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RESEARCH ARTICLE

Equity analysis of an augmented reality-mediated group activity in a college biochemistry classroom

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Abstract

The use of two-dimensional images to teach students about three-dimensional molecules continues to be a prevalent issue in many classrooms. As affordable visualization technologies continue to advance, there has been an increasing interest to utilize novel technology, such as augmented reality (AR), in the development of molecular visualization tools. Existing evaluations of these visual–spatial learning tools focus primarily on student performance and attitude, with little attention toward potential inequity in student participation. Our study adds to the current literature on introducing molecular visualization technology in biochemistry classrooms by examining the potential inequity in a group activity mediated by AR technology. Adapting the participatory equity framework to our specific context, we view equity and inequity in terms of access to the technological conversational floor, a social space created when people enter technology-mediated joint endeavors. We explore three questions: What are the different ways students interact with an AR model of the potassium channel? What are salient patterns of participation that may signify inequity in classroom technology use? What is the interplay between group social dynamics and the introduction of AR technology in the context of a technology-mediated group activity? Pairing qualitative analysis with quantitative metrics, our mixed-methods approach produced a complex story of student participation in an AR-mediated group activity. The patterns of student participation showed that equity and inequity in an AR-mediated biochemistry group learning activity are fluid and multifaceted. It was observed that students who gave more explanations during group discussion also had more interactions with the AR model (i.e., they had greater access to the technological conversational floor), and their opinion of the AR model may have greater influence on how their group engage with the AR model. This study provides more nuanced ways of conceptualizing equity and inequity in biochemistry learning settings.

KEYWORDS

biochemistry, diversity, educational technology, equity, gender/equity

1 | INTRODUCTION

Educational technology is a billion-dollar industry. Technology is now being used to mediate classroom discourse across the globe and applied to a myriad of educational problems, in the hopes of increasing equity and access (Foulger et al., 2017; Hood, 2018). But technology dollars do not always translate into student success, as the One Laptop Per Child program has shown (Kraemer et al., 2009). Existing literature has reported that the use of technology impacts equity in the classroom and identified numerous issues of inequity when educational technology is integrated into classroom instruction (Lowell & Morris Jr, 2019; Opie, 2018). For example, the term "digital divide" has been proposed by some scholars to describe the discrepancy between different socio-economic groups in terms of their use of technology in the classroom (Warschauer et al., 2004). When comparing the availability and use of new technologies in a group of high schools with students identified as primarily low- or high-socioeconomic status (SES), Warschauer et al. (2004) found that although the student-computer ratios of the schools were similar across schools, the students tended to use their computers differently in the classroom. Computer use at high-SES status high schools involved greater amounts of research and analysis in mathematics, while that at low-SES status high schools involved greater amounts of visual presentations in social studies. The similar student-computer ratios in both schools and the variation in students' use of the computers showed that similar material access to technology did not mean similar social access to participation in learning activities that could be mediated by technology. Attending to equal physical access to technology may attenuate issues of technological inequity to a certain degree. However, attention toward access to technology-mediated social discourse is also an important consideration when investigating the implementation of educational technology.

Along with the transformation of the material conditions of the classroom as a result of research and development in educational technology, recent reform efforts in STEM education have also placed significant attention on transforming the social discourse of classroom instruction to provide student-focused learning opportunities through the implementation of active learning pedagogies that often involve students working in small, informal groups (Freeman et al., 2014). In these spaces, students enter into networks of power relations with their peers, the instructor, and the biochemistry content and instructional material. Through these relations, potential inequities can be amplified or attenuated (Shah & Lewis, 2019; Tanner, 2013). The influence that classroom discourse and the introduction of novel technology have on each other may further complicate the issues of inequity in the classroom. Therefore, examining the interplay between social dynamics in small group activities and the introduction of technology is critical for understanding technology-mediated group activities and attenuating potential situations of inequity within these spaces. However, existing research on educational technology mostly focuses on determining the impact of technology on individual performance, while research on the interplay between technology and classroom social discourse is less plentiful (Anderson-Pence, 2017; Hao et al., 2020). Without knowing how technology is being used in the classroom, studying the impact of technology in terms of change in individual performance offers little help to improve both the user experience of these technologies and the instructional practices that aim to maximize the potential for learning with these technologies.

1.1 | Role of technology in biochemistry instruction

In the context of biochemistry teaching and learning, visualization and spatial reasoning have been identified as essential skills for students studying the molecular and cellular biosciences (Bussey et al., 2019; Oliver-Hoyo & Babilonia-Rosa, 2017; Schönborn & Anderson, 2006). Since molecular structures and events are not directly visible to the naked eye, biochemists use data to construct models and hypotheses to explain biochemical phenomenon. The communication of these models, whether within the community of biochemists or in educational settings, relies on external representations such as diagrams, animations, three-dimensional (3D) models, etc., that are realized through multimedia technologies (Bussey et al., 2019; Oliver-Hoyo & Babilonia-Rosa, 2017; Sung et al., 2019). The importance of visualization and external representation in biochemistry teaching and learning has directed research efforts toward determining the affordances of utilizing novel technologies in the development of external representations for biochemistry classroom instruction (Garcia-Bonete et al., 2019).

In recent years, augmented reality (AR) technology has received increasing attention in biochemistry educational research for its potential as a simple tool that can be used by students and instructors to visualize and interact with 3D models of macromolecular structures (Argüello & Dempski, 2022; Peterson et al., 2020; Sung et al., 2019). AR technology affords the user the ability to experience a computer-generated 3D object superimposed on top of the real world. Students can interact with the virtual 3D macromolecular structure by directly changing their point of view around the object in the real world and manipulate the virtual 3D object in simpler, more naturalistic ways as compared to current software systems such as PyMol (Sung et al., 2019). However, existing research on AR technology in the context of biochemistry education (similar to other educational technologies noted previously) mainly focus on measuring individual student performance and student preference, with less attention toward how students are participating in technology-mediated learning activities, or the interplay between group social dynamics and technology use (Argüello & Dempski, 2022; Fombona-Pascual et al., 2022; Peterson et al., 2020; Vega Garzón et al., 2017; Wahyu et al., 2020). Without knowing how students are using AR technology in the classroom and how group social dynamics interact with technology use, new technological implementations are often treated as an intervention on learning rather than as a dynamic transformation of the learning environment.

1.2 | Impact of student-focused pedagogies

In the past, researchers have investigated the impact of student-focused pedagogies such as group activities on classroom equity, without considering the integration of novel educational technology, and have found that students do not participate in and benefit from these learning activities equitably (Marbach-Ad et al., 2016). Research on group activities in the classroom has found a variety of factors that may influence student participation, including academic achievement, group dynamics, and task structure (Chizhik, 2001; Marbach-Ad et al., 2016; Theobald et al., 2017). When using pre- and post-tests to measure student learning gains in an introductory biology course that implemented small group activities, Marback-Ad and colleagues (2016) found that students with cumulative GPA greater than 3.2 showed more improvement than those with lower cumulative GPA. Features such as student voice, visibility, and authority have been identified as key to equitable collaboration in group activities, while dysfunctional group dynamics such as inequitable participation between group members has been shown to negatively impact the learning experiences and outcomes of some students (Patterson, 2019; Theobald et al., 2017).

Similarly, Bianchini (1997) investigated the strengths and limitations of using group work to promote equity in science education. After administering a questionnaire to determine students' academic achievement and popularity as perceived by their peers, Bianchini analyzed classroom video data of a sixth-grade science classroom and showed that students with higher perceived academic achievement and popularity, that is, higher status, had greater access to their groups' material and discourse. Members in a student group valued the ideas of students with higher status more as signified by the group members copying the answers of higher status students. Student with low status, on the other hand, were often excluded from certain forms of participation in the group, such as fulfilling the role of the reporter, because members of the group did not perceive low status students as having the academic capacity for such tasks (Bianchini, 1997). From statistical analysis of students' rate of on-task talk, Bianchini also reported that higher status students had a significantly higher rate of on-task talk as compared to students with lower status. These findings showed that students' participation in group discussion was constrained both quantitatively and qualitatively by their peer-perceived academic achievement and popularity (Bianchini, 1997).

In addition to the perceived academic achievement and popularity, Chizhik (2001) examined how task characteristics may influence equity in collaborative group work and found modest evidence supporting the hypothesis that open-ended tasks, that is, tasks with multiple correct solutions, are more equitable for participation than single-answer tasks. Open-ended group tasks often require group members to make collective decisions, which offers multiple entry points for participation. When working on single-answer group tasks, however, students' social interactions mainly involve giving explanations and a single student may dominate or prematurely close off the group discussion. However, Esmonde (2009) investigated equity in group activities by analyzing the influence of activity structure and found that the activity structure itself is not enough to assess equity. More importantly, how the students perceive the activity and how the activity is executed by the students seem to influence whether the activity will produce equitable interactions. Given the complex social dynamics that influence student participation in group learning activities, understanding the role of technology in mediating student learning must also account for the social discourse around using and thinking with technology.

Race and gender differences were also observed in student participation in classrooms that adopted active-learning strategies such as group activities (Aguillon et al., 2020; Eddy et al., 2014). Despite representing an average of 60% of students enrolled in introductory biology courses, women participated less than expected in active-learning classrooms (Aguillon et al., 2020), and their voices represented an average of 40% of those heard by the instructor (Eddy et al., 2014). In a study on the outcomes for black students in team-based learning courses, researchers found that although peer evaluation scores had a positive, significant correlation with both course grade and cumulative GPA, black students received significantly lower peer evaluation scores despite having comparable course grade and cumulative GPA (Macke et al., 2019). These differences suggest that issues of inequity, particularly impacting historically minoritized populations in STEM such as women and people of color, remain prevalent in active-learning classrooms. The introduction of novel technology further complicates this situation and produces a unique intersection of race, gender, pedagogy, and technology.

1.3 | Theoretical framework

To investigate student participation in a group activity mediated by AR technology, we adapted the framework of participatory equity to our context (Shah & Lewis, 2019). Underpinning the participatory equity framework is a Foucauldian perspective on learning situations that views participation in classroom discourse as organized by power relations (Cornelius & Herrenkohl, 2004). From the Foucauldian perspective, power is understood not as an oppressive force that is possessed by some to impose upon others, but as a fundamental aspect of all social relations that produces discourse (Foucault, 1980). As students enter classrooms, they are entering into networks of power relations where power can be exercised in different ways during participation in social interactions, such as being recognized as capable learners and validating or dismissing certain ideas during group discussion (Cornelius & Herrenkohl, 2004). These valued forms of participation in the classroom are vital resources for learning and identity formation (Lave & Wenger, 1991). However, power relations can also produce hierarchal discourse patterns in which students access valued forms of participation differently. Inequity in this context can be thought of as the configuration of power relations that produces a social discourse that prevents some student from accessing the forms of participation that influence the potential for learning (Shah & Lewis, 2019). We explicitly focus on inequity because we see the potential for inequity as ever-present when students enter the classroom (Shah & Lewis, 2019). Linking the ideas of power, participation, and equity, the participatory equity framework provides a foundation for investigating the distribution of learning opportunities in a technology-mediated group learning activity.

Central to participatory equity is access to the conversational floor, a social space created when people enter joint endeavors. Engle et al. (2014) defined access to the conversational floor as "the degree to which the participant can initiate turns [in the conversation] when desired, complete them without interruption, and control who else has access to the [conversational] floor" (p. 8). Since this study focuses on the use of technology in the classroom, participatory equity can be thought of in terms of access to the technological conversational floor. As students engage in joint endeavors that involve the use of novel technology, the different ways that they are accessing the socially negotiated space of using technology to make arguments and solve problems can result in different situations of equity and inequity. Consistent with the participatory equity framework, we have focused our analysis on patterns in the quantity and quality of turn taking between students during a technology-mediated group learning activity. In addition, classroom inequity can become amplified within group work through small interactional moves, such as issuing commands to peers, that accumulate to broader patterns of inequity (Shah & Lewis, 2019; Shah et al., 2020; Wieselmann et al., 2020). As these small interactional moves continuously happen, the potential inequity in group work is also fluid and multifaceted. Even groups with the most equitable collaboration may have instances of inequity. Therefore, as we applied the construct of a technological conversational floor in the data analysis, we paid close attention to student interactions that may contribute to broader patterns of inequity (Ernest et al., 2019).

1.4 | Research questions

Given the increasing interest in developing and implementing AR-based molecular visualization tools in biochemistry classroom instruction, as well as the dearth of research on how inequity may emerge when new technology is introduced into group activities, the present study examines the student participatory patterns that emerged during a group activity with an AR visualization tool. Recognizing the ongoing-ness of technology development and the fluid nature of group dynamics, we have focused on understanding situations of potential inequity as they emerge from the interplay between technology implementation and social discourse in group activities, rather than evaluating technology as finished products and assessing their effect on reducing variations among individual student performances. Our investigation centers around a newly developed mobile application that utilizes AR technology to superimpose a computer-generated 3D model of the potassium (KcsA) channel onto the real environment (Doyle et al., 1998; Sung et al., 2019). The initial development of the AR model of KcsA channel was selected because it is a seminal, illustrative example of fundamental concepts in membrane transport that could also be broadly applicable to a wide range of course content (Doyle et al., 1998; Sung et al., 2019). The development of the AR model as well as the instructional module can be found in a previous publication (Sung et al., 2019). The focus of the current study is on understanding the different ways in which students interact with the AR model and the interplay between group social dynamics and how students engage with AR-mediated activities. Foregrounding equitable participation in the use of technology in the classroom, our guiding research questions are:

RQ 1. What are the different ways in which students participate in an AR-mediated group activity in a biochemistry classroom?

RQ 2. What are salient patterns of participation that may signify potential inequity in classroom technology use?

RQ 3. What is the interplay between group social dynamics and the introduction of AR technology in the context of a biochemistry technology-mediated group activity?

In the following sections, we will first describe the research context and methods of our study. Then, in our results section, we will first present the qualitative findings on the different ways in which students participate in an AR-mediated group activity. We will then present salient patters of student participation by organizing the quantified metrics of student participation at different resolutions, from whole class level to group level. We will lastly highlight potential inequity that emerged as we investigate the interplay between group social dynamics and technology use. In our discussion section, we will relate our research findings to the existing literature to situate this work within the broader context of biochemistry instruction, educational technology, social discourse, and equity.

2 | METHOD

2.1 | Research context

The current study is situated within a larger project aimed at iteratively developing and implementing AR-mediated instructional modules in biochemistry classroom instruction (Sung et al., 2019). Data in this study was collected from a Fall 2019 biochemistry course at a private college on a trimester system in the Midwest. The group activity involved the use of an AR model and was implemented in the fifth week of the term. As shown in Figure 1, the classroom was an active learning space with eight round tables that each sat 5–7 students, and one video camera was set up on each end of the classroom. In addition to the cameras, audio recording devices were placed at each table to capture student discussions during class.

The activity of interest in the present study is a group worksheet activity involving the use of AR technology in which students would collaboratively answer a series of single-answer questions about the potassium (KcsA) channel (Sung et al., 2019). The development of the AR model and the group worksheet activity has been published previously (Sung et al., 2019). Students were instructed to form groups at each table and engage in the worksheet activity collaboratively. At the midpoint of the group activity, each table of students was provided with two copies of the QR code and two iPads to engage with the AR models of the potassium (KcsA) channel and subsequently answered related questions (Sung et al., 2019). Some groups shared their materials collectively, while other groups divided themselves into two subgroups, with each subgroup having one copy of the QR code and one iPad. Class sessions were recorded (both video and audio) for the entire term to normalize the presence of the recording devices.

FIGURE 1 Layout of the classroom in this study. Students were free to choose their own seats and self-organize into groups during class.

2.2 | Participants

As the project set out to explore the phenomenon of student participation in an AR-mediated group activity in the biochemistry classroom space, the sample of this study consisted of students enrolled a biochemistry course where the AR-mediated group activity was implemented. This sample population was chosen because the AR mobile application of interest was implemented as part of the course curriculum. As the data analysis progressed, with-in case sampling was done to further focus the analysis on the student group that engaged with the activity most extensively in order to gain more insights into the interplay between social dynamics and technology use (Rapley, 2014). A total of 34 students were enrolled in the course. However, due to the placement of the cameras, not all students were visible in the classroom video data. In addition, some students did not consent to participate in the study. As a result, a total of 22 students were included in this analysis, and 16 out of those 22 students completed the demographic survey. Information from the demographic survey is reported in Table 1. All student names are random pseudonyms.

2.3 | Data analysis

For our data analysis, we investigated classroom equity at multiple levels, from the whole class level to the individual student level, to highlight different patterns of student participation (Reinholz & Shah, 2018). We engaged in three stages of data analysis to gain insights on patterns of student participation in the AR-mediated group activity. At the beginning of the first stage of data analysis, raw data from the classroom video and audio recordings of group discussions were transcribed to produce descriptive accounts of the video data and transcripts of the audio recordings, respectively. From the descriptive accounts, relevant segments of the classroom video recordings, that is, those of the AR-mediated group activity, were identified to reduce the raw video footage to vignettes for further analysis. Since the goal of the data analysis was to investigate the emergent patterns of student participation in the AR-mediated group

TABLE 1 Student demographic survey results

Pseudonym	Gender	Year	Major	Ethnicity	Post-grad plan
Barry	Man	Senior	Biology	White	Medical School
Maya	Woman	Junior	Computer Science	Asian	Medical School
Eymen	Man	Junior	Biology	White	Medical School
Eustaquio	Man	Senior	Biology	Asian	Medical School
Vedran	Man	Junior	Chemistry	Black	MD/PhD
Michael	Man	Senior	Chemistry	Asian	Medical School
Paulene	Woman	Senior	Biology	White	PhD
Nelly	Woman	Senior	Computer Science	White	Medical School
Adsila	Woman	Senior	Chemistry	White	MD/PhD
Yolotl	Woman	Senior	Biology	White	Vet School
Rose	Woman	Senior	Chemistry	Black	MD/PhD
Marlies	Woman	Senior	American Studies	White	Medical School
Shun	Woman	Senior	Biology	White	Medical School
Nick	Man	Senior	Biology	White	Medical School
Erik	Man	Senior	Biology	Black	Medical School
Steve	Man	Senior	Chemistry	White	Unsure

activity and model the interplay between group social dynamics and technology use, vignettes of classroom video recordings were then coded using an inductive coding method inspired by grounded theory (Corbin & Strauss, 1990; Strauss, 1987; Taber, 2000). Because the intersection of educational technology and group activity is rarely examined for the interplay between social dynamics and technology use, the inductive coding process affords us the flexibility to attend to emergent categories and relationships while remaining informed by existing literature and the framework of participatory equity (Shah & Lewis, 2019). The coding process began with creating analytical memos and preliminary codes that notes the incidents where students were interacting with the AR technology and contributing to group discussions. Using the constant comparative method, the analytical memos and preliminary codes were compared and grouped into categories of different types of interaction that students had with the AR model (Corbin & Strauss, 1990). The descriptions and definitions for each category were compared with those from previously analyzed video segments to confirm or disconfirm conjectures, and the variations between the categories were delineated (Corbin & Strauss, 1990). Two undergraduate research assistants and one graduate research assistant independently coded the classroom video recordings and used a process of argumentation to come to consensus regarding the development of the codes (Schoenfeld, 1992). The three researchers debated and fully resolved any disagreement during research team meetings to refine the descriptions and definitions of each category. Three modes of interaction with the AR technology and four types of contribution to group discussion emerged in this stage of data analysis. After debate and argumentation, all three researchers agreed on more than 93% of their coding.

In the second stage of data analysis, we used the EQUIP web app to analyze quantitative patterns of student engagement by tracking the frequency of participation (Reinholz & Shah, 2018). The EQUIP web app was first developed by a mathematics education researcher to quantify participation patterns in mathematics classroom discourse (Reinholz & Shah, 2018). It has also been applied across a variety of STEM and non-STEM settings (Reinholz et al., 2020). Using the web app, dimensions of classroom discourse can be cross tabulated with demographic markers from survey results to identify patterns of inequitable participation within a learning activity. For our study, the types of interactions and contributions identified in the first stage of data analysis were used as discourse dimensions to quantify students' participation in the AR-mediated activity. Definitions and illustrations of the types of interactions are provided further below in the results. Regarding the types of contributions, since the group activity was structured as collaborative single-answer tasks, we focused on the dimension of "giving an explanation" when analyzing the patterns of student participation because of its significance in accessing the technological conversational floor. Giving explanations during group discussion provided opportunities for students to express their ideas and have them validated by their peers. Since each student group was only given two iPads, the duration of each interaction was selected as a secondary discourse dimension to analyze the patterns of participatory inequity of the AR activity. We used interaction rate as a metric to capture proportional participation among group members (Reinholz et al., 2022). Interaction rate is defined as the total number of contributions divided by the number of students. As the data analysis progressed, with-in case sampling was done to further focus the analysis on the student group that engaged with the activity most extensively in order to gain more insights into the interplay between social dynamics and technology use (Rapley, 2014). Quantified participatory metrics were organized at the whole class level, group level, and individual student level to illustrate the complexity and dynamics of student participatory patterns.

Lastly, in the third stage of data analysis, informed by the salient patterns of student participation identified in the second stage, with-in case sampling was done to further focus the analysis on the student group that includes the students who emerged as dominant participants in order to gain more insights into the interplay between social dynamics and technology use (Rapley, 2014). Transcript excerpts and the quantified metrics of student participation were then analyzed together within the participatory equity framework to gain further insights into the interplay between group social dynamic and individual student participation. Transcripts of group discussions were analyzed for AR-related student talk. We then included quantified metrics of student participation in our analysis that focused on interactions that may signify students' social positioning of peers and valuation of the AR technology.

3 | RESULTS

Our findings will be presented in three parts. In the Part I, we will present the results from the qualitative analysis of the video data. We will describe the emergent modes of interaction that students had with the AR models, as well as their different types of contribution to group discussion. In Part II, we will discuss the patterns of participation from analysis using the EQUIP web app. Quantified metrics of participation will be presented from the whole class perspective first to give an overview of student participation. We then focus on the patterns of participation of one group to highlight differences in individual students' participation during the AR-mediated group activity. In Part III, we will remain focused on the single group and present qualitative analysis of the group discussion recordings to shed light on the interplay between group social dynamic and group members' access to the technological conversational floor.

3.1 | Part I: Qualitative analysis of student participation

3.1.1 | Modes of interaction

Three main modes of interaction emerged from the first stage of data analysis: (1) direct interaction, (2) indirect interaction, and (3) playful interaction. These modes of interactions are summarized in Table 2 below. To further illustrate the different modes of student interaction with the AR model, we present in the following vignette: a selection of snapshots from students interacting with the AR model as a group.

3.1.2 | Vignette 1: Student interactions with AR model

We observed three types of direct interactions: manipulating the iPad, manipulating the QR code while holding the iPad, and gesturing (Figure 2). These were grouped together as direct interaction because these interactions required students to directly make physical contact with the equipment used in the AR module. Moreover, these interactions provided greater degrees of access to the technological conversational floor since it was easier for a student to initiate their use of the AR model and complete without interruption when the iPad was in their direct control. In addition, direct interactions also afforded students greater influence on how others could access the technological conversational floor. For example, when a student was manipulating the iPad themselves, they could decide the angle from which the group viewed the AR model.

Indirect interactions included leaning over to look at the iPad screen, leaning over to touch the iPad screen, and holding the QR code for other students. These types of indirect interaction afforded less access to the technological conversational floor than direct interaction. For

TABLE 2 Modes of interaction with AR

Mode of interaction	Types of interaction	Description
Direct interaction	Manipulate iPad	The student holds the iPad and moves it around to view the AR model from different distance and angles.
	Manipulate QR code	While holding the iPad still, the student moves the QR code around to view the AR model from different distance and angles.
	Gesturing	While holding the iPad in one hand, the student gesture with the other hand in reference to the AR model.
Indirect interaction	Lean over to look	The student leans over to look at the iPad that is held by another student.
	Lean over to touch	The student leans over to touch the iPad that is held by another student.
	Hold QR code	The student holds the QR code and moves it around to help another student who is holding the iPad view the AR model from different distance and angles.
Playful interaction	Take picture with AR model	The student poses with the AR model as if it is a physical object and takes photos with the AR model in various poses.

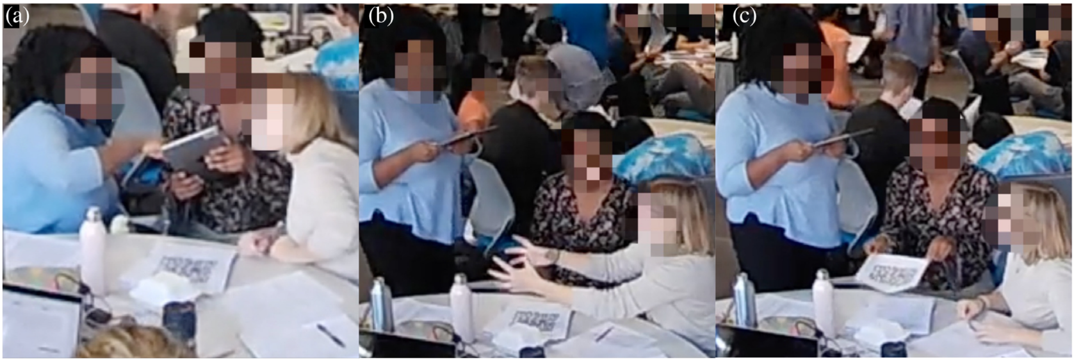

FIGURE 2 Types of student interactions with AR during group activity. (a) The student on the left is leaning over to touch the iPad (indirect interaction), the student in the middle is manipulating the iPad (direct interaction), and the student on the right is leaning over to look at the iPad (indirect interaction). (b) The student on the right is pretending to be holding the AR model while the student on the left is taking a picture (playful interaction). (c) The student in the middle is holding the QR code (indirect interaction) for the student on the right who is holding the iPad and viewing the AR model (direct interaction).

example, when a student was leaning over to look at the iPad screen, they did not have the privilege of choosing a viewing angle of their liking. When a student was holding the QR code for others, they often did not have access to the screen at all, and their interactions with the QR code were strongly influenced by the student holding the iPad.

Playful interactions with the AR module were more rarely seen, and mostly involve taking a picture with the AR model in various poses (e.g., taking a picture where the student is pretending to eat the AR model or hold the AR model in their hands). We interpret these playful interactions as nonacademic related interactions that may present students opportunities for community building.

3.1.3 | Types of contribution

We identified four main types of contribution that a student would make during group discussion: (1) asking a question, (2) giving an explanation, (3) challenging other's ideas, and (4) revoicing other's ideas. In the following vignette, we present an excerpt from a student group discussion as an illustrative example of the different types of student contributions. The excerpt shows a conversation between Barry and Maya about the stabilization of the potassium ion as it passes through the KcsA channel. The conversation took place prior to the group's engagement with the AR model.

3.1.4 | Vignette 2: Student contributions during group discussion

142: *Barry*: The carbonyl oxygen atoms basically serve as a proxy to the hydration shell.
143: *Maya*: And that makes it get rid of dehydration?
144: *Barry*: So, it compensates for the fact that you are losing the enthalpic stability of the

145: hydration shell by having all the interactions enthalpically favorable with the carbonyl
146: oxygen atom and the potassium ion.
147: *Maya*: Is it making it more stable? Wait. Wait a minute. Wait a minute. Maintaining
148: oxygen, replaces hydration shell, but they are compensating with what? What is
149: happening with the dehydration?
150: *Barry*: Normally the potassium by itself is a positive charge, not super stable, so what
151: normally would happen is that you have water forms a shell around it, so that stabilizes it,
152: but because it enters a small pore, potassium ion loses all of these. So now, um, when it
153: loses all the water molecules, it desolvates. So, it is back to its unstable single… imagine
154: that maybe…the carbonyl oxygen, serving as a proxy for [water].
155: *Maya*: Right, yeah.

The transcript excerpt above demonstrates the value of giving an explanation as a form of participation in group discussion. Barry and Maya were having a discussion on the chemical mechanism that stabilized the potassium ion as it enters the potassium channel. Barry offered an explanation that the potassium ion is stabilized because the carbonyl oxygen atoms can function similarly to the hydration shell (Lines 144–146). Maya then asked clarifying questions to Barry for a more detailed explanation (Lines 147–149), and Barry responded with an explanation that connects enthalpy to the stabilization of the potassium ion by carbonyl oxygen atoms (Lines 150–154). During this interaction, Barry was contributing most of the explanations and making connections between different chemical concepts. Maya's contribution, on the other hand, mostly consisted of asking clarifying questions and revoicing parts of Barry's explanation. Through giving explanations during discussion, Barry had the opportunity to verbally express the connections that he saw between the structure of the potassium channel, enthalpy, and the stabilization of potassium ion. As Maya accepted the explanation, Barry was also afforded the opportunity to have his ideas validated by peers and be recognized by his peers as a capable learner of biochemistry. Therefore, as we move to analyzing the patterns of student participation, we pay special attention to student contributions that involved giving explanations.

3.2 | Part II: Salient patterns of student participation metrics

To provide a multi-layered view of student participation, we analyzed patterns of student interaction and organized the quantified metrics at different resolutions, from patterns of the whole class to patterns of individual students. As previous literature has documented gender differences in participation in active learning classrooms, we will present participation patterns of the whole class in terms of gender first. We will then compare the participation patterns within and between student groups, and finally present the different patterns of participation on the individual student level.

As shown in Figure 3, the whole class equity analysis shows the broad patterns of student participation along the dimension of gender. Since no student self-identified as nonbinary, we

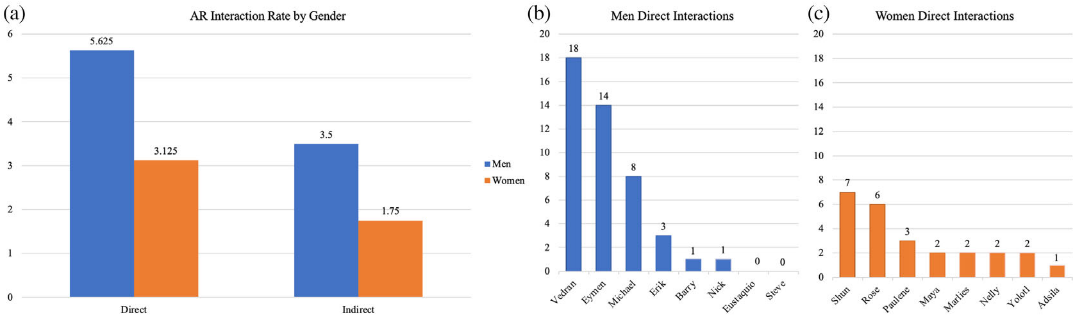

FIGURE 3 Whole class AR participation pattern analyzed along the dimension of gender. (a) AR interaction rate of men and women. (b) Total number of direct interactions of each man. (c) Total number of direct interactions of each woman.

compared our data for patterns within and across two reported genders. Overall, whole class participation patterns suggested that a small number of dominant men took up a disproportional amount of space in the technological conversational floor. Men had more total direct interactions with the AR model than women, but the participation disparity among men was wider. While women had fewer interactions with the AR module than men overall, there was also less disparity among women.

A total of 8 students in our study self-identified as men on the demographic survey, and they had a total of 45 direct interactions with the AR model, resulting in an interaction rate of 5.6. Similarly, a total of 8 students self-identified as women on the demographic survey. However, they had a total of 25 direct interactions, resulting an interaction rate of 3.1 for women. Although men represented only half of study participants, they accounted for *over* 60% of both direct and indirect interactions with the AR model. These whole class level participation metrics suggest that at there might be potential inequity between men and women. In addition, there was a large disparity of participation among men. The two most dominant participants, Vedran, a Black man who was a junior chemistry major, and Eymen, a White man who was a junior biology major, had over two thirds of direct interactions with the AR model, while Steve, a White man who was a senior chemistry major, and Eustaquio, an Asian man who was a senior biology major, did not have any direct interactions. These quantified metrics seem to suggest that there might be potential inequity among men as well. Women interacted with the AR model less frequently, but there was also less disparity in the participation among women than as was observed among men. Like the pattern of men's participation, two women, Shun, a White woman who was a senior biology major, and Rose, a Black woman who was a senior chemistry major, emerged to be the more dominant participants in the group activity. However, all women directly interacted with the AR model as shown in Figure 3. These metrics suggest that there might be potential inequity both between different genders and within the same gender. As such, gender alone does not seem to sufficiently capture the factors that are generating the potential for inequity.

As we have mentioned earlier, the AR model was used in a group activity. As such, we will now present our analysis of the patterns of participation for each group.

From Figure 4, we see that although each group was given the same number of iPads to access the AR model, the total number of interactions with the AR model varied greatly. The same physical material access to the AR model was provided by the instructor, but the six

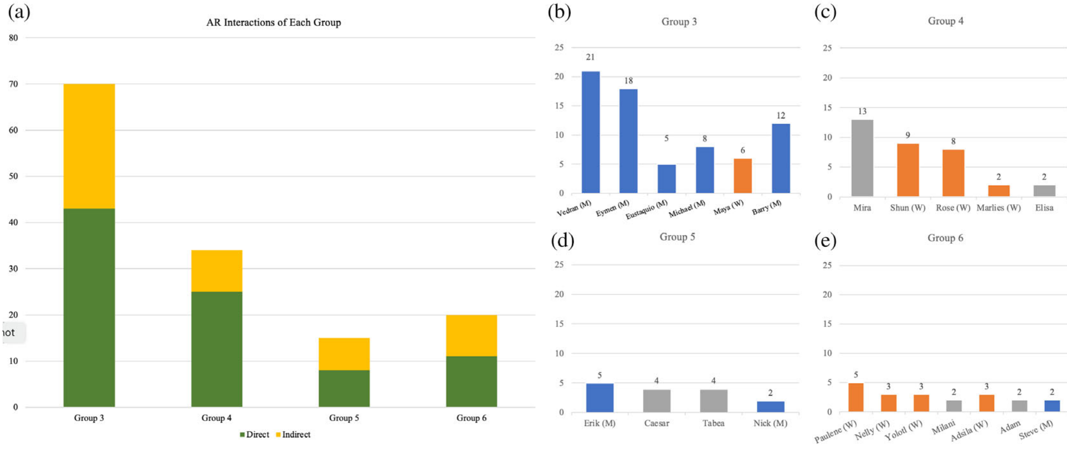

FIGURE 4 AR participation pattern of each group. (a) Each group's total number of interactions with AR. (b) Total number of AR interactions of each student in Group 3 (with gender information in parenthesis). (c) Total number of AR interactions of each student in Group 4 (with gender information in parenthesis). (d) Total number of AR interactions of each student in Group 5 (with gender information in parenthesis). (e) Total number of AR interactions of each student in Group 6 (with gender information in parenthesis).

students in Group 3 had a total of 70 interactions with the AR module while the seven students in Group 6 had only 20 interactions with the AR model. These group level participation metrics suggest that there might be potential inequity in how different student groups interact with the technology provided to them. Eymen and Vedran were identified as the dominant participants at a table that also engaged with the AR model most extensively (Group 3). As we have previously mentioned, Eymen and Vedran were responsible for two thirds of all interactions with the AR model by men for the whole class, and the analysis of group participation patterns showed that they were also responsible for more than half of all interactions in their group. Eustaquio, on the other hand, despite being in the same group as Eymen and Vedran, had no direct interaction with the AR model and a share of only 7% of all interactions in the group. Despite having the fewest interaction with AR model in his group, Eustaquio had the same number of interactions as Erik from Group 5 and Paulene from Group 6, who each had the most interactions in their respective groups. These quantified metrics suggest that in addition to potential inequity between different groups, there might be potential inequity in how members of the same group participate in an AR mediated group activity.

In addition to the variation in the quantity of the interactions, the quality of the interactions also varied. As shown in a more detailed analysis below, Eymen and Vedran not only interacted with the AR model more but also incorporated the AR model into their explanations more. These were considered higher quality interactions by the research team since they afforded access to AR-mediated science talk, which signified greater access to the technological conversational floor. As we moved from patterns of participation at the whole class level to individual groups, more complex patterns of student participation emerged. Students in Group 3 were the most engaged with the AR model, but two students within the group seemed to dominate access to the AR model.

As such, we will focus our further investigation exclusively on Group 3 for two reasons: (1) the quantity and quality of student interactions with AR model differ greatly between the two subgroups at this table and (2) the quantity and quality of individual student interaction with AR model differ greatly within each subgroup at this table. These variations in how Group 3 students were participating in the AR-mediated activity signify potential situations of inequity, so the patterns of participation of Group 3 students can provide rich information on the interplay between social discourse and technology use in the classroom space.

In Vignette 3, we present snapshots taken from video recordings of Group 3 student discussions to provide examples of students' interactions with AR. Shown in Figure 5, Group 3 divided themselves into two different subgroups according to instruction. Unlike other subgroups, the two subgroups of Group 3 seemed to work independently, in which members of different subgroups do not engage in any collaborative discussion between subgroups. The material resources for engaging with the AR model was also divided among the subgroups, with one copy of QR code and one iPad available for each subgroup.

3.2.1 | Vignette 3: Group 3 students' interactions with AR

Group 3b engaged with the AR model longer during the group activity as compared to Group 3a. As we can see in panel c of Figure 5, Group 3b was continued to engage with the AR model after all members of Group 3a had stopped and put the iPad away. In addition to quantity, the quality of interaction also varied between Group 3a and Group 3b. Group 3b used the AR model to mediate a significant portion of their discussion on the worksheet problems, while Group 3a switched to other tools, such as pen and paper, to mediate much of their discussion on the worksheet problems and treated the AR model more as a novelty object rather than a learning tool. The two subgroups in Group 3 presented two contrasting cases of interacting with the AR model. To provide insight on the contrast between how the two subgroups in Group 3 interacted with the AR model, both in terms of quantity and quality, we further focus our analysis on the difference in the patterns of student participation within Group 3.

Even though the two subgroups were sitting at the same table, they interacted with the AR model differently. As shown in Figure 6 above, Group 3b had almost double the number of total interactions with the AR model as compared to Group 3a, but one of the group members, Eustaquio, only shared around 10% of all interactions. As we mentioned earlier, Eymen and Vedran had the two highest incidents of direct interactions with the AR model while Eustaquio had none. Illustrated in Figure 5, the pattern of participation for Group 3b students seemed to be Eymen and Vedran physically taking charge of the AR model with Eustaquio leaning over to look at the iPad, which was either in Eymen's or Vedran's possession.

Students in Group 3a were engaging with the AR model less extensively as compared to Group 3b. Barry emerged as the student with the greatest number of interactions with the AR model in Group 3a, but his interactions were mostly indirect interactions. On the other hand, all of Michael's interactions were direct interactions with the AR model. Barry was engaging with the AR model extensively, but most of his interactions were collaborative with Michael in which Michael was holding the iPad and Barry was leaning over. We can also see from Figure 6 that Maya and Eustaquio were sitting furthest from the iPad. As such, they needed to overcome the physical distance to access the material for interaction with the AR model. Maya had to leave her seat and move to the other side of the table to see the iPad, and Eustaquio had to create space for himself between Eymen and Vedran. Maya and Eustaquio's physical distance from the material for accessing the AR model seems to be reflected in the number of interactions that they had. They were sitting the furthest from the iPad and had the least number of interactions with the AR model.

FIGURE 5 Group 3 students' interactions with the AR model at three different time points during the group activity. Two distinct subgroups formed within Group 3: on the upper left side of the table, Maya (left), Barry (middle), and Michael (right) formed Group 3a, and on the lower right side of the table, Eymen (left), Eustaquio (middle), and Vedran (right) formed Group 3b. (a) After obtaining the material for engaging the AR activity, Group 3 students divided into two subgroups, and each subgroup has their own iPad and QR code. (b) During the AR activity, both subgroups were interacting with the AR model collaboratively, but interactions between the subgroups were few. (c) Group 3a stopped interacting with the AR model while Group 3b was still engaging with the AR model collaboratively.

3.3 | Part III: Interplay between group social dynamics and use of AR

As we have shown in our analysis thus far, patterns of participation and situations of inequity involving technology in the classroom is multi-layered. Broader patterns of student

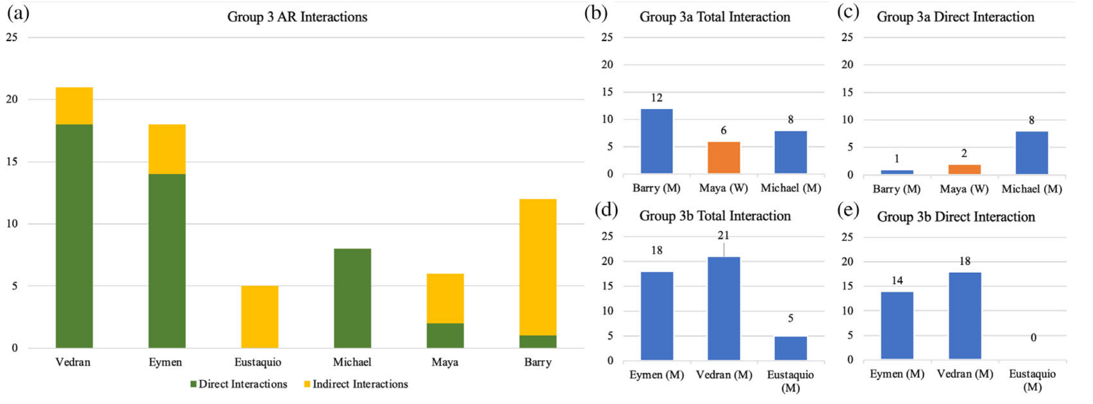

FIGURE 6 AR participation pattern at Group 3. (a) Each student's total number of interactions. (b) Total number of AR interactions of each member in Group 3a (with gender information in parenthesis). (c) Number of direct interactions of each member in Group 3a (with gender information in parenthesis). (d) Total number of AR interactions of each member in Group 3b (with gender information in parenthesis). (e) Number of direct interactions of each member in Group 3b (with gender information in parenthesis).

participation can be observed in the participation patterns of each group, subgroup, and individual student. In the next section of our findings, we will highlight the interplay between the social discourse among students and students' technology use by relating students' patterns of participation in group discussion to their patterns of interaction with the AR model. We will focus on giving an explanation as the main discourse dimension because previous literature has suggested that students who give more explanations have more access to learning opportunities in group discussions. Hence, we consider those students who gave more explanation during group discussion to be the more dominant participants.

In Figure 7, unlike the participation pattern of students interacting with the AR model, the participation pattern of students giving explanation during group discussion shows that the two subgroups gave similar total numbers of explanations. Members in Group 3a gave a total of 19 explanations during group discussion, and members in Group 3b gave 22. The participation pattern of students giving explanation during group discussion had strong resemblance to the participation pattern of students interacting with the AR model. Eymen, Vedran, and Barry all gave more explanations during group discussion, and they also had higher frequency of interactions with the AR model. Despite similar total numbers of explanations given during group discussion, members of Group 3b referenced the AR model in their explanations a total of 6 times while members of Group 3a did not incorporate the AR model into their explanations at all. The disparity between how much each subgroup incorporated the AR model into their explanations indicates not only a difference in how the two subgroups interacted with the AR model, but also in how the members of the subgroups potential value to the information provided by the AR model. While the AR model might be physically available to students, but it might not be incorporated into student learning in meaningful ways. We will present below two vignettes of students discussing the AR model to explore potential interplay between social dynamic and the ways in which the two subgroups interacted with the AR model.

Not only did students who gave more explanations have more access to the technological conversational floor, their opinion of the AR model also greatly influenced how their group interacted with it. For the two subgroups in Group 3, the students who gave the greatest number of explanations positioned the AR model differently.

3.3.1 | Vignette 4: Group 3a discussion on the AR model

502: *Maya*: Oh my god this is so cute! There's a protein on the QR code.
503: *Barry*: Yeah, but it's not very interactive. Although it being cool…but it does not… it's
504: not practical. Albeit cool, it is not the most… I don't know… I think I actually prefer
505: PyMol in this case.
506: *Maya*: I do not know about that!

From the excerpt above, we can see that Maya was excited about using the AR model during group activity and tried to challenge Barry's positioning of the AR model as not practical for their task at hand. However, since Barry was giving more than half of the explanations during group discussion, he dominated the access to the group's technological conversational floor. A significant portion of the group's problem-solving discourse revolved around Barry's ideas, so his attitude toward the AR model greatly influenced how the group interacted with the AR model. As the group worked through the worksheet questions together, despite Maya's enthusiasm about the AR model, the group did not engage with the AR model extensively. In addition, as shown in Figure 6, Maya herself also did not get many opportunities to interact with the AR model. Despite having few direct interactions with the AR model, Barry's overrepresentation in accessing the group's technological conversational floor may have contributed to a social discourse that suppressed further exploration of the AR model and subsequent incorporation of AR into group discussion. This may have exacerbated inequity in accessing the technological conversational floor for students who saw AR as a beneficial learning resource in subgroup 3a.

3.3.2 | Vignette 5: Group 3b discussion on the AR model

524: *Eymen*: It's gonna be so cool. I'm ready for it!
525: *Eustaquio*: It's not really gonna be that useful.
526: *Eymen*: Okay. Calm down. I'm excited. I'm not gonna let you kill my vibe.

Students in Group 3b had a similar conversation about the AR model, where one student expressed their excitement while another student doubted the usefulness of the new technology. One key difference between the two student conversations shown above in Vignettes 4 and 5 is the students' relative access to the group's technological conversational floor. Accounting for 46% of the explanations given during group discussion and 44% of direct interactions to the AR, Eymen was overrepresented in Group 3b's technological conversational floor. The social discourse produced by such a configuration of power relations valued the use of AR, and Eymen's enthusiasm was not suppressed by Eustaquio's doubt about the usefulness of the AR model. Unlike Barry, Eustaquio was giving few explanations during group discussion, so his attitude toward the AR model did not exert as much influence on the way in which the group discussion was mediated by the AR technology. The more dominant participants in Group 3b, Eymen and

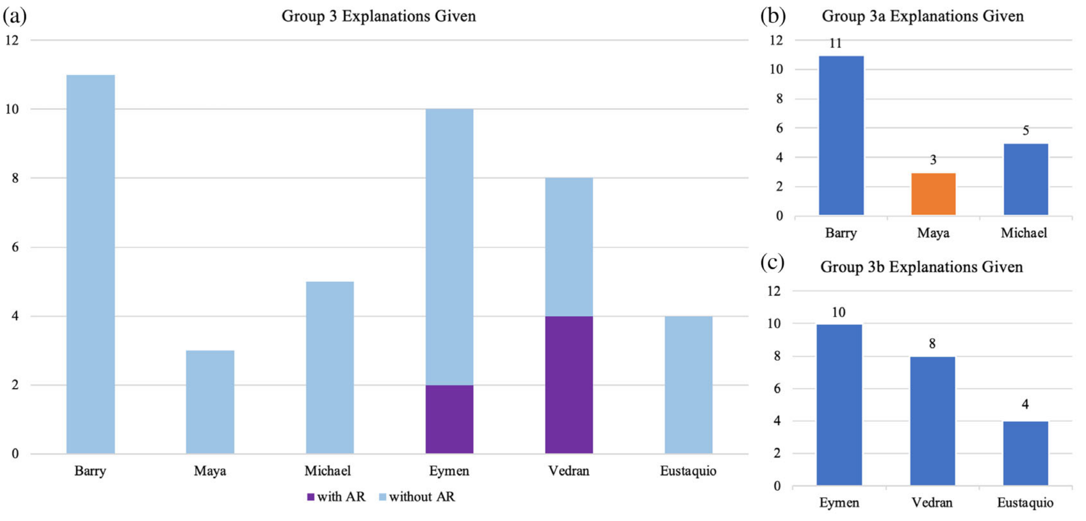

FIGURE 7 Group discussion contribution pattern at Group 3. (a) Total number of explanations that each student contributed during group discussion. (b) Number of explanations that each member of Group 3a contributed during group discussion. (c) Number of explanations that each member of Group 3b contributed during group discussion.

Vedran, continued to incorporate references to the AR model with relatively high frequency when they gave explanations during group discussion. The situations of inequity in group activity were fluid. The interplay between group social dynamic and the introduction of technology can produce different situations of inequity.

4 | DISCUSSION

The findings of this study add to existing literature on the introduction of AR technology into the biochemistry classroom by investigating potential issues of inequity in student participation. Prior work has primarily focused on inequity in terms of differential knowledge- or skill-based outcomes (e.g., Habig, 2020). Instead of assessing whether students were producing correct answers more frequently with an AR model, our analysis illustrated that the introduction of AR technology in the context of a student group activity in a biochemistry classroom was entangled with power relations that differently produced student subjectivities and their social status. Complex patterns of student participation could be produced by the interplay between social dynamics and the introduction of the technology.

Group 3's pattern of participation is an illustrative example that showed the perceptions that high-status group members had about AR seemed to influence how the group as a whole engaged with the technology and the value that was placed on the AR as a tool for learning. This, in turn, may shift the dynamics of who accesses opportunities to provide explanations during discussion, that is, limiting access to the technological conversational floor and subsequently limiting the potential for thinking with and learning from the AR. When Barry, a student with relative high status, signified by his dominant participation in giving explanations, positioned the newly introduced AR technology as less useful than those that were traditionally available, the group used the novel technology with relatively low frequency. On the other hand, Eymen, a student who gave more explanation during group discussion, positioned the AR model as a useful resource, his group's scientific discourse involved the AR model more extensively. However, engagement with the AR model did not extend to Eustaquio, the less dominant participant in the group. Whether these patterns of dominance in access can be shifted or modulated by instructional changes remains an area of future exploration. For example, along with instructions on getting familiar with the AR technology that mediated the group activity, it could be helpful to also include guidelines of equitable participation as part of the instruction. Requiring every student to submit their own picture of certain parts of the AR model may ensure that each student can have the opportunity to directly interact with the model and think about the spatial relationship between different parts of the model.

The potential of AR technology to improve student's learning experience is not a property of the technology itself but emerges through the interplay between the material conditions afforded by AR technology and the social discourse in classroom learning activities. Student can interact with AR models in ways different from models constructed with other technologies. For example, in our study students can interact with the biomolecular model by moving around physically rather than pressing buttons on a keyboard or moving the object with a mouse. The added movement can potentially offer opportunities for spatial learning and reasoning (Özçakır & Çakıroğlu, 2022; Papakostas et al., 2021). However, only those who were directly interacting with the AR module could access these learning opportunities. Direct interactions with the AR module may offer more access to the technological conversational floor, but our classroom video and audio data suggests that there were instances where an individual student would dominate their group's technological conversational floor by positioning the AR technology as less useful (Shah & Lewis, 2019).

4.1 | Discourse reflected in individual student participation

The participation of Maya, an Asian woman with hopes to attend medical school after graduation, emerged from our analysis as a particularly interesting case for the following reasons: (1) she was enthusiastic about the introduction of AR in the group activity but had few interactions with the AR model; (2) during group discussion, Maya took up the task of recording the group's answers on the worksheet, but these answers mostly came from the explanations that were contributed by Barry or Michael, her male group mates; (3) our demographic survey suggested that she was the only Asian woman who participated in the study. From Figure 5c, we can see that Group 3a completely stopped using the AR model. At this point in the group discussion, although no one is using the material for accessing the AR model and despite being enthusiastic about the AR model, Maya continued with her task of recording the group's answers instead of interacting with the AR model.

Although we did not have interview data to inform us on Maya's perception of her experience, from what we could observe in the video and audio recordings of the group activity, her pattern of participation reflected the societal broader discourse around race and gender in STEM. Asian women experience STEM learning environments as both racialized and gendered spaces, often confronting different stereotype threats (e.g., the stereotype that Asians are innately good at STEM, and the stereotype that Asian women are passive and compliant) simultaneously (Castro & Collins, 2021; Shah, 2019). These stereotype threats can pressure Asian women to avoid behaving in stereotypically masculine ways, such as asserting themselves when their peers expressed doubt about their ideas (Castro & Collins, 2021). During group discussion, Maya did not assert her own ideas as frequently as her male groupmates; and we can also see from Vignette 4 and 5, Maya and Eymen responded to remarks that challenge their enthusiasm toward AR very differently. Maya's response seemed polite and passive, expressing reservation toward Barry's criticism of AR. On the other hand, Eymen's response to Eustaquio seemed assertive, dismissing Eustaquio's criticism of AR while reiterating his unfazed enthusiasm. As a result, Maya and Eymen had different access to their respective subgroup's technological conversational floor. Maya's participation in the AR-mediated group activity was reflective of the intersectionality of Asian women in STEM and future work investigating how the existing inequitable discourse resulting from intersectionality between race and gender can be experienced by individual students as differential access to the technological conversational floor should be considered.

4.2 | Limitations and future work

One of the limitations of our study was that our investigation centered on only one technology-based group activity in a biochemistry course largely composed of fourth-year students in their last year of college. It is likely that these contextual factors—frequency of interactions with technology and student experience/familiarity with each other and the institution—could also exert an influence on the observed differences in power relations and group dynamics. Future work is necessary to examine the influence of these technology-related inequities in broader contexts, such as use technology-mediated group activities by first- and/or second-year students and impacts of these technology-related inequities on student experience within STEM as a whole.

Our investigation was limited to the implementation of only one type of technology, that is, AR, but our findings showed that students related and compared the different types of technology that were implemented in the course. For example, Barry compared AR to PyMol when voicing his opinion that the AR model was not practical. Future work is needed to examine the differences in student participation in learning activities that were mediated by different types of technologies and how different types of technologies could be coordinated to attenuate potential inequity in student participation.

4.3 | Toward a more nuanced view of equity and inequity in biochemistry instruction

Rather than investigating differences in performance-based outcomes, we adapted the participatory equity framework to provide a view of equity that is attentive to the power relations that may orient students and technology differently to move research on issues of inequity in biochemistry educational technology beyond assessments of knowledge- and skills-based outcomes. Pairing quantitative metrics with qualitative analysis, our mixed-methods analysis produced a complex story of student participation in an AR-mediated group activity. The patterns of student participation at different resolutions, from whole class to individual students, showed that equity and inequity in AR-mediated biochemistry group learning activities are fluid and multifaceted. This study provides a more nuanced way of conceptualizing equity and inequity in biochemistry learning settings and technology-mediated experiences. We explicitly focused on inequity rather than equity because we see the classroom as a network of power relations, and the potential for inequity as ever-present within power relations. As such, investigating potential situations of inequity in AR mediated group activity can provide useful insight for attenuating inequity in the broader effort of incorporating technological and pedagogical innovations to build more equitable learning environments. As technology becomes ever more prevalent in our classrooms, it is imperative to continue expanding our conception and evaluation of equity beyond access to the physical technology itself and performance- or knowledge-based outcomes to how utilization of that technology in the classroom impacts access to opportunities to participate in learning.

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