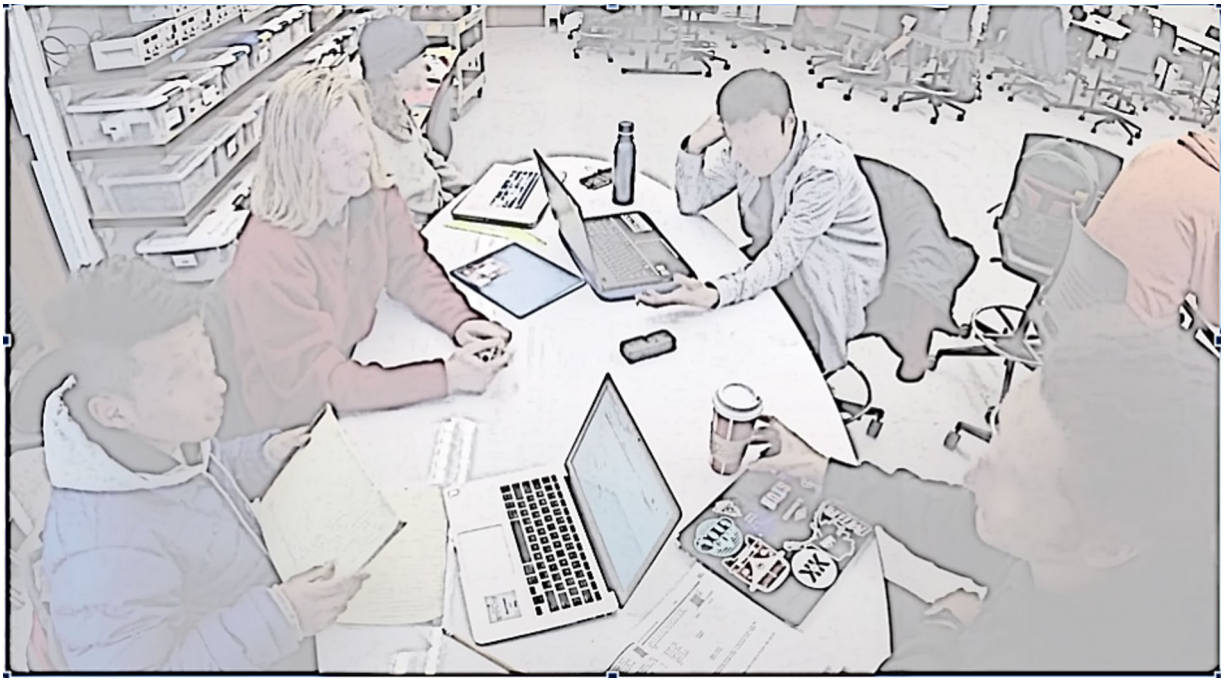

FIGURE 5
Clockwise from left: Tashi, Damien, Richard, Kevin, and Nick.

efforts. Overall, the discourse pattern is one of collaborative co-construction. When Kevin watched a video of this episode and was asked to describe what he saw happening in this interaction, he began with, "Pierce is not present on this because he attended the other lab session for the other time slot. I think Damien is apparently not present at all." He did not mention Richard's absence. Later, Kevin contrasted the dynamic on Thursdays with the dynamic on other days, explaining the difference in terms of Pierce's absence:

> So Pierce is a mathematics major, and he is like … He particularly knows a lot about physics, so I think he thought a lot of the time this class in general was like … I don't know; but he would carry most of our discussions. But on this particular day, it's a Thursday, so he wasn't present 'cause he goes to [another section] on Thursdays. So that means like … Well … I think we are very much just kind of thinking about these concepts, it could be like … It might not be true. Right? Like some of the stuff is of like, what we think about what's going on, and just kind of explore those ideas. And yeah I think there is a little bit of deviation in between one person dominating the discussion or like all of us giving our own thoughts and ideas to it. (Kevin)

In other words, Kevin describes the group dynamic when Pierce is absent as jointly collaborative and exploratory.

In the second episode (High School), and in much of the rest of the class, by contrast, Pierce is strongly centered: he offers relatively long, authoritative explanations to Damien, Kevin, and Richard, taking up a position as the "knower" who explains things to an audience of "learners." These contrasting participation structures are not explicitly negotiated among the participants, but seem to depend on who is present. When only Tashi, Nick, and Kevin are present, Tashi is centered, and the other two are positioned close to him; when Pierce and Damien are also present, Pierce is centered, Damien is positioned close to him, Kevin and Richard are more peripheral, and Tashi and Nick are distantly peripheral.

In interviews, Pierce describes a model of small-group work in which students who understand the material (such as himself) explain it to the others:

> I was explaining stuff to my table. I've gotten a reputation for that…I've become the person at our table if someone has a question, and we're doing stuff in a small group, that they'll ask me how to do something or what's going on. Last quarter of physics was not difficult, because it was pretty much a review of stuff basic stuff that I had done in high school. And I have a really good memory for this sort of stuff, so I remembered it all from high school and how to solve these problems. So, I often explain things to my table. (Pierce)

Kevin affirms Pierce's understanding of his position in the group:

> I think it [this pattern] is pretty standard; Pierce is giving an explanation and he wants us to understand… He probably knows this [physics] already but he's trying to iterate it to the rest of the group. (Kevin)

Kevin associates Pierce's central position with academic merit ("knowing the physics already"), as does Pierce himself ("I remembered it all from high school"), consistent with a classic SLT analysis of natural movement to the center through expertise. The implication is that the other students in the group stand to benefit

from having things explained to them. Kevin, however, disputes this interpretation: when given the opportunity to change groups, he elected to do so, because he felt that Pierce's explanations did not support his learning.

> I actually decided to change over… I think self-discovery is important for your own knowledge. I don't think it was always good, is what I'm saying…Just cause you listen to an explanation, that doesn't necessarily affirm that you understand something. (Kevin)

Kevin's experience undermines the idea that the purpose of small group work is for knowers to explain to learners. Instead, Kevin believes that understanding comes from figuring out the material for yourself, and intentionally seeks a group that supports him in that. Kevin's experience is consistent with modern research on successful small-group collaborations (Roschelle and Teasley, 1995; Barron, 2003; Miyake and Kirschner, 2014; Theobald et al., 2017).

In interviews, Tashi also contests Pierce's model of their group, but for a different reason. Tashi believes that Pierce underestimates the other students in the group:

> Maybe like Pierce just thinks all of us are like – he definitely thinks we're doing way worse in class than we're actually doing. (Tashi)

Tashi described himself as a "knower":

> Back in my country, I was the good student, the one who did good in exams and all that, and I used to always help my friends or someone try to understand ideas. (Tashi)

Tashi attributes his expertise partly to the challenging academic conditions created by the socioeconomic situation in his country of origin (one of the Least Developed Countries (Department of Economic and Social Affairs, n.d.) in the world):

> "For how it works back in my country, science was not very practical explained. It was very political because of limited resources in my country… Whenever the professor or teacher was explaining something we always had to work it in our mind and kind of make a mental picture of how it would look like and how things work. I think that makes it really easy whenever I'm attending a lecture or listening to something, I'm always making a mental picture or a mental explanation of how this would look like, and that really helps me grasp the idea." (Tashi)

Tashi's perspective undermines Pierce's (and Kevin's) attribution of academic merit primarily to Pierce. Instead, Tashi asserts that he has substantial academic merit: where he comes from, he performed well on exams, helped other students, and developed a talent for working things out in his mind. In this group, though, Tashi feels marginalized by Pierce's positioning as a "knower":

> Even though I might have something to say about it, realizing the fact that he [Pierce] is more knowledgeable than me kind of pushes me backward and kind of feel not confident to share what I think. (Tashi)

The variable positioning of students in this group undermines the model that small groups are effective because knower-explains-to-learner, as well as the model that centering is a natural result of expertise. Pierce is centered when he is present, and some attribute his centering to academic merit: in this view, he occupies the center rightfully, because he is the "knower." However, this view is undermined by multiple features of the group interaction. Tashi also has academic merit, and is appreciated by his peers when Pierce is absent; but when Pierce is present he is marginalized ("pushed backward"). Kevin has a sophisticated model of learning through supported independent discovery, but is also marginalized – enough so that he physically distances himself from the group when the opportunity is offered to him, because he judges that Pierce's positioning does not support his learning. As with Bill in the first analyzed group, we take the position that Pierce is centered at least partly for nonacademic reasons, such as race and gender, and that his reputation of academic merit is attached to him after the fact, to justify his central position. The first episode (Yayy) illustrates that Tashi is also a "knower" of physics, but this is not sufficient for him to be centered when Pierce is present. In the third episode (Night Before), Damien attempts to put the three students of color in the group, Tashi, Nick, and Kevin, into a marginal role by characterizing them as procrastinators who cannot get their work done in time, thus justifying their marginalization in terms of their lack of work ethic (Feagin, 2020).

In sum, Pierce and Damien are centered, and Tashi, Nick, and Kevin are marginalized when Pierce and/or Damien are present. Richard is also marginalized. Tashi is centered in one episode on a day when Pierce and Damien do not attend class.

Norms of dominant behavior in groups include getting a disproportionate share of attention and credit, as well as disattending to non-dominant participants. Pierce takes and is given more time, more credit, and more attention than other students in this group. Pierce identifies himself, and is identified by others, as someone who merits this attention because of his physics knowledge: he regularly explains physics concepts to his peers and gets their attention for doing so, while other students' contributions are not valued, taken up, or even noticed. Interviews suggest that this happened regularly, because several months after the class ended, both Tashi and Kevin remembered many academic details about Pierce. Both mentioned that he was a math major, that he took physics in high school, that he knew a lot of physics, and that he carried many discussions in class. Tashi also remembered details of how Pierce came to be enrolled in this class and how he felt about it:

> I think he was kind of frustrated too, because he couldn't transfer his credits or something with his physics class, so he'd basically done all the things in high school, but just because the credit wouldn't transfer he had to do those same things again, I guess that was the case so he would basically already know most of the steps in class. (Tashi)

Both Kevin and Tashi described choosing to not to sit with Pierce and Damien the next term even though they were in the same section. Pierce, on the other hand, did not mention any personal details about Kevin or Tashi. He said he was still at a table with Richard and Damien (the other two white students in his group), and when asked whether Tashi, Nick, and Kevin were still in his class he replied, "Things got switched around at tables, and I do not remember if they are in a different section or not." Tashi knows that Pierce knows a lot of physics, but Pierce does not appear

to know that Tashi also has a strong understanding of physics. In the interview, Tashi says, "Maybe like Pierce just thinks all of us are like – he definitely thinks we are doing way worse in class than we are actually doing." Pierce presents as a white man, and participates strongly in the dominant behaviors associated with whiteness and maleness, including lacking awareness of the experiences and perspectives of people of color (Bonilla-Silva, 2006; Botelho and Rudman, 2009; Feagin, 2020).

Damien also participates in norms of dominant behavior by aligning himself with Pierce. He orients towards Pierce as the knower and explainer of answers, and dismisses other students as not working hard enough. Damien rarely engages with Tashi and Nick, and when he does, it is to criticize their work ethic:

> Now you guys can procrastinate even more than usual. Guys, what if, let me just throw an idea out there. What if you guys just had your homework done the night before? (Damien)

This comment serves to justify Tashi and Nick's marginalization in terms of their work ethic and to hide the dominance that is leading to their marginalization. In his interview, Tashi contests this justification and suggests that it is a cover for Damien to "look smart":

> I think Pierce explains him [Damien] everything and helps him with everything and he's very like he gets all the work done when it needs to be and yeah, he always used to ask us like did you finish the homework and stuff and we'd always be doing in the last hour or last minute… we were never bothered with them because he was also like, he was just trying to look smart I think like aside Pierce, but was not actually that much smart or he didn't understand all the concepts that much I think. (Tashi)

Damien, unlike Pierce, regularly struggles to understand the problems they are working on in class and asks other students for help. When Pierce is present, Damien primarily asks Pierce for help. On a day where only Damien, Kevin, and Richard are present (not shown in any of the episodes above), Damien interacts much more with both Kevin and Richard, with all three students regularly engaging in conversation about physics concepts. However, even on this day, it is Damien's understanding that is centered: Richard's and Kevin's ideas are not part of the conversation, although Richard does seem to have questions (he stays after class to talk to the instructor for eight minutes). Overall, Damien actively upholds the norms of dominant behavior associated with white masculinity, norms that are strongly reinforced for white men in American society. Richard, though also presenting as white and male, does not participate in dominant norms to the same extent.

Tashi is centered on the day when he is in class and Pierce and Damien are not, but does not participate in norms of dominant behavior. On the day that Tashi is centered, he exhibits the a shared leadership more typical of healthy groups, soliciting and discussing others' ideas in a discourse pattern of collaborative co-construction of knowledge (Roschelle and Teasley, 1995; Barron, 2003; Miyake and Kirschner, 2014; Theobald et al., 2017). His interview provides evidence that he takes a similar role in other contexts, when he says "Back in my country, I was kind of like the good student or the one who did good in exams and all that, and I used to always help my friends or someone try to understand ideas." However, when Pierce and Damien are present, Tashi says very little or speaks only to Nick. Because of this, the group misses out on Tashi's physics ideas and leadership skills, and Tashi misses out on being able to participate as a full member of this group. Tashi understands this and contrasts it with his new group the following term:

> It's more like all of us are trying to explore rather than someone lecturing or explaining a concept to someone. (Tashi)

Case 3: task assignment

The following episode takes place in the laboratory portion of an introductory physics class at a small campus of a public university in the western United States. The lab emphasizes the development of skills for original scientific research. The project videotaped three different lab sections for three weeks in the middle of the spring quarter lab in mechanics, recording two out of six groups for each two-hour, once-weekly class session.

In the following episode, a student group (Figure 6) is getting ready to prepare a presentation about lithium batteries. The students, pseudonymed Aidan, Ben, Curtis, and Derek, have been lab partners for several weeks at the time of recording. All students in the group present as male. Aidan and Ben present as white, and Curtis and Derek appear Asian.

Episode: handwriting

In the beginning of the episode, Ben suggests recording their work in writing, and asks who has the best handwriting:

> Ben: Who has the best handwriting? Cause it's not me.
>
> Derek: Aidan?
>
> Aidan: No, definitely not me.

Ben suggests a writing competition. Derek says it will take too much time, and Ben says to just write one word:

> Ben: Let us here - let us have a writing comp.
>
> Derek: No, it will take too much time.
>
> Ben: No you just write like, a whole word. Just write your name.

Ben looks at Derek and points at the paper in front of him, and Derek writes on the piece of paper. Derek passes the paper to Ben. When Ben starts writing, Derek says, "Well, you are going to try to write worse on purpose," suggesting that Ben is trying to avoid being the one to do the writing. Ben responds by saying "I'm writing like I usually am," though his posture is awkward for writing. After everyone writes, Ben and Derek each look at the paper:

> Derek: Oh Curtis's pretty good.
>
> Ben: Let us see it. Yeah I feel like Curtis has the best.
>
> Derek: Alright that's not-that's not cursive though is it?
>
> Ben: it does look like it.

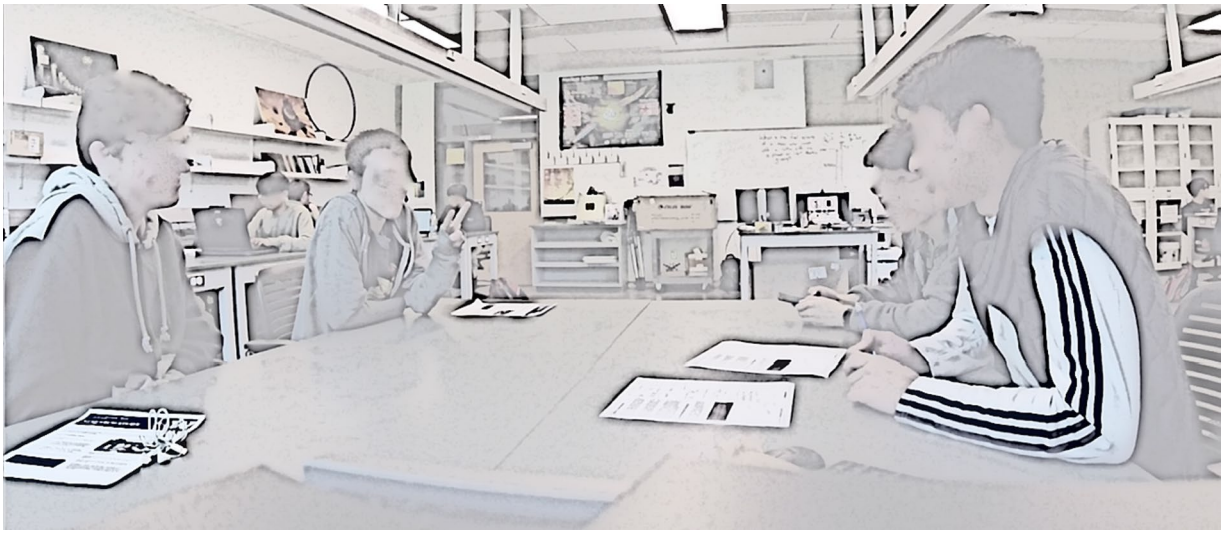

FIGURE 6
From left to right: Aidan, Ben, Curtis, and Derek.

Ben passes the paperit back to Derek, and says "I'd argue either Curtis or Derek." Ben turns to Aidan as if to ask what he thinks; Aidan nods, and Derek says "You would, Aidan," as if to chide him for agreeing with Ben. Ben then calls for a decision:

> Ben: All right, let us give our votes. We get-we get two votes: Curtis, or Derek.
>
> Aidan: I vote for Derek.
>
> Derek: I vote for Curtis because I do not want to do it.
>
> Curtis: I go with that [pointing at paper], I believe we should do that.
>
> Ben: That's Derek's. So Derek, looks like you are writing, bud.
>
> Derek: I'm not gonna be scribe but you are making me write this thing-.

In summary, Ben narrows the slate of candidates down to either Curtis or Derek; Derek votes for Curtis, and Aidan, Curtis, and Ben all vote for Derek. Derek objects, but puts his head down to focus on the paper and begins writing.

Analysis

In this episode, Ben is centered: he makes decisions for the group, directs others at the table, and effectively rebuts criticism of his actions. For example, when Ben introduces the idea of a handwriting competition, Derek says it will take too much time, but Ben responds by saying they will only write one word, and the competition proceeds. Ben decides on their next activity (the competition) and what they need (a scribe). When that decision is challenged ("No, it will take too much time"), a quick comment from Ben is sufficient to keep the group on his suggested course of action ("No, you just write, like, a whole word. Just write your name"). In another example, after everyone has written a word, Ben states that the group can only vote for either Derek or Curtis. By removing himself and Aidan from the competition, Ben not only insures that he will not be the scribe, but also increases the chance that Derek will be selected. Finally, Ben is the one to deliver the verdict for the handwriting competition, directing Derek to begin writing. Derek explicitly states that he does not want the role, but Ben still says, "Looks like you are writing, bud." Ben's statement (that Derek will be the scribe) supersedes Derek's statement (that he does not want to do it).

In this episode, Derek is not only outside the center, but is actively pushed to the margins: his concerns are dismissed and the group's decisions go against his expressed wishes. As seen above, Derek voices a number of concerns about the group's direction and Ben's actions (the contest will take too much time, Ben is writing poorly on purpose, Derek does not want to write), but Ben rejects or ignores these comments. In other words, although Derek shares his understanding and opinions, they are not treated as valuable or important. Instead, Derek winds up taking a role that he explicitly and repeatedly stated he did not want.

Tedious tasks are part of the functioning of any group; someone has to do them, and decisions have to get made about how the group will function. That said, there were equitable alternatives in this case: for example, they could have taken turns, or use a collaborative document instead of writing on paper. The group did not consider alternatives, and thus did not contest the pattern of centering and marginalization.

Ben participates in norms of dominant behavior: he decides that there will be a handwriting competition, dictates its terms (in his own favor), and determines its outcome, even over the objections of other participants. Ben presents as a white man, and behaviors such as those in this episode are strongly reinforced for white men in American society. Aidan also presents as a white man, and while he is not centered in this episode, Ben excuses him from the undesirable role of being the group scribe. Curtis and Derek are marginalized: their objections are passed over, and they are the two that are made to compete for an apparently undesirable group role. Curtis and Derek

appear to be Asian men, and the pattern of marginalization that they experience echoes the American history of limiting employment opportunities for Asian men to "feminine" work such as laundry (Takaki, 2012). Derek makes moves toward the center in that he talks more and objects more to Ben's decisions; perhaps as a result, he is actively pushed to the margins more than Curtis, raising the possibility that Ben is working to keep Derek on the periphery.

Summary

When students collaborate in small groups in physics classes, they are not only negotiating physics ideas, but also negotiating social relations. For some students, full participation is limited by how they are situated in these social relations. Some people seem to be centered (or marginalized) for reasons other than the strength of their physics reasoning, and some people's contributions are elevated (or neglected) for reasons other than their scientific merit. In some cases, sensemaking within groups is interrupted by social relationships. For example, in the second case analyzed above, Pierce is centered when he is present, and Tashi is neglected; but there is evidence that Tashi has significant expertise, and when Pierce is not present, Tashi is at the center of a productive collaboration. These effects are made visible with SLT analysis that includes a critical consciousness lens.

Some of the behavioral patterns that we observe typify racialized and gendered interactions that are common in broader U.S. society. For example, Cindy, who presents as the only female in her group, has limited access to lab equipment; Ben, who presents as a white man, assigns relatively menial tasks to Derek, who presents as an Asian man, in spite of Derek's objections. Our analysis provides evidence that students do not leave their social identities at the door of the physics classroom. Rather, they bring their social identities to the small-group table, and either play into or contest norms of dominant behavior into which some have been socialized. In this sense, our paper adds to the evidence that race and gender matter for learning environments that physics educators have historically thought of as race neutral (Robertson et al., 2023). Becoming aware of the ways in which race and gender shape physics classrooms may allow us to see ways in which we can reshape them for more equitable access to learning.

Data availability statement

The datasets presented in this article are not readily available because IRB restrictions prohibit sharing identifiable human subjects data. Requests to access the datasets should be directed to RS, rescherr@uw.edu.

Ethics statement

The studies involving humans were approved by the Seattle Pacific University Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

RS oversaw the study, collected the data, identified and analyzed some episodes, wrote the paper as a whole, and supervised all authors. WH conceived and wrote the theoretical framework. SaM collected the data, identified and analyzed some episodes, and wrote some data analysis sections. SoM identified and analyzed some episodes and wrote a data analysis section. All authors contributed to the article and approved the submitted version.

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Conflict of interest

WH was employed by Equitable Development LLC. SaM was employed by Alder Science Education Association.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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