Investigating the Effects of Instructor Facilitation on Student Engagement in a POGIL-based General Chemistry Class

by
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Dedication

This study is wholeheartedly dedicated to my family. A special feeling of gratitude for my loving late grandmother, Awatef Macein, and late God-grandmother, Marcil Atalla, who gave me the heart that I have today and who always prayed for me and my success.

I also dedicate this dissertation to my great parents who never stop giving of themselves in countless ways and whose words of encouragement and push for tenacity ring in my ears. I will always appreciate what they have done and constantly do for me.

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Finally, I would like to express my gratitude to my family and friends. Without their tremendous understanding and encouragement over the past few years, it would be impossible for me to complete my study.

Abstract

Student participation in small group discourse is a vital role in language acquisition, student engagement, and ultimately student achievement. Scholars note that even minor differences in facilitation can create significant differences in students' engagement in discursive practices, and ultimately their understanding of chemistry concepts. This research investigates the relationship between the instructor facilitation approach and student discourse in a POGIL-based General Chemistry Classroom. The following research question guided the study: How does the instructor's facilitation approach affect student engagement in a POGIL-based General Chemistry Class?

Transcripts of class meetings were qualitatively analyzed for the nature of social interactions using previously established discourse frameworks. Mainly, the participating instructor used a Noninteractive/Authoritative facilitation approach to facilitate the POGIL activities. It was found that the instructor discourse impacts students' level of student-student discourse. However, different group compositions were affected by instructor facilitation differently.

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CHAPTER I:
Introduction

Science, technology, engineering, or mathematics (STEM) classes introduce various scientific, multi-meaning concepts with precise usages that may differ from the common meaning of words. In General Chemistry classrooms, professors aim to help students develop a broad understanding of ideas, methods, and an array of concepts in chemistry (National Research Council, 2012). Since conversational strategies and other methods of communication develop meanings in science classrooms, it is important for one to observe and analyze patterns of student-student and student-facilitator discursive moves in various classrooms and group discussions. Student Discourse, or students talking on-topic in an academic environment, is vital to language acquisition, student engagement and ultimately student achievement. Student discourse can happen at the partner, group, whole class, or student-to-teacher level. When students discourse, they reveal their thoughts and ideas to their peers and instructor. When students gain knowledge of concepts, they tend to spend time debating, justifying, and explaining (Stanford et al., 2016). Student argumentation is usually associated with a strong understanding of concepts and improved critical thinking skills and scientific literacy.

Recent research confirms that students are less likely to learn and engage in knowledge construction in traditional STEM lecture-based classrooms. While lectures, visuals, and readings are considered passive learning, active learning is when students engage in deep discussions, exercise problem-solving, and teach each other important methods and concepts. Through discussions and negotiations, students are provided the opportunity to practice applying the skills that they are in the process of learning. Also, discourse allows students to externalize, objectify, and reflect on knowledge, which reinforces critical concepts by allowing students to form personal and meaningful connections with the information presented (Wiggins et al., 2017). Key features of an active learning classroom exercise are that students are given a question or problem to solve, work together in teams, and have some prior knowledge that informs their ability to respond to questions.

Active learning creates student-centered environments that enable students to question information, synthesize knowledge, and apply their understanding. In active learning-based classrooms, the instructor becomes the facilitator and knowledgeable co-learner rather than the master of the subject matter. Often active learning environments include a collaborative component that requires students to interact with one another and with the instructor (i.e., facilitation; Freeman et al., 2014). Collaborative learning is one of the many educational approaches that employ active learning. Process-oriented guided inquiry learning (POGIL) is a teaching strategy that is used to engage students in the classroom and to promote learning (Hanson, 2006). The POGIL strategy begins by introducing students to a diagram, problem, or set of data and then requiring students to work in small groups on answering a series of questions leading to the development of a concept or principle (guided inquiry). Thus, POGIL uses elements found in team-based and problem-based learning.

Wright (2019) mentions that for a classroom to truly be student centered, it needs to effectively implement collaborative learning. However, the effects of collaborative, student-centered POGIL activities are mediated by several factors including, but not limited to, the learning interactions (Anderson et al., 2007; Fredricks et al., 2004). Learning interactions include the interactions that a student has with his or her peer and instructor to construct knowledge. Since the factors effecting POGIL-based classrooms inform instructors about the outcomes of their facilitation, it is important to analyze how these factors affect students' discourse. The facilitator's role is to create learning opportunities, guide the discourse, and simplify the tasks while maintaining the students' active role in learning (Ejiwale, 2012). When successfully implemented, the instructor's facilitation can be a critical aspect of the learning process and an indicator of the students' engagement (Martin et al., 2019), course performance, and reinforcement of critical thinking (Emmanuel & Ekpo, 2016). Scholars note that even minor differences in facilitation can create significant differences in students' engagement in discursive practices, and ultimately their understanding of chemistry concepts (Daubenmire et al., 2015; Stanford et al., 2016). Different facilitation approaches used by instructors seem to be associated with improved student discourse and interactivity.

This project is a small portion of a major collaborative team project that explores classroom discourse in active-learning environments for large-enrollment chemistry courses. The purpose of this study is to characterize classroom discourse using a qualitative research approach. Since the classroom learning environment is complex, it is easier to focus on specific areas of interest. For this project, I focus on examining the instructional approaches and discourse moves used by the instructor to foster productive conversations among students in their small groups. The information gleaned from this project answer questions about critical features necessary to foster student engagement, productive discourse, and knowledge construction in the classroom. The following research questions guide this study:

- What are the different facilitation approaches used by the instructor in a collaborative, POGIL-based, introductory General Chemistry course?

- What is the relationship between various facilitation approaches used by the instructor and student discourse patterns in a collaborative, POGIL-based, introductory General Chemistry course?

CHAPTER II:
Review of the Literature

POGIL

Recent studies have revealed that students have positive learning outcomes when engaging in collaborative settings that use active-learning strategies (Cooper et al., 2008). Process Oriented Guided Inquiry Learning (POGIL) is an instructional, student-centered approach in which students work collaboratively to develop an understanding of a specific concept (Moog & Spencer, 2008). In a typical POGIL classroom, students work together in a small group to work on specially designed activities, which allow students to investigate viable ideas through prior knowledge. POGIL activities consist of models and questions that are designed to encourage student engagement and discourse.

As each group of students work through the POGIL activities together, they share and discuss information, assess contributions made to the discussion, and reflect on their understanding. Students' discourse can allow each student to construct new understanding of concepts and knowledge during the conversation (Vanags et al., 2013). Various studies have found POGIL to be an effective active-learning strategy at different levels of chemistry classrooms (Artuz & Roble, 2021). Since these activities require collaborative learning environments, instructors act as facilitators and take a passive, supporting role in this student-centered environment.

Active Learning

The research question in this study focuses on facilitation talk and its effects on students' discourse moves, argumentation, and knowledge construction in active-learning settings. Although there are plenty of studies that research collaborative and active learning, the underlying mechanisms behind knowledge construction, student argumentation, and student discourse are frequently not understood due to the complicated nature of relationships and the many elements of students' experiences that affect learning. Multiple research studies suggest that the learning performance of a student in collaborative settings is mediated by several factors including learning interaction (Chacón-Díaz, 2020), learning design (Simonson, 2019), and learning environment (Thai et al.,2020). Learning design is the activity used to facilitate learning or structure of learning. Learning interactivity refers to student-student interactions and the student-instructor relationship, and the learning environment is the space, context, and/or culture in which students learn.

Facilitation

Although active-learning settings are student centered, the facilitator's role in collaborative learning is undeniable (Stanford, 2016; Liyanage et al., 2021). For a classroom to truly implement student-centered learning, collaborative learning needs to be effectively implemented. However, sometimes students lose their sense of accountability and/or have trouble understanding concepts (Wright et al., 2019). It is the role of the facilitator to manage and check on students' status. While the facilitator guides the learning process, students must be the primary drivers of this active educational process to be independent, successful learners. Scholars note that even minor differences in facilitation can create significant differences in students' engagement in discursive practices, and ultimately their understanding of chemistry concepts (Daubenmire et al., 2015; Stanford et al., 2016).

Since instructors mainly use their words to interact and facilitate teams, instructors' discourse needs to be analyzed to understand its effects on students' discourse and interactions (Anderson et al., 2007; Fredricks et al., 2004). Analyzing the discourse moves of an instructor provides insight into the effective facilitation of active-learning environments and assists instructors in recognizing how they can support learning. The talk-turn analysis particularly suits POGIL classrooms where students talk about course content in groups. In this study, the Communicative Approach and the Inquiry-Oriented Discursive Move (IODM) are two analytical frameworks that are used to characterize student-instructor discourse in inquiry-driven classroom settings (Mortimer & Scott, 2003; Rasmussen et al., 2008). The Student Interaction Discursive Moves (SIDM) framework is used to describe student-student interactions, (Nenning et al., 2021). To visualize and analyze all interactions in the classroom, Social Network Analysis (SNA) is utilized in this study (Liyanage et al., 2021).

Instructor Communicative Approach

Instructor discourse presents an essential part of students' understanding of ideas in STEM courses. To understand discourse in active-learning classrooms, both student and instructor talk needs to be considered. Focusing on the instructor talk first, the instructor talk was coded using Mortimer and Scott's Communicative Approach framework (Mortimer & Scott, 2003). This analytical framework categorizes patterns of instructor talk considering student-instructor conversations as a whole. The Communicative Approach framework characterizes facilitation on two dimensions: Authoritative/Dialogic and Interactive/Noninteractive. The first dimension considers where the talk lies on a scale from Dialogic to Authoritative. Dialogic interactions consider more than one perspective or point of view while Authoritative interactions focus on only one point of view, usually considering the teacher's point of view or the correct answer to the task. The second dimension considers where the talk lies on a scale from Interactive to Noninteractive. Interactive discourse is when the instructor allows for the participation of students in a talk. Noninteractive discourse is when the instructor talks while students listen with excluded from the conversation. Figure 1 shows how the two dimensions generate the four categories of talk.

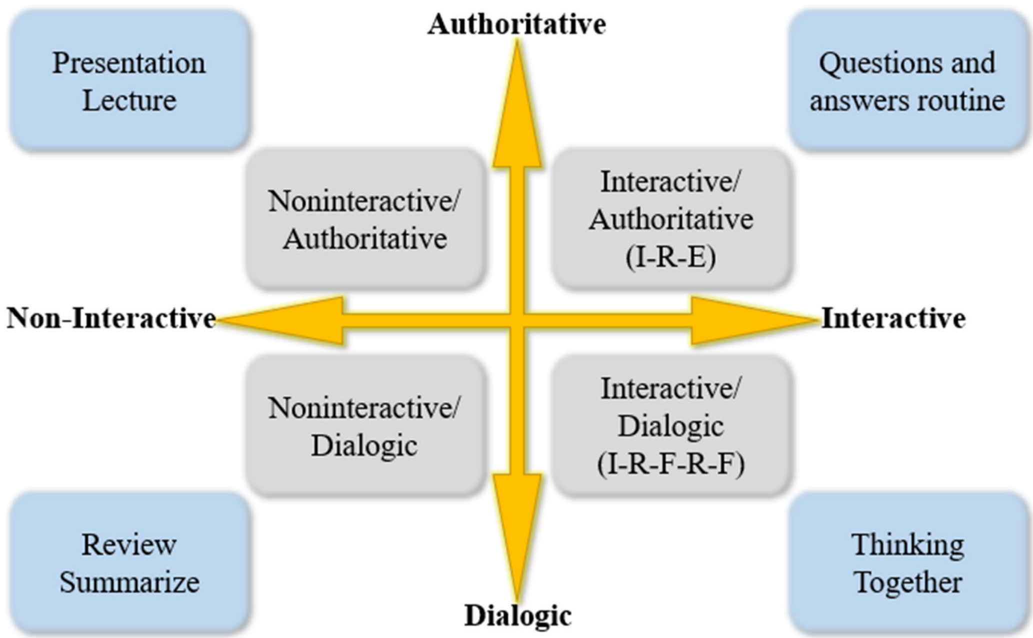


Figure 1. Dimensions and categories of the Communicative Approach (Mortimer & Scott, 2003).

The first category is Noninteractive/Authoritative. This is when the instructor focuses on one point of view without considering students in the conversation. One primary example of this category is when the instructor lectures to explain or convey information to the students about concepts or procedures without involving them in the talk. The Interactive/Authoritative category is when the instructor initiates the conversation with a single correct answer in mind. This is a very common interaction that uses the Initiation-Response-Evaluation (IRE) pattern. In this type of conversation, the instructor checks student understanding and/or guides students to recite the correct answer. In the Interactive/Authoritative category, the instructor uses closed-ended questions, allows students to utter brief responses, and evaluates students' responses against the correct answer or concepts. This generates a question-and-answer routine that leads students to a certain answer.

The third category is Noninteractive/Dialogic interactions. This describes when the instructor tells students about different points of view (Alexander, 2020). In these types of interactions, the teacher dominates the talking, but he or she acknowledges different points of view and considers them. Primarily, the instructor reasons through or across different perspectives on his or her own. For example, an instructor can reference an idea that was previously expressed by a student as the instructor explains his or her own point of view. Interactive/Dialogic interactions are when an instructor thinks with students through different points of view (Phillipson & Wegerif, 2016). For example, the instructor can initiate using an open-ended question that bears no correct answer while showing interest in and value for the student's contributions. In this case, the instructor explores different answers without evaluating them, but he or she provides feedback. It is yet better when other students dwell and provide their feedback on others' ideas or points of view. It is important to note that each and all approaches are valuable and contribute to student engagement and learning. During a single teaching episode, instructors may switch between Communicative Approaches, depending on the instructors' teaching objective. To gain a better understanding of student-student and student-instructor interactions, other analytical frameworks consider the use of talk-turns as the units of analysis. All definitions and examples of each category are included in the Communicative Approach codebook (see Appendix A).

Inquiry-oriented Discursive Move (IODM)

To further understand the discursive moves occurring in a classroom, one may use the Inquiry-Oriented Discursive Move (IODM) framework to code and process collected classroom data. Like the Communicative Approach framework, the IODM framework is an analytical tool used to interpret and analyze the instructor discourse in the classroom. However, the IODM framework studies the influence of four types of teachers' discursive moves on classroom learning and teacher-and-student inquiry (Stanford, 2016). Evaluating classrooms' discourse using the IODM framework provides a detailed understanding of the instructional discursive techniques necessary to improve inquiry-based classrooms.

Since this study examines the role of the facilitator in students' learning, the Inquiry-Oriented Discursive Move (IODM) framework is used to define and analyze the instructor's discourse in the classroom (Rasmussen et al., 2008). This framework is used to focus on aspects of discourse not captured by the Communicative Approach framework. The IODM framework answers questions about how the talks of an instructor contribute to classroom learning in an inquiry-based classroom. This framework looks at and provides codes for every single talk-turn uttered by the instructor separately. The IODM framework studies the influence of four types of teachers' discursive moves on classroom learning and teacher-and-student inquiry (Stanford, 2016). The IODM framework focuses on and codes individual utterances separately. The discursive moves used by the instructor provide a comprehensive understanding of effective facilitation in active-learning environments. This framework categorizes the instructor's discourse moves into four major types, and each major discourse move is further divided into four subcategories of discourse types. Figure 2 shows the major categories of discourse moves and the subcategories contained under them.

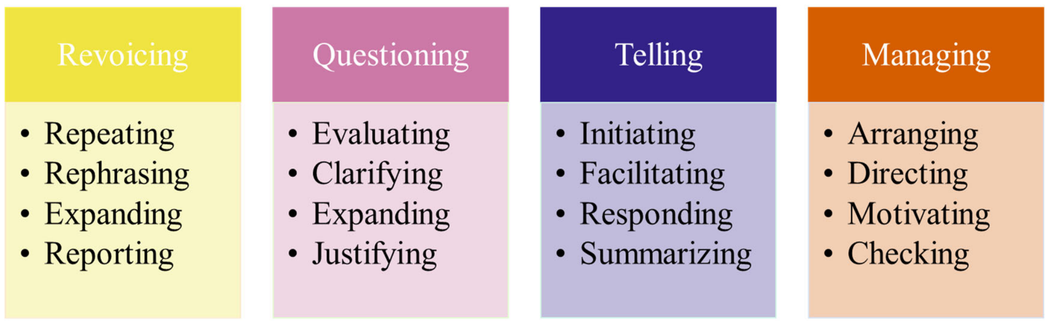


Figure 2. Inquiry-oriented Discursive Move (IODM). Codes of instructor discourse and corresponding subcategories. Each type of discourse is assigned a colour, which will be used to indicate instructor engagement as node colours in graphs (Rasmussen et al., 2008).

"The four discursive moves are Revoicing, Questioning/Requesting, Telling, and Managing" (Rasmussen et al., 2008). A Revoicing discursive move is when an instructor repeats someone else's utterances (Nam et al., 2008). Revoicing shows a high level of interest in what the students were saying in a team. A Questioning discursive move is when an explicit question is directed to students. These questions serve various purposes, such as checking students' understanding, requesting clarification, or seeking justification for an answer. A Telling discursive move is described by information being stated, procedures presented, and/or answers provided. This discourse move is used to move discussions forward, guide students to tasks or ideas, or direct students' argumentation. Normally, a Managing discursive move does not contain content-related information, but it focuses on classroom directing attempts that are used to arrange, motivate, or check on the status of students to increase student engagement. All definitions and examples of each discourse move are included in the IODM codebook (see Appendix B).

Student Interaction Discourse Moves (SIDM)

After understanding the instructor's discursive moves, the Student Interaction Discourse Moves (SIDM) framework is needed to code and understand students' discourse. The SIDM codebook is divided into three levels of discourse: type of interaction, primary intent, and nature of utterance. Figure 3 shows the three levels of student discourse and the codes included under each level. Type of Interaction is the surface-level code of students' utterances, and it describes students' interactions during small group activities. The Primary Intent codes describe for what purpose the student is speaking while the nature of utterance codes describe how students engage in a specific discourse move. The Nature of Utterance codes are the deepest levels of student discursive moves. All definitions, key features, and examples of each level of discourse are included in the SIDM codebook (see Appendix C).

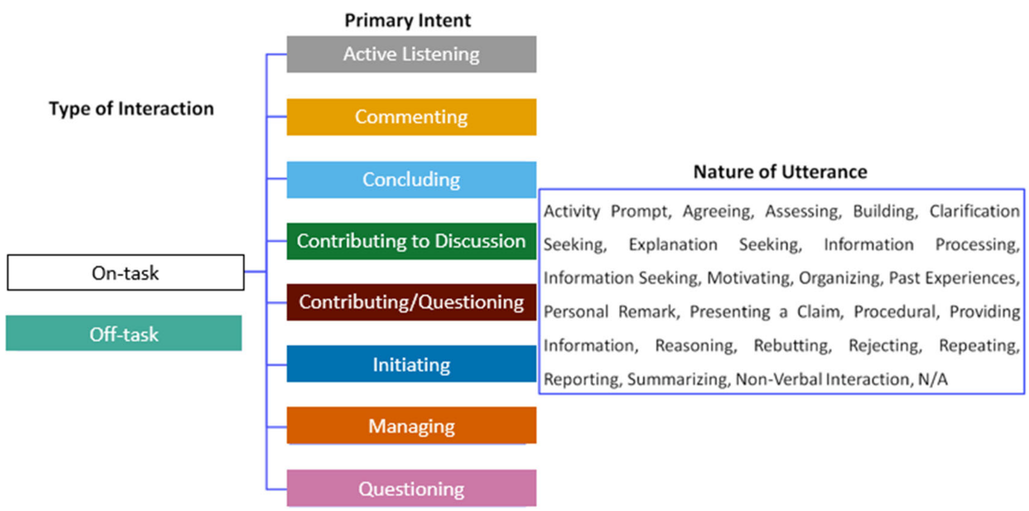


Figure 3. Student Interaction Discourse Moves (SIDM). Modes of student engagement behaviours and corresponding primary intents. Each level is assigned a colour which will be used to indicate student engagement as edge colours in graphs (Nenning et al., 2021).

Social Network Analysis (SNA)

In recent years, there has been an increased focus on analyzing the patterns of classroom discourse between students and teachers to support meaningful learning. Student discourse is the active engagement of students in on-topic discussions with one another about an academic topic in a classroom (Lloyd et al., 2016). When instructors analyze student interactions in their classrooms, the instructors learn the patterns of student interactions and gain insight into students' understanding. These analytical observations help instructors develop appropriate activities and classroom strategies, which in turn improve academic learning and class outcomes (Lemke, 2012). Data and observations collected from the student discourse analysis assist instructors in building suitable activities and using appropriate approaches in their classrooms.

In discourse analysis, talk turns are the organization of student conversation where one participant speaks at a time. In a conversation, a talk turn starts when one person starts talking while the other person listens, and a talk turn ends when the person who was talking stops. A new talk turn starts when the person listening starts talking. As a conversation progresses, the listener and speaker roles are exchanged back and forth. In this research, talk-turn analysis is considered while analyzing the data using Social Network Analysis (SNA) to qualitatively investigate student discourse. The use of social network analysis allows instructors to visualize data to detect critical issues in a network, which would be otherwise overlooked by simple classroom observation (Martineza, 2003).

SNA of student-centered classrooms is the study of the social structure of the group members, and it is based on theoretical constructs of sociological and mathematical foundations of graph theory. The SNA is an analytical tool that relates data and analyzes it with visual, statistical, and mathematical procedures to understand the characteristics and mechanisms of social interaction (Freeman, 2011). Since it is important to analyze and understand factors that affect student discourse and knowledge construction, the SNA can reveal important information about the course design, the group composition, and students learning.

A social network perspective is different from that of traditional analyses because it focuses on individuals with similar network positions due to shared attributes rather than dividing students into groups based on their common attributes. These similar network positions may cause the same social influences on the students. The influences may be an important piece of a causal chain that produces a similar outcome. In social networks, individual students are nodes, and the relationships among the individuals are edges. The number of edges between nodes plays a role in the calculation of the importance or centrality of a node.

Figure 4 illustrates the steps of constructing a social network graph using a hypothetical student discussion. Figure 4a is a transcribed student discussion used to determine the students' order of speaking. Then, the transcribed discussion is converted to an edge list as shown in Figure 4b. Each edge represents a talk-turn and is depicted as a directed arrow pointing from the student who has just spoken to the student or students being directly spoken to. Therefore, an edge may represent how the discussion turns from one participant to another. Edges were directed to all students in the group if the student speaking to everyone in the group because everyone in the group could be listening.

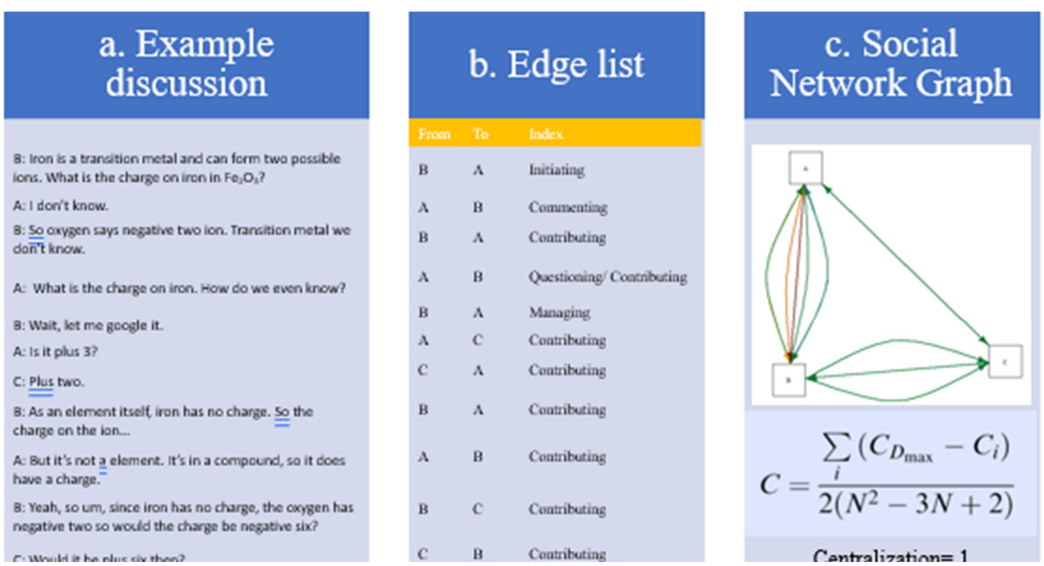


Figure 4. Graph construction from a discussion. The transcript of a sample discussion is coded and (a) converted to a list of edges (b), and the edge list is used to construct a discourse network graph (c) (Liyanage, 2021).

A social network could be directed or undirected depending on the type of edges present in them. In a directed network, edges are usually visualized as arrows pointing from the starting node to another node. Undirected networks link two nodes reciprocally with straight lines, without arrowheads. In this study, only directed networks are used and analyzed. Figure 4c shows an example of a directed social network. The strength of social relationships is measured in a social network in terms of in-degree and out-degree. Node degree describes the number of edges or links connected to a node. In directed social networks, the in-degree is the number of edges leaving the node, and the out-degree is the number of nodes pointing towards a node. As the number of edges increases between any two nodes, the proximity (distance) between nodes decreases, representing a stronger relationship.

CHAPTER III:
Methodology

Participants and Setting

To answer the research question, data were collected during the Spring 2021 semester from a General Chemistry I classroom at a large public university located in the southeastern United States. The course was taught by a professor from the university's chemistry department. She had been a chemistry professor for more than 20 years and is an experienced POGIL trainer. The professor utilized POGIL activities in each class meeting to foster collaborative learning opportunities for students and facilitate the exploration and integration of relevant disciplinary content. All class meetings began with the instructor facilitating 10-15 minutes of whole-class discussions. The instructor occasionally offered mini-review lectures about the content when students struggled with certain concepts or when introducing a new topic. Also, she worked with the students during the last 10-15 minutes of each class period to form a general agreement about the correct answers to the tasks and called on students from each team to write answers on the whiteboard. No slides or teaching assistance was used in this course. Students' main sources of information came from the POGIL activities and the mini lectures that the instructor provided.

The course had a total enrollment of 28 students. Students met with the professor three times a week, on Mondays, Wednesdays, and Fridays, for 14 calendar weeks. The class met for 55 minutes. In general, there was a short test every week on Fridays. No make-up tests were allowed without a documented unavoidable excused absence, but every student got to drop one test, and each test counted for 45 points. Over the duration of the course, students had nine online homework assignments, and each assignment counted for 21 points. The final test was comprehensive of all content covered in the course and counted for 150 points. Consent forms were made available to all students during the first week of the course. During the course's meeting time, every four students worked together as a small group to discuss and solve the POGIL activities. By the second week of the course, students who consented were assigned to their groups randomly. Due to COVID-19, the in-person attendance of students was restricted by university policies to reduce exposure to COVID-19. Therefore, the instructor divided each group into two subgroups. Each of the subgroups took turns meeting in person and on Zoom on each of the class meeting days. For example, if students A and B attended class in-person on one Monday and Friday, students C and D, of the same group, attended the class on Zoom on Wednesday of the same week, and vice versa. Although only half of the students attended the class in person during each meeting, the course was offered in a medium-sized lecture hall with movable tables and chairs. Students who attended class in person were not required to sit close in proximity to each other, although students sometimes chose to move closer to their team member who was in person.

Zoom is a reliable virtual meeting platform that allows attendees to connect through video, audio, phone, and/or chat features. All students, whether in-person or online, were expected to join the classroom on Zoom because the instructor divided the students into their appropriate groups during the POGIL activity time using the breakout-room feature in Zoom. Students, both in-person and online, communicated through Zoom's chat, video, and/or audio features to work on group activities together in their separate groups. While students worked on the POGIL activities, the instructor walked about the classroom and bounced between Zoom breakout rooms to facilitate students' discussions and answer any questions. Each of the breakout rooms was audio and video recorded to be used by the research team in capturing the student-student and student-instructor interactions.

Although students were not given team roles due to the complicated nature of the course during the pandemic, one of the in-person students from each of the participating groups was given an iPad along with an Apple pencil during every class meeting, and his or her role was to be the recorder of the group. Students used the iPad to join the Zoom meeting and then share the iPad's screen with the appropriate POGIL activity. The iPads allowed students to work on the same questions, share answers as a group, and record answers to questions. The recorder was allowed to send a copy of the completed POGIL activity to the group members and themselves to keep a record. The shared iPad screen and the Zoom video and audio features were recorded for research purposes and to be used by the instructor to evaluate students' progress because the in-class assignments (POGIL activities) counted for 30 points of the total possible points.

Data Collection

This study was approved by the Middle Tennessee State University IRB (19-2253) (see Appendix D), and 24 students consented to participate. For this study, audio and video recordings only from the breakout rooms, where students collaboratively discussed the POGIL activities, were used rather than the whole-class discussions. After the retrieval of all data, all recordings of each breakout room were uploaded to an online data-collection cloud service, and classroom conversations were transcribed verbatim using Otter transcription services. Otter is a transcription software that uses artificial intelligence to transcribe recorded conversations, apply speaker identification, and use time stamps. Only periods where students collaboratively discussed a POGIL activity were considered in this study. Breakout rooms began when the instructor told the class to work in their teams on specific questions within an activity, and breakout rooms ended when the instructor brought the entire class to the main lobby on Zoom and stopped students' conversations to jointly discuss the material. All breakout rooms during each meeting date were transcribed and uploaded to the online data-collection cloud service along with the recordings. The generated 177 transcripts, from the video and audio recordings, were the primary data sources of this research.

To answer the research question concerning facilitation, only the 80 transcripts, which were the only transcripts that included facilitator interventions, were considered for analysis. After developing an inter-rater reliability (IRR) of at least 85% between Rushton's chemistry discourse team members, the transcripts were divided among the team members and coded according to the Communicative Approach, a framework that is developed to analyze the genres of speech in a classroom with a focus on the role of the teacher in classroom discussions. The Communicative Approach codebook was developed by Mortimer and Scott (2003) to describe how the teacher works with students in a classroom to facilitate learning. Each breakout-room conversation that the instructor facilitated was coded, and a consensus was formed among team members about the Communicative Approach used by the facilitator.

Although the Communicative Approach codebook is developed to include a variety of speech types, there were a few conversation genres that were not recognized by the Communicative Approach. The Communicative Approach codebook assumes that all talk made by a facilitator in the classroom is about the content itself. However, this is not only a false assumption, but it also fails to recognize the impact of instructors' off-task utterances on students' learning in a collaborative classroom. Markee (2005) states that off-task talk catalyzes students' intellectual growth because no one can separate the social and cognitive aspects involved in the process of learning. In this research, there were many instances of off-task talk where the instructor predominantly focused on talk that is not related to the content itself. For example, the instructor would sometimes come and ask, "How are you guys doing," and students usually responded with "Fine" or "we are working on it." This type of off-task utterance or interaction described above does not fall under any of the categories included in the original Communicative Approach codebook. Therefore, the "off-task conversation" code was added to the Communicative Approach codebook to better represent the interactions taking place in this classroom.

Nine transcripts from three small groups were chosen (viz. Alpha, Bravo, and Foxtrot) based on the number of consenting students in each group and the variation of group composition in terms of students' demographics, grades, and English Learner (EL) status. As shown in Figure 5, groups Charlie and Delta consisted of students who did not consent to this study, and group Echo lacked the desirable variation in group composition. The chosen groups and transcripts are the cases in this study. By random sampling, groups Alpha and Bravo consisted of four non-ELs and group Foxtrot was made up of two ELs and two non-ELs. However, group Alpha had two female and two male students while there were one male and three females in the Brave and Foxtrot groups.

The selected groups were examined across class meetings where the facilitator used one of each Communicative Approach type. One transcript that represented each of the Communicative Approaches, including the added codes, was chosen based on which meetings had the most talk turns and on the availability of the data. Talk turns are the units of analysis. Male participants were underlined in Figure 5, and EL students were colored in green font to rep resent the composition of the groups used in this study. The presented student names are pseudonyms.

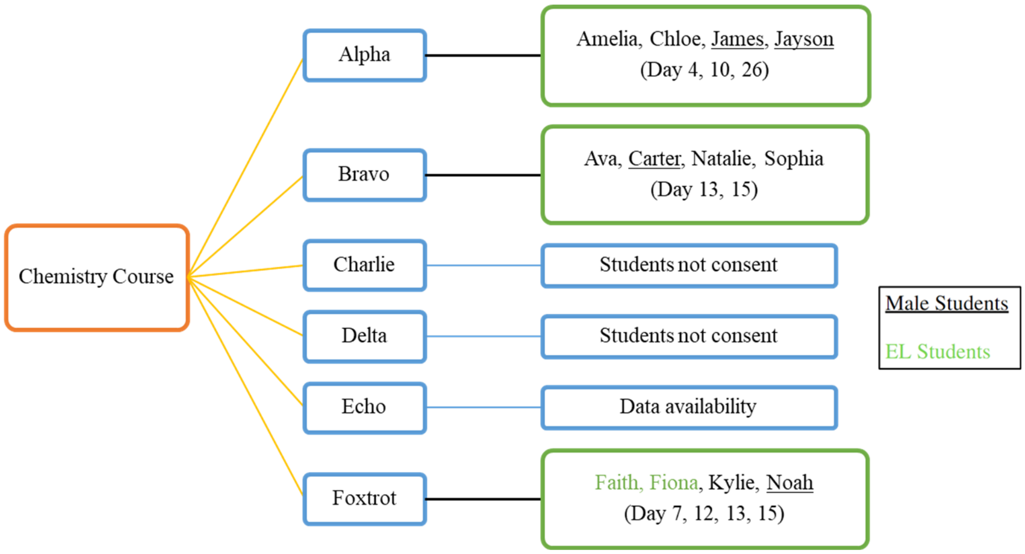


Figure 5. Description of teams in this study.

Data Analysis

After examining all instructor interactions in all the meetings, no examples were found of the Noninteractive/Dialogic and Interactive/Dialogic Communicative Approaches. In Table 1, dashes were placed where no examples were found of a certain Communicative Approach. All conversations were analytically quantified based on the talk-turn analysis in multi-participant conversations (Liyanage, 2021). When participants used vocal interactions, each utterance was considered one talk-turn until the person talking was interrupted by the talking of another participant. When participants used the chat feature in Zoom, chat messages were considered one talk-turn until the person chatting was interrupted by a chat of another participant or if the person chatting stopped typing for one or more minutes.

Table 1. Description of the chosen class meetings that represent one of each Communicative Approach used in this study.

	Noninteractive/ Authoritative	Interactive/ Authoritative	Noninteractive/ Dialogic	Interactive/ Dialogic	Off-task
Alpha	Alpha- Day 10	Alpha- Day 26	--	--	Alpha- Day 4
Bravo	Bravo- Day 13	Bravo- Day 15	--	--	--
Foxtrot	Foxtrot- Day 15	Foxtrot- Day 7	--	--	Foxtrot- Day 13

After all the chosen transcripts were divided into talk-turns, all students' talk was coded according to the SIDM framework to further understand the nature of the classrooms' conversations and to characterize students' behavior in a classroom. Each student's utterance was coded with the type of interaction, the primary intent of the talk, and the nature of the utterance. The SIDM codebook captures the purpose behind many types of student talk. However, there were many instances where one talk-turn included two or more purposes. Contributing and questioning tended to frequently appear together as double codes in students' utterances. Therefore, a Contributing/Questioning code was created to capture the complicated nature of these utterances. Usually, students use Contributing/Questioning when they were presenting a claim and seeking confirmation that their claim was correct. Additionally, all instructor's interactions were coded according to the IODM framework to discern how instructors enhance student argumentation. A consensus was formed among research group members about the SIDM codes to avoid bias and generate an inter-rater reliability.

Sociograms showing the sequence of student talk-turns were generated from the transcripts to depict the relationships among individuals in the groups. Each team's discussion was mapped by the social network graph in which the students are the nodes (or vertices) of the graph. Every time someone talks to another person, a directed edge between the two people is generated. Each edge represented what was defined as a talk-turn. The edges are directed, pointing from the speaker to the receiver. Students' talk-turn behavior was determined from the transcripts, and the resulting sociograms were generated using Rstudio. Rstudio is a free software that uses R and Python for data science and research. R is a graphing system that helps generate high-quality graphs.

The teams were set up by the instructor, and each team had four students. Nodes represent team members who attended the class meeting, whether in-person or online (even if students did not talk during a conversation). The transcribed discussions were used to determine the students' order of speaking, which were then converted to edge lists. Each edge represents a talk-turn and is depicted as a directed arrow pointing from the person who was talking to the person being talked to. The audience was determined by the natural flow of the conversation. However, if students made statements to the whole group without directing the talk to a specific person, the edge is depicted as an arrow pointing at all the team members present in the breakout room. Therefore, an edge connects the name of the person speaking to whom were each was talking, and the type of discourse move used.

To create the edge list, a table containing the discourse of each group on each meeting date was created. Figure 4b shows an example of how an edge list would look like. The first column contained the names of the speakers. A second column consisted of the names of the audience, whether one person or the whole group. The third column was the nature of students' utterances or the facilitator's inquiry discursive move; this column characterized only the speaker's discursive move. When the speaker was a student, only the primary intent was used to limit the number of codes without losing the description of what purpose the student is speaking. When the instructor talked, the IODM main codes were used.

The generated edge lists were divided into three sets of edge lists: before facilitation, during facilitation, and after facilitation. Before-facilitation edge lists start from the beginning of the small-group discussion until the facilitator joins that group's breakout room or when one of the students asks the instructor for assistance. During-facilitation is the period when the facilitator is in a group's breakout room or is assisting a group. The after-facilitation edge list starts once the facilitator leaves the group until the end of the small-group discussion. The edge lists were divided to be able to note the change in group discourse before and after facilitation. The sociograms for each period allows the visualization of how facilitation affects the centralization of discourse in a group and the temporal nature of students' conversations.

The edge lists before, during, and after the facilitation of each group on all meeting days were imported to R to generate the sociograms. In each network, the nodes represent students, and the edges (arrows) represent talk-turns. A circle represents students who attended a meeting only online, while a square illustrated students who attended a meeting in person. Green-filled nodes are EL students; white-filled nodes are non-EL students, and the instructor is a blue-filled node. Edges were color-coded according to the type of discourse move. Figure 5 presents the specific colors associated with each discourse move used in this study.

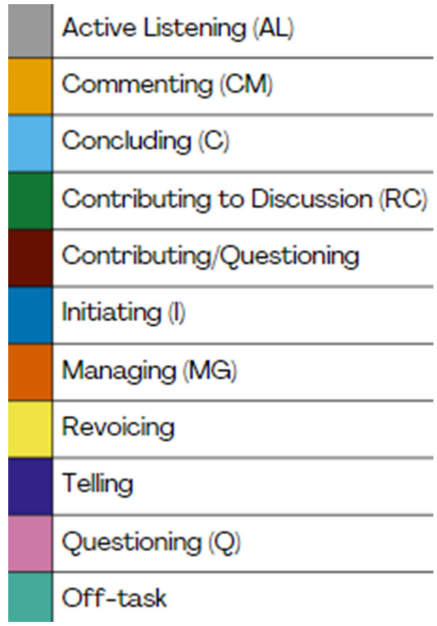


Figure 6. Colors associated with the instructor’s and students’ discourse moves in the generated social network graphs.

Each node’s degree centrality measures the number of links connecting to it. Node’s degree is the number of interactions a node had. Centralization (C) describes the extent to which the network is concentrated on one single node. In a directed network, nodes have two degrees of centrality: in-degree and out-degree centralities. In-degree centrality is the number of edges pointing toward a node, and out-degree centrality is the number of edges pointing away from a node. As the centralization of the discourse increases, the centralization score gets closer to one. Centralization ranges from zero to one and is calculated as

$$C = \Sigma \, (C_{Dmax} - C_{Di}) / \, 2(N^2 - 3N + 2)$$

where C_{Dmax} is the maximum degree centrality of all nodes in a graph, C_{Di} is the centrality of one node, and N is the total number of nodes in the graph. C_{Di} is calculated by summing the in-degree and out-degree centralities of a node. For example, a team that has four members has an *N*=4. In this case, the denominator would equal 12, the maximum number of edges coming from and toward a node. If one or two students take most of the talk-turns in a meeting, degree centrality increases toward one. However, if all students contribute to the conversation equally, the degree of centrality decreases to a minimum of zero. Group discourse is most interactive when the centralization is zero.

CHAPTER IV:
Results

Ultimately, all 80 transcripts that included facilitator interventions were used to answer research question one. Since the first research question focuses on the ways in which the instructor talks with the students to address the different ideas that emerge from the POGIL activities, only the Communicative Approach framework was used to code all 80 transcripts with instructional intervention. Figure 7 represents the Communicative Approach used in the classroom by the instructor across all episodes that included facilitation. Half of the time, the participating instructor chose to observe the student-student interactions in the breakout rooms without intervening. This type of interaction is excluded from the Figure because it is non-verbal interaction that we do not look at in this study.

When the instructor decided to intervene in the students' discussion, the instructor preferred to use the Noninteractive/Authoritative Communicative Approach. This means that the instructor preferred to guide students to the single correct answer for the presented task without including students' perspectives and ideas. The Interactive/Authoritative approach came in a close second. It indicates that the instructor still focused on guiding students through the tasks to arrive at the single correct answer, but the instructor chose to use a question-and-answer routine in this type of interaction. She allowed students to reply with short utterances to her closed-ended questions. The question-and-answer routine was structured to lead students to a certain answer.

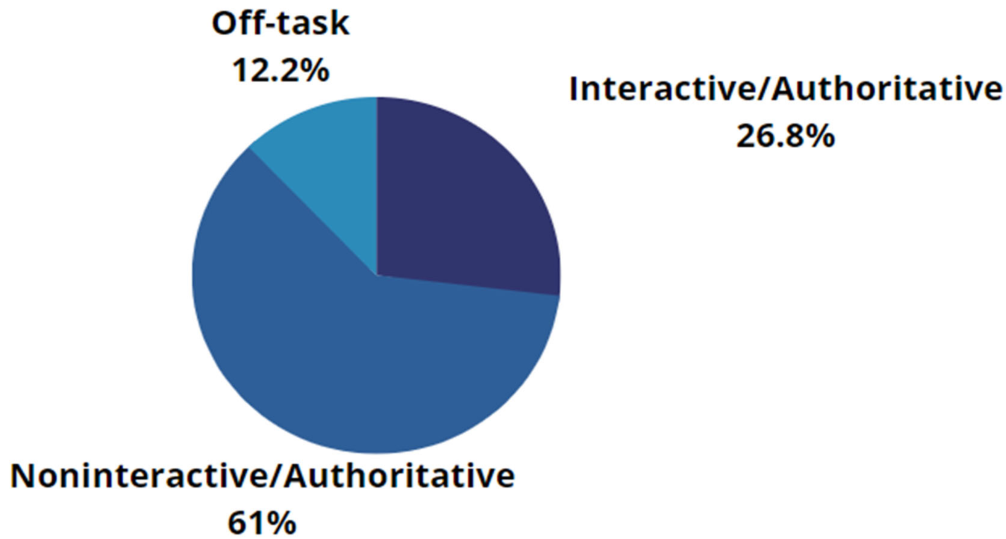
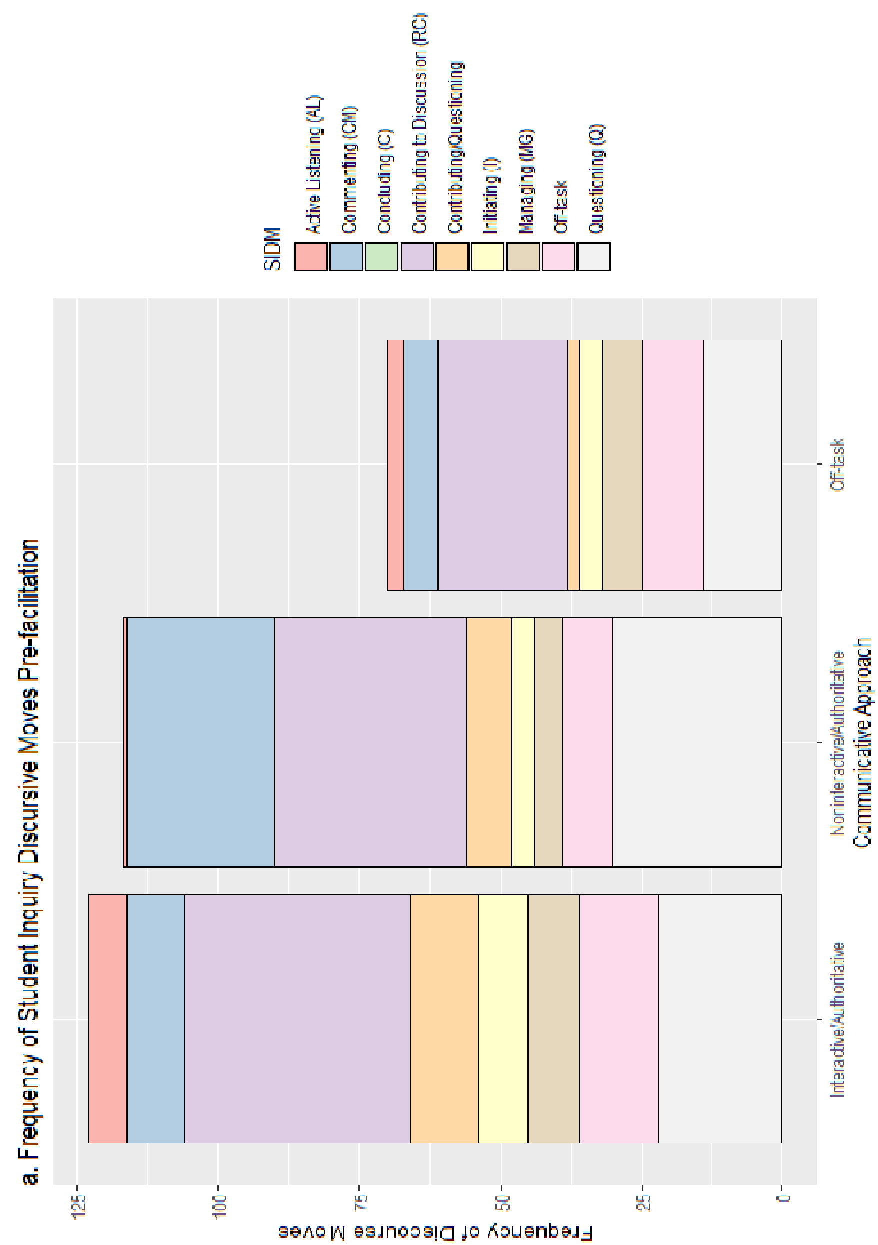


Figure 7. Frequency of Communicative Approaches used by the instructor in the POGIL-based classroom.

To answer the second research question, Figure 8 considered only the chosen cases and transcripts shown in table 1. Generally, the participating students had less discourse after facilitation. Also, students' discursive moves are more diverse before facilitation of any type. Student-student discourse generally remained the same after Interactive/Authoritative facilitation, but the frequency of student-student discourse generally decreased after Noninteractive/Authoritative and Off-task facilitation. The Noninteractive/Authoritative Communicative Approach decreased student-student discourse by about 30%.

Initiating, Managing, and Off-task student interactions decreased after the instructor used the Interactive/Authoritative facilitation approach. Commenting, Contributing, and Questioning student interactions increased after the instructor used the Interactive/Authoritative facilitation approach while Active Listening remained the same before and after facilitation. Only Active Listening and Managing student interactions increased after the instructor used the Noninteractive/Authoritative facilitation approach while all other student interactions decreased after the instructor used the Noninteractive/Authoritative facilitation approach. Only Contributing and Initiating student interactions remained the same after the instructor used the Off-task facilitation approach while all other student interactions decreased.



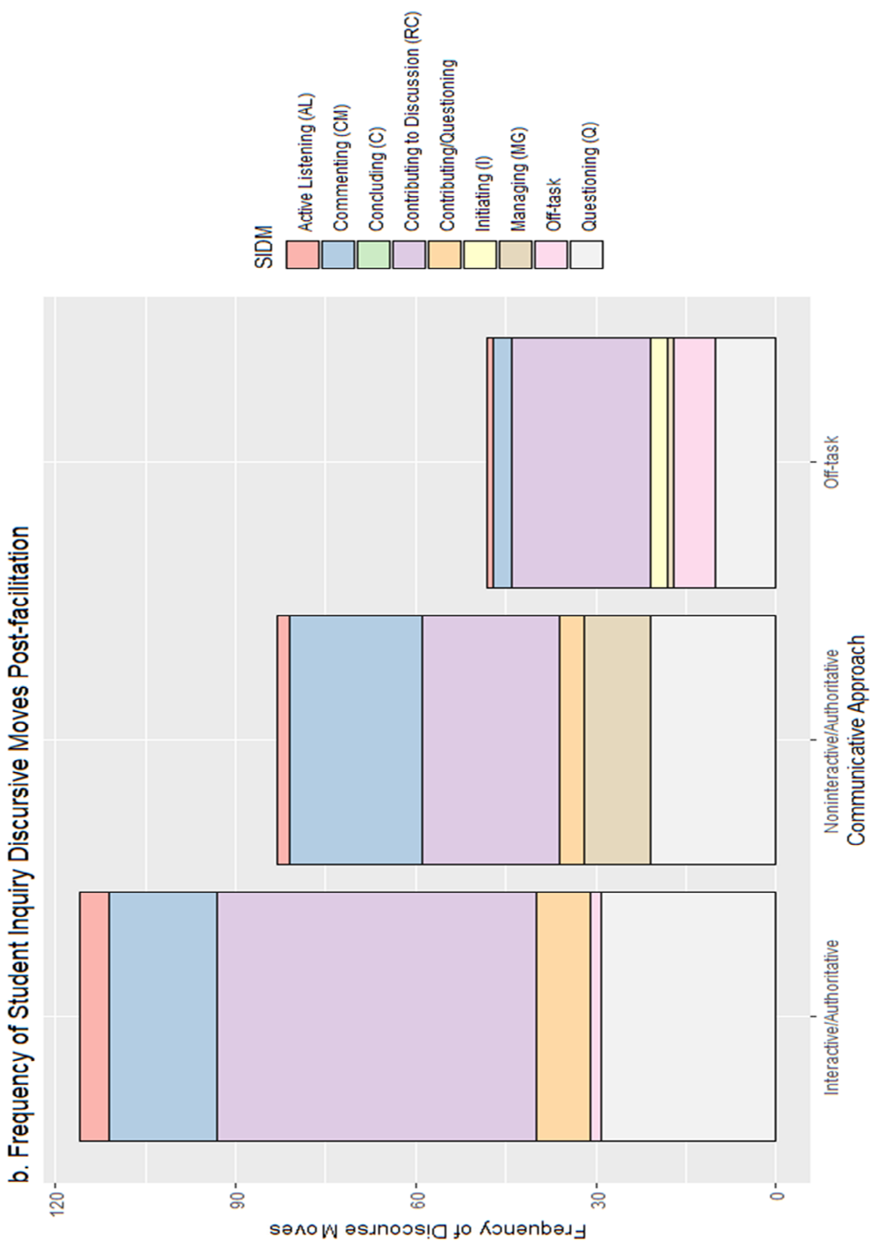


Figure 8. Frequency of Student Interaction Discourse Moves (SIDM) used by students in Interactive/Authoritative, Noninteractive/Authoritative, and Off-task environments before facilitation (a) and after facilitation (b).

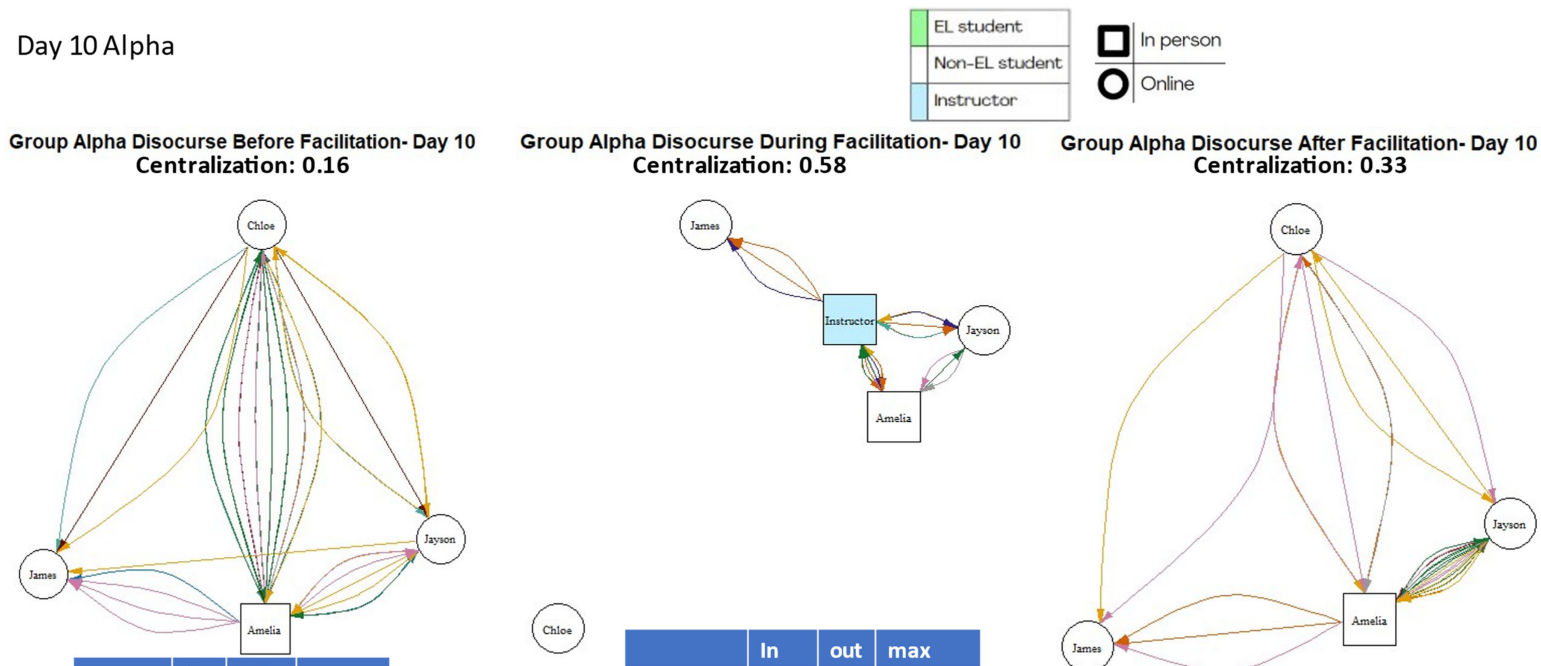
Figures 9-16 representing student-student and student-instructor interactions before, during, and after various facilitation approaches. The key to the shapes and colors of the nodes is included at the top right of each graph. Only student who were present in-person or online are depicted as nodes in the graphs. For example, Fiona and Faith, students in group Foxtrot, were absent in day 13. Students in circular nodes are those who attended class online while students in square nodes are those who attended class in-person. Students who identified as English Learner (ELs) were highlighted in green nodes while native-speaking English students were not highlighted and are depicted with white nodes. For simplicity, the instructor was represented with a light blue node. All colors associated with the instructor's and students' discourse moves were used in the generated social network graphs. Figure 6 presents the specific colors associated with each discourse move (edge) used in this study.

All in-degree, out-degree, and maximum centrality of each student and of the instructor are included in small tables under each social network graph. Centralization of each graph is included under the title. Generally, centralization increases (gets closer to 1) during facilitation. Although the centralization degree describes how central the discourse is around a single node, it does not describe the relative centrality of each node.

Figure 9 describes group Alpha's discourse before, during, and after the use of the Noninteractive/Authoritative Communicative Approach. Group Alpha's centralization is higher after facilitation than before facilitation. This means that the conversation became more central around one or two nodes after facilitation. Because the centralization score is less than 0.5, there is still a lot of conversation happening between all group members although the conversation becomes slightly centralized around Amelia and Jayson.

Figure 10 represents group Bravo’s discourse before, during, and after the use of the Noninteractive/Authoritative Communicative Approach. Although group Bravo’s centralization is the same after facilitation and before facilitation, there is significantly more talk happening before facilitation than after facilitation.

Figure 11 represents group Foxtrot’s discourse before, during, and after the use of the Noninteractive/Authoritative Communicative Approach. Although group Foxtrot’s centralization decreases after facilitation than before facilitation, the two central students in the before-facilitation social network graph are the same two central students in the after-facilitation network. Noticeably, both EL students did not participate in any student-instructor talk.

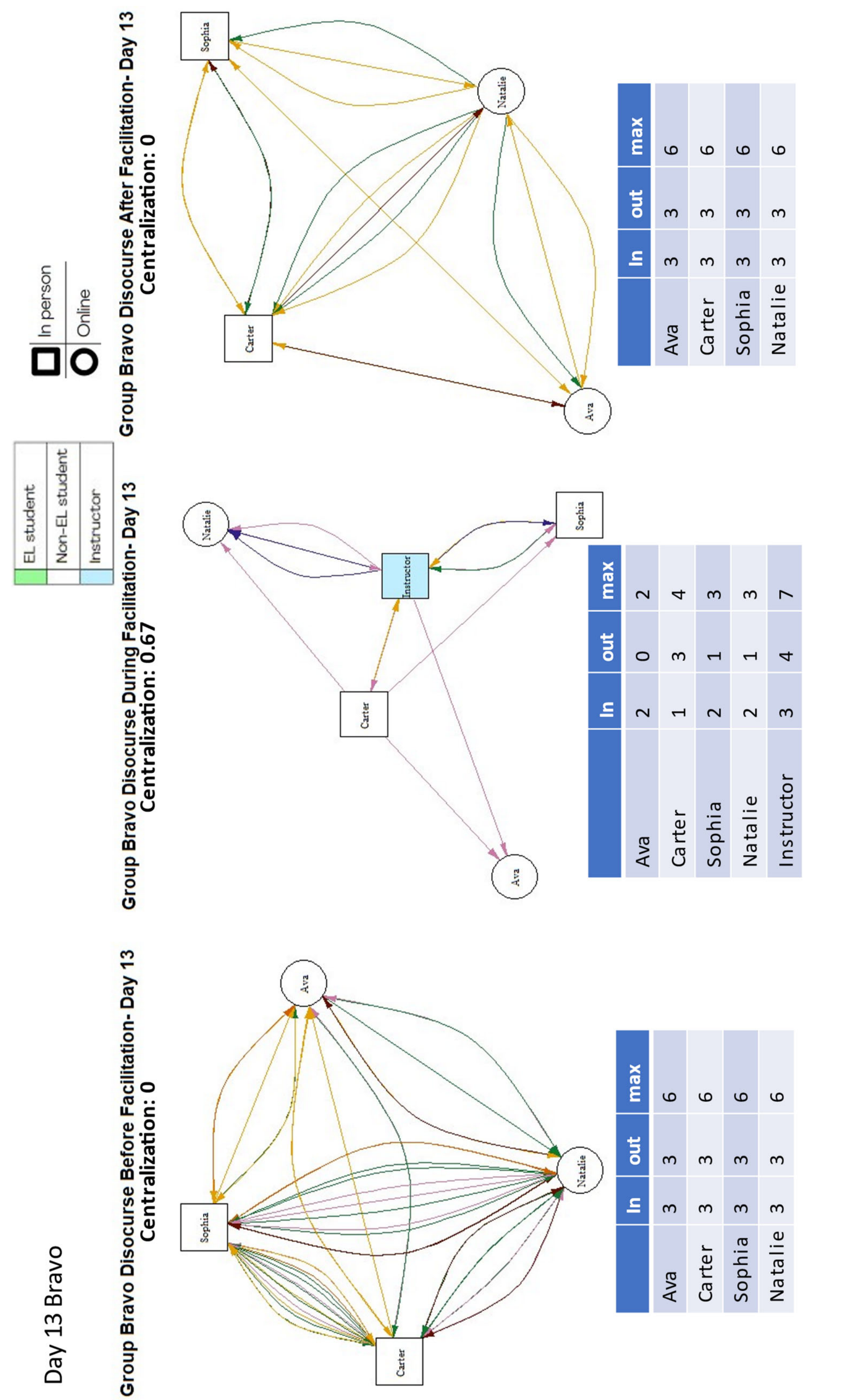


	In	out	max
Amelia	2	3	5
Chloe	2	3	5
Jayson	2	3	5
James	3	0	3

	In	out	max
Amelia	2	2	4
Chloe	0	0	0
Jayson	2	2	4
James	1	0	1
Instructor	2	3	5

	In	out	max
Amelia	2	3	5
Chloe	2	3	5
Jayson	2	2	4
James	2	0	2

Figure 9. Graph representing student interactions before, during, and after Noninteractive/Authoritative facilitation (Group Alpha- Day 10).



	In	out	max
Ava	3	3	6
Carter	3	3	6
Sophia	3	3	6
Natalie	3	3	6

	In	out	max
Ava	2	0	2
Carter	1	3	4
Sophia	2	1	3
Natalie	2	1	3
Instructor	3	4	7

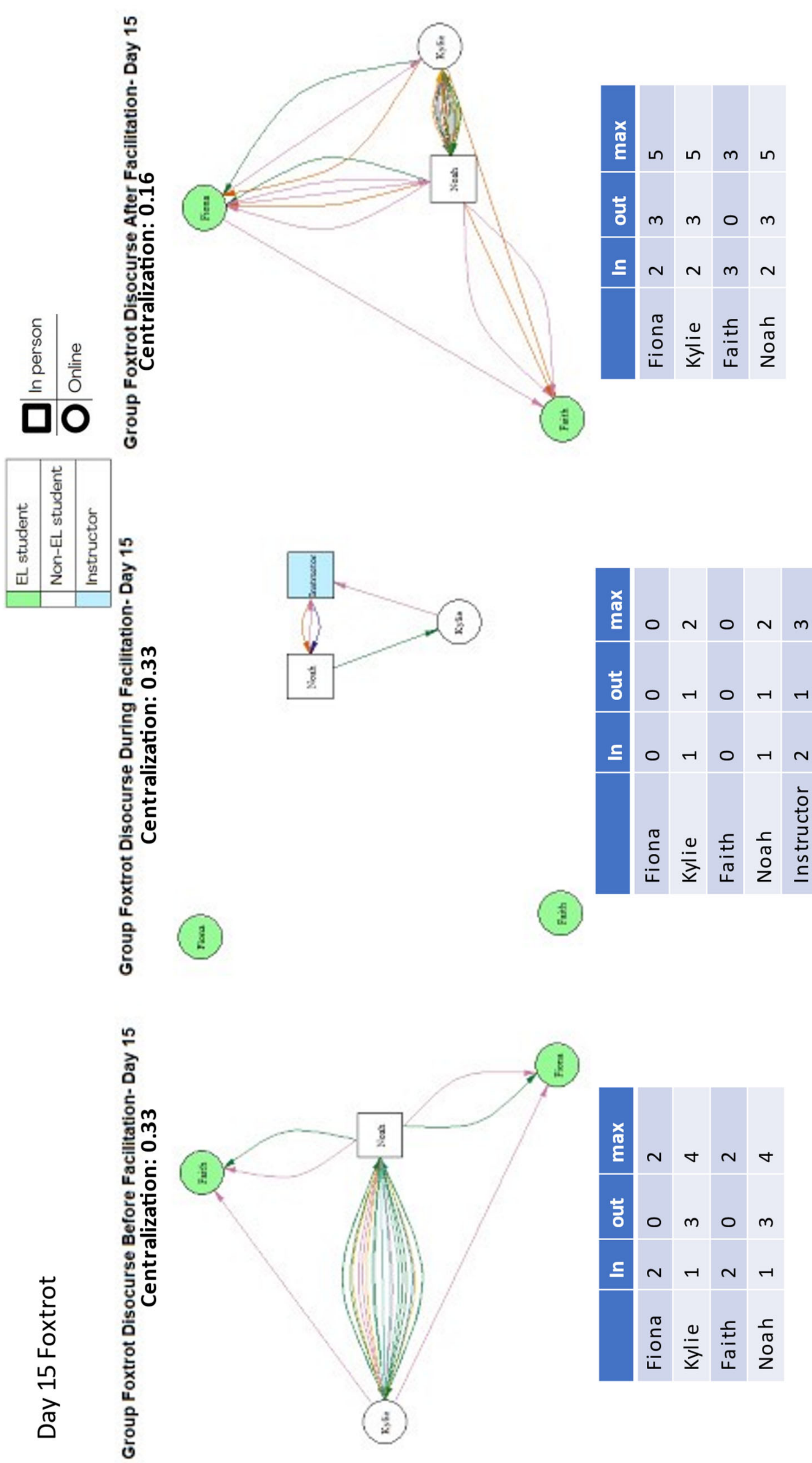
	In	out	max
Ava	3	3	6
Carter	3	3	6
Sophia	3	3	6
Natalie	3	3	6

Figure 10. Graph representing student interactions before, during, and after Noninteractive/Authoritative facilitation (Group Bravo- Day 13).

Figure 12 represents group Alpha's discourse before, during, and after the use of the Interactive/Authoritative Communicative Approach. Group Alpha's centralization increases after facilitation than before facilitation. During facilitation. all students participated in student-instructor talk. Significantly less conversation happened after facilitation.

Figure 13 represents group Bravo's discourse before, during, and after the use of the Interactive/Authoritative Communicative Approach. Group Bravo's centralization remained the same after facilitation and before facilitation. Only Natalie talked to the instructor, but when the instructor talked, she chose to talk to all students in the group.

Figure 14 represents group Foxtrot's discourse before, during, and after the use of the Interactive/Authoritative Communicative Approach. Group Foxtrot's centralization increases after facilitation than before facilitation. Although Noah and Fiona were the central students before facilitation, Noah became the center of almost all conversations facilitation.

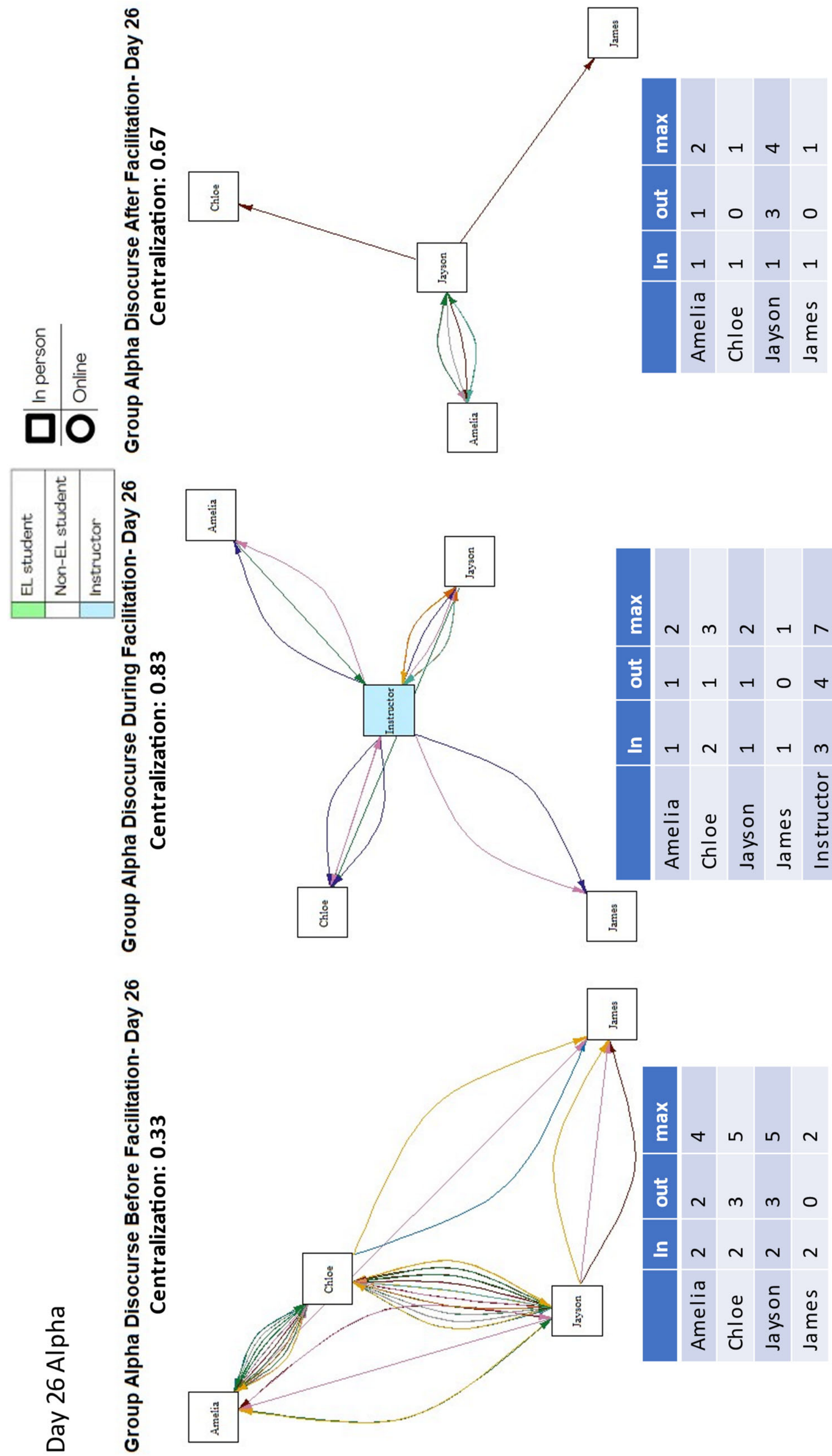


	In	out	max
Fiona	2	0	2
Kylie	1	3	4
Faith	2	0	2
Noah	1	3	4

	In	out	max
Fiona	0	0	0
Kylie	1	1	2
Faith	0	0	0
Noah	1	1	2
Instructor	2	1	3

	In	out	max
Fiona	2	3	5
Kylie	2	3	5
Faith	3	0	3
Noah	2	3	5

Figure 11. Graph representing student interactions before, during, and after Noninteractive/Authoritative facilitation (Group Foxtrot- Day 15).

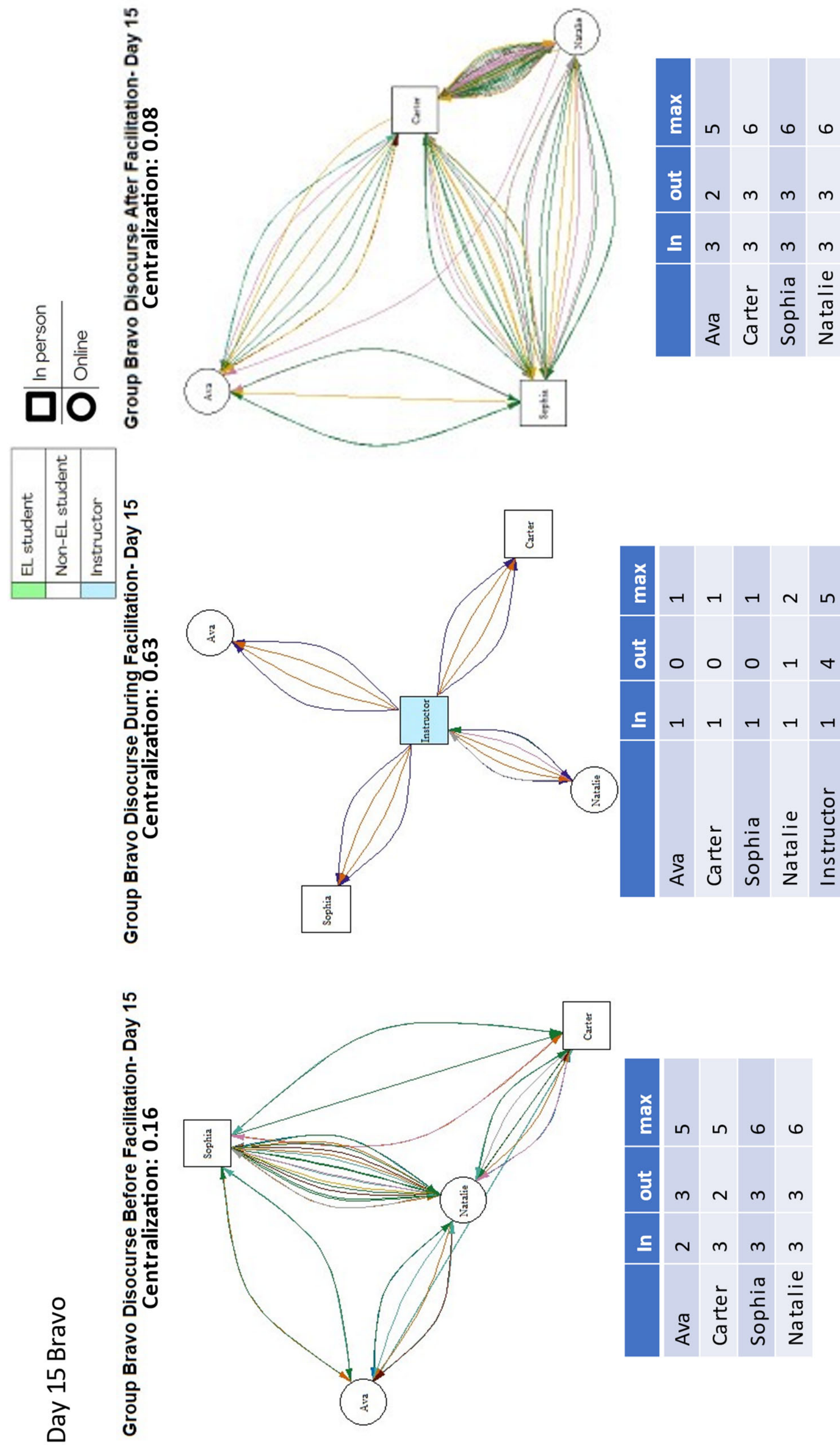


	In	out	max
Amelia	2	2	4
Chloe	2	3	5
Jayson	2	3	5
James	2	0	2

	In	out	max
Amelia	1	1	2
Chloe	2	1	3
Jayson	1	1	2
James	1	0	1
Instructor	3	4	7

	In	out	max
Amelia	1	1	2
Chloe	1	0	1
Jayson	1	3	4
James	1	0	1

Figure 12. Graph representing student interactions before, during, and after Interactive/Authoritative facilitation (Group Alpha- Day 26).



	In	out	max
Ava	2	3	5
Carter	3	2	5
Sophia	3	3	6
Natalie	3	3	6

	In	out	max
Ava	1	0	1
Carter	1	0	1
Sophia	1	0	1
Natalie	1	1	2
Instructor	1	4	5

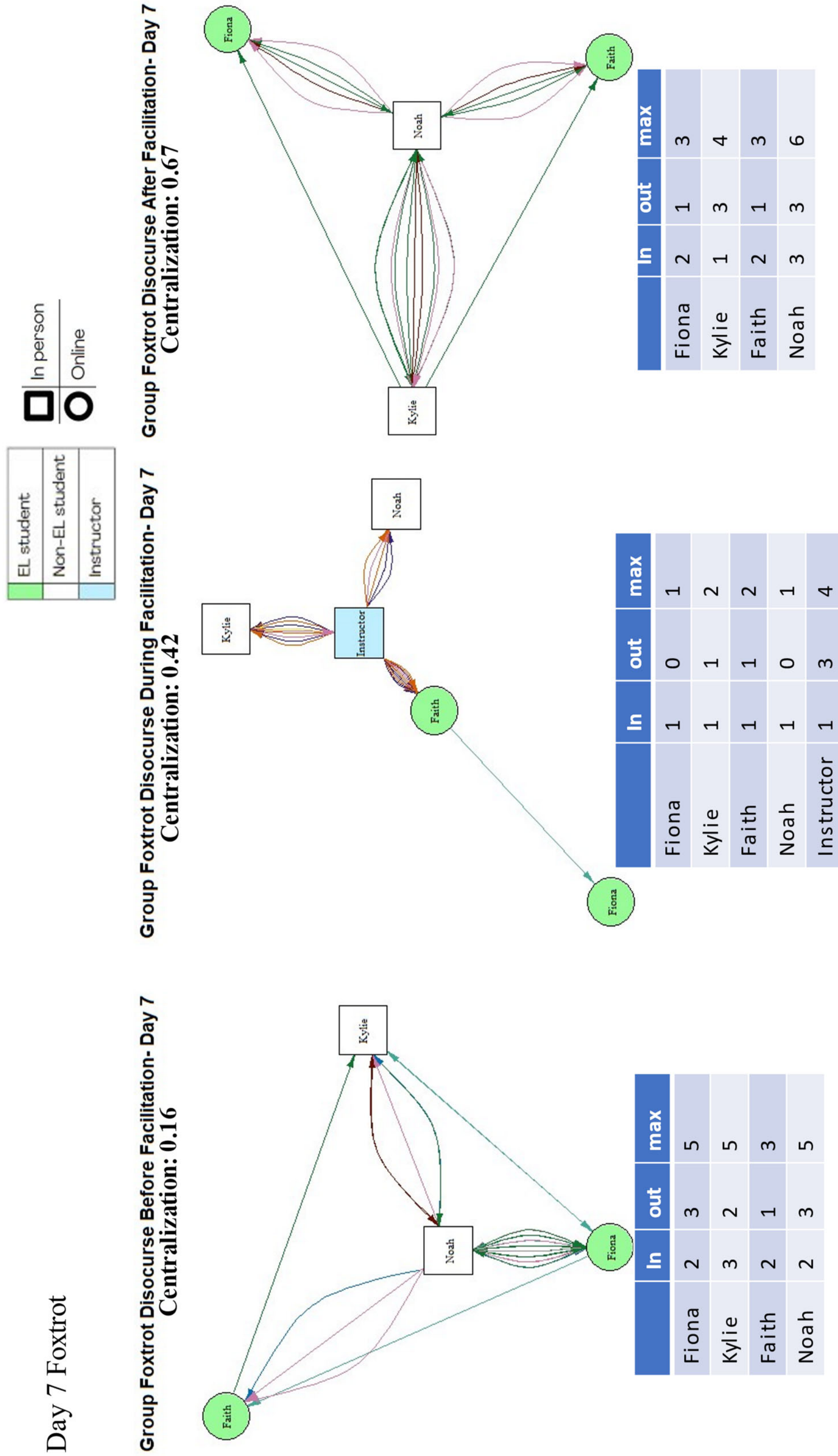
	In	out	max
Ava	3	2	5
Carter	3	3	6
Sophia	3	3	6
Natalie	3	3	6

Figure 13. Graph representing student interactions before, during, and after Interactive/Authoritative facilitation (Group Bravo- Day 15).

Figure 15 represents group Alpha's discourse before, during, and after the use of the Off-task Communicative Approach. Although group Alpha's centralization increases after facilitation than before facilitation, students had plenty of conversation both before and after facilitation. Also, no one or two students were more central in the conversation before or after than other group members.

Figure 16 represents group Foxtrot's discourse before, during, and after the use of the Off-task Communicative Approach. Group Foxtrot's centralization is the same after facilitation and before facilitation. Two students were absent during this class meeting. Therefore, the centralization did not change before or after facilitation. The two students who attended that class meeting talked back and forth reasonably both before and after facilitation.

Generally, the instructor had more discourse during the Interactive/authoritative approach. EL students had minimal discourse or edges linking each other. When Non-interactive/Authoritative is used, centralization increases after facilitation in a group with EL students, but it decreases after facilitation in a group with non-EL. Also, EL students and students who attended the class online had less active discourse with the instructor when she was facilitating the group.

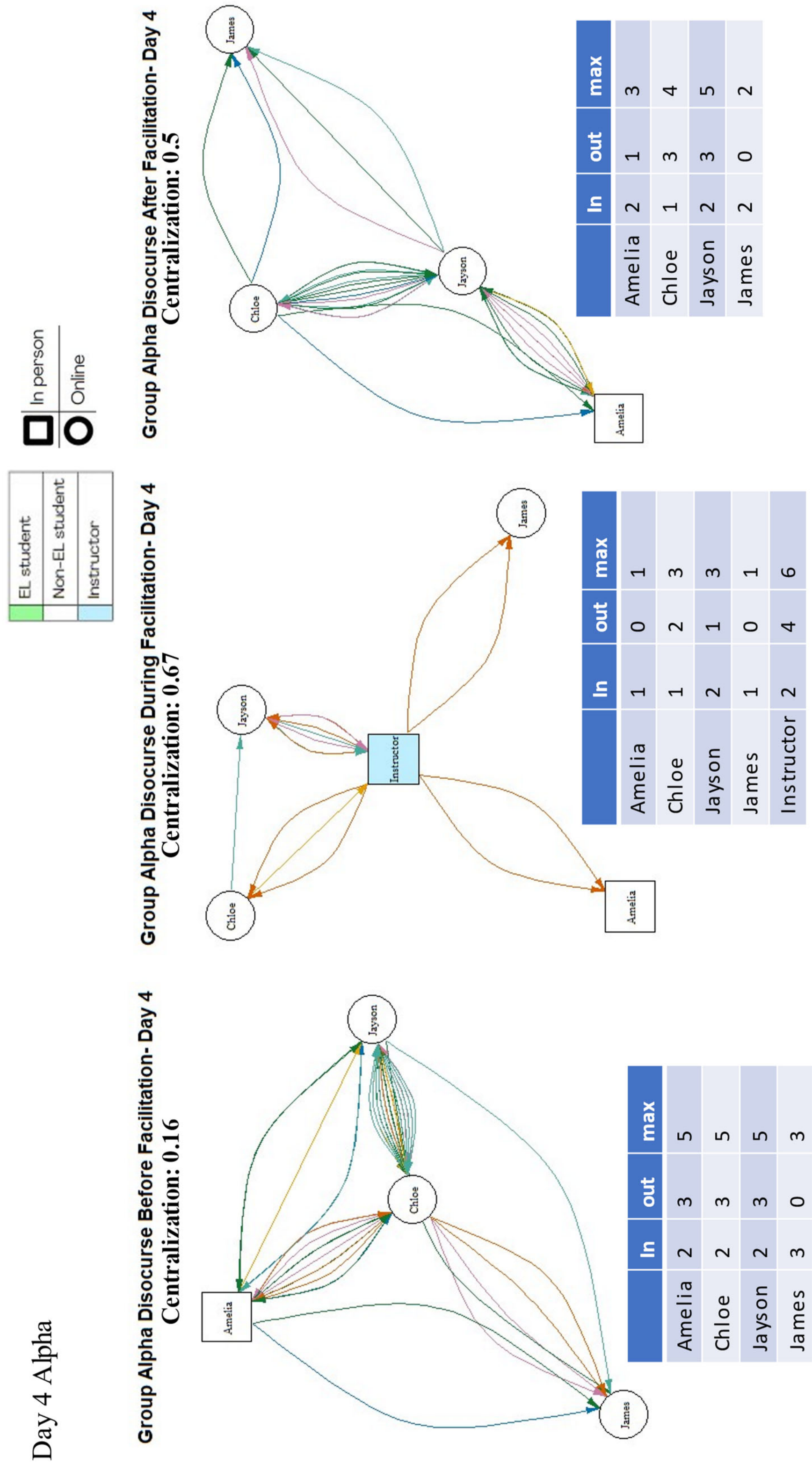


	In	out	max
Fiona	2	3	5
Kylie	3	2	5
Faith	2	1	3
Noah	2	3	5

	In	out	max
Fiona	1	0	1
Kylie	1	1	2
Faith	1	1	2
Noah	1	0	1
Instructor	1	3	4

	In	out	max
Fiona	2	1	3
Kylie	1	3	4
Faith	2	1	3
Noah	3	3	6

Figure 14. Graph representing student interactions before, during, and after Interactive/Authoritative facilitation (Group Foxtrot- Day 7).

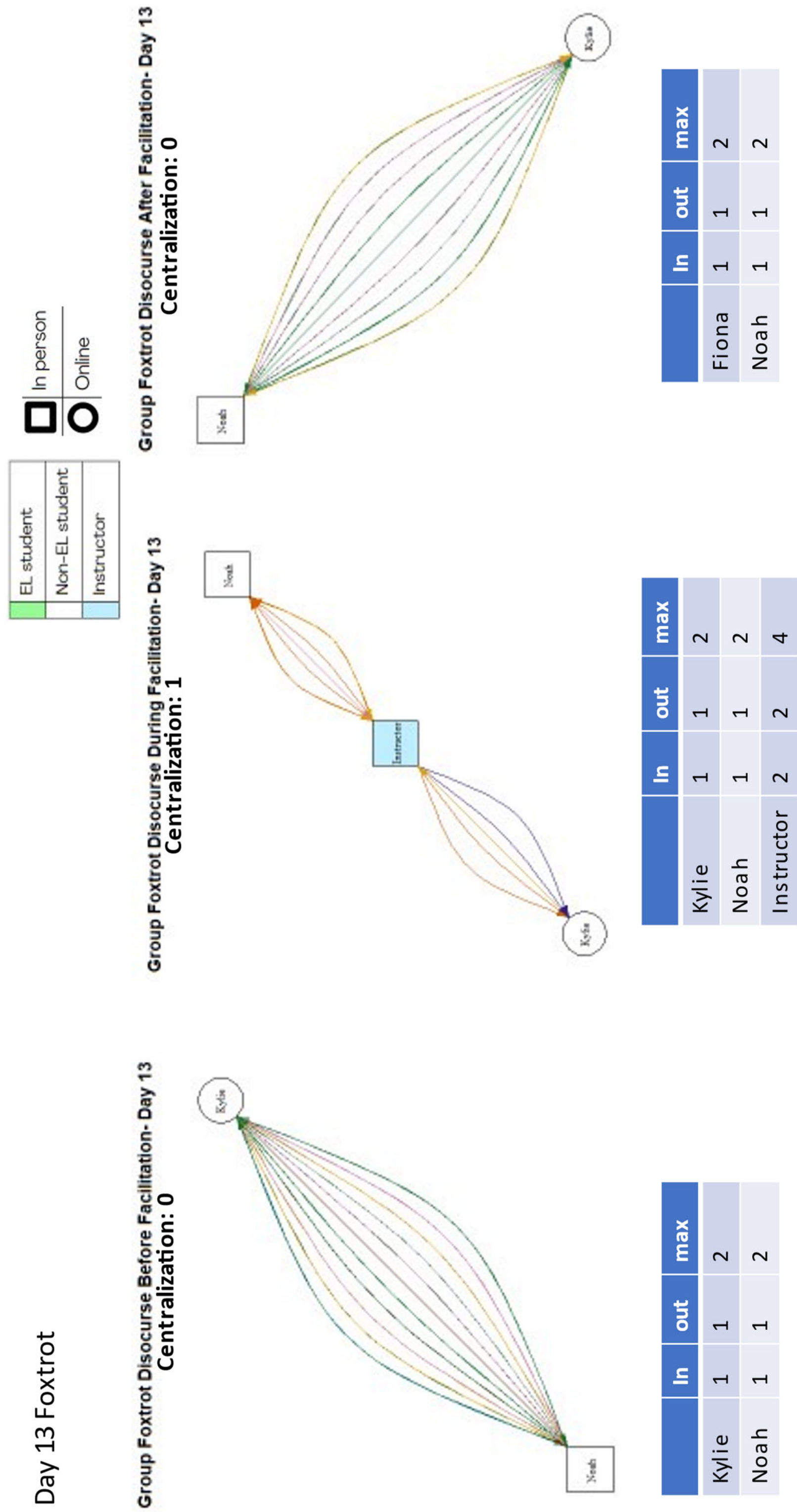


	In	out	max
Amelia	2	3	5
Chloe	2	3	5
Jayson	2	3	5
James	3	0	3

	In	out	max
Amelia	1	0	1
Chloe	1	2	3
Jayson	2	1	3
James	1	0	1
Instructor	2	4	6

	In	out	max
Amelia	2	1	3
Chloe	1	3	4
Jayson	2	3	5
James	2	0	2

Figure 15. Graph representing student interactions before, during, and after Off-task facilitation (Group Alpha- Day 4).



	In	out	max
Kylie	1	1	2
Noah	1	1	2

	In	out	max
Kylie	1	1	2
Noah	1	1	2
Instructor	2	2	4

	In	out	max
Fiona	1	1	2
Noah	1	1	2

Figure 16. Graph representing student interactions before, during, and after Off-task facilitation (Group Foxtrot- Day 13).

CHAPTER V:
Discussion and Study Limitations

Discussion

Student Discourse, or students talking on-topic in an academic environment, is vital to language acquisition, student engagement and ultimately student achievement. Student discourse can happen at the partner, group, whole class, or student-to-teacher level. Student-instructor discourse presents an essential part of students' understanding and learning in STEM courses. As it has been expected, the instructor used a Noninteractive/Authoritative communicative approach to facilitate students' discourse. This aligns with the instructor's course objectives and purpose of facilitation. The time of the course is limited, and the instructors' objective is not to confuse students but rather assist them to arrive at the correct answer quickly enough to be able to cover all the course concepts and objectives. The centralization of an instructor during facilitation enables faster and clearer alignment around the purpose and goals of the reform throughout the classroom.

The expectation was that student discourse would increase in centrality when the facilitator used a Noninteractive/Authoritative communicative approach. Conversely, I expected that student discourse would decrease in centrality when the facilitator used an Interactive/Authoritative Communicative Approach. However, the findings from the social network analysis were more complicated than what was expected at the outset of this research. A fully centralized social network graph can limit instructor engagement, while fully decentralizing the network can create unnecessary redundancies and inefficiencies in a group.

Only one transcript out of three demonstrated that the Noninteractive/Authoritative communicative approach increases the centrality of students in a network. Although the discourse centrality remained constant before and after facilitation in a different transcript, where the instructor also used Noninteractive/Authoritative communication, the network shows that students' discourse and argumentation decreased after facilitation. The decrease in students' discourse reflects that students' strong understanding of the concept is affected by the facilitative approach. In a group with two ELs and two non-ELs, the Noninteractive/Authoritative communicative approach had a positive effect on students' discourse and network centrality. This could be due to students' prior knowledge or cultural understanding of discourse. A recent study suggests that ELs struggle with comprehension of non-ELs talk (Pourhosein Gilakjani & Sabouri, 2016). This might support the claim that ELs comprehend information when explicitly stated, rather than when argued and extracted from a conversation.

Only one transcript out of three demonstrated that the Interactive/Authoritative communicative approach decreases the centrality of students in a network. The other two transcripts suggest that Interactive/Authoritative communication increases the centrality of students' discourse. The increase in students' discourse reflects that students' strong understanding of the concept is negatively affected by the facilitative approach. In a group with two ELs and two non-ELs, the Interactive/Authoritative communicative approach had a negative effect on students' discourse and network centrality. As discussed before, ELs prefer to receive explicit information because they struggle with comprehending discussions and reflections. Due to their inability to comprehend the student-instructor discussions, ELs relied on one non-EL student to explain the material to them and answer any questions that ELs had after facilitation.

Limitations

The findings reported here represent a case study of an instructor's facilitation of Chemistry POGIL material and how it affects student-student discourse in a small-group setting. It is not to be taken as a generalization for how all instructors affect student behavior. It should be noted that many factors affect student engagement in chemical discourse and argumentation. Due to that, I am not making claims as to the generalizability of the instructor's approaches to implementing the chemical POGIL materials. More research is necessary to observe how instructors with various levels of experience, different facilitation approaches, and varied classroom settings can influence how students generate discourse in the classroom. Furthermore, because this study examined student discourse, I am not able to assess how instructor facilitation influenced how students construct discourse independently on items like exams.

Because this qualitative research is open-ended, results cannot be objectively verified against the course style, course material, or students' experience. Students sign up for classes with different levels of chemical background. We cannot quantify students' experiences and prior knowledge, both of which effect students' learning and knowledge construction. Also, it is difficult to investigate the exact causality of a students' certain talk pattern or engagement level due to the complicated nature of human interactions. Additionally, the researcher's presence during data gathering, which is often unavoidable in this type of qualitative research, can affect instructor's and students' talk.

The outbreak of COVID-19 was a great limitation for data collection and student communication. Throughout the semester, many students were in quarantine due to their infection, which allowed students to miss multiple class meetings and thus reduced the amount of data available for this study to use. Due to the hybrid nature of this course's environment, I am not able to talk about students' non-verbal knowledge construction. Students could have been present in the online meeting without participating in discourse or even paying attention to the class meeting. Also, the hybrid nature of this class hindered the instructor's ability to manage and visualize students in the classroom. Considering groups' dynamics, students' prior knowledge, and course material may be useful for understanding how to optimize the use of certain facilitation approaches.

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Appendices

Appendix A: Code Book for Communicative Approach

Communicative Approach	Description	Example
Interactive/Dialogic	Teacher and students consider a range of ideas. If the level of interanimation is high, they pose genuine questions as they explore and work on different points of view. If the level of interanimation is low, the different ideas are simply made available. (Mortimer & Scott, 2003, p. 39)	**1. Episode: What do experiments tell us?** Teacher: Can I just borrow that tube then, Rebecca, and see if we can think of perhaps why – in this particular tube – we might have had something go rusty. Think about this carefully. Right – anyone got any ideas – Clare? Clare: Maybe not enough oil, some air might have got in. Teacher: Right – so one point might have been that there – in fact it is quite a thin layer of oil – but it still seems to cover it quite well. So it's a good point, but I think, looking at it – what d'you think, Matthew? Do you think there's enough oil on there to stop air getting back? Matthew: No. Teacher: No – well actually Matthew says perhaps there isn't quite enough, so that might have been one point – right? Is there another reason though – Rebecca – can you think about your own experiment then, and think why? Rebecca: Miss, when I spilt it all out – a lot of it flew out. Teacher: Right – right. So – you put the boiled water in here, and then you dropped the tube and it – no? Rebecca: The oil, Miss. Teacher: You spilt the oil – it dropped out – so that could have been – did any

		water get out as well? Rebecca: Yeah, it went all over. Teacher: So it was all around. Can anyone think why that might have affected Rebecca's experiment then? Right – Philip do you want to give me an answer? Philip: Y'know when she spilt it? It could have cooled down and let air in. Teacher: Right – I think that's a very good point – and I heard somebody down here – was it Dean? – saying the same thing. Perhaps when it spilt – the air got in. **(Mortimer & Scott, 2003, pp. 62-63)**
Noninteractive/Dialogic	Teacher revisits and summarizes different points of view, either simply listing them (low interanimation) or exploring similarities and differences (high interanimation). (Mortimer & Scott, 2003, p. 39)	**1. Episode: Let's just think back again** Teacher: Let's just think back again. At the start, you were suggesting that it was cold, it was warm, it was dark, it was light, it was acids, or it was – water and air. All those things that were causing rust. That's what we started off thinking. And what we've done now – we've now come to the point where you've decided and you've proved in fact that it's just two things, with the iron. **(Mortimer & Scott, 2003, p. 64)**
Interactive/Authoritative	Teacher focuses on one specific point of view and leads students through a question and answer routine with the aim of establishing and consolidating that point of view. (Mortimer &	**1. Episode: Is that telling us something important?** Teacher: So in fact everyone's got their hand up, telling me that with air and water then the nail has gone very rusty. Right – now then. Is that telling us something very important, d'you think? Have we narrowed this information down any more? Dawn? Dawn: Well, it means that, means, er,

	Scott, 2003, p. 39)	you have to have them both together for the nail to go rusty. Teacher: Right. I think that is an excellent point – and I think it's an excellent way of saying it too. Listen carefully and I'll just re . . . can you just repeat for everyone what you just said? Dawn: Erm, if, if you've got air and water mixed together it's the only time when the nail will go rusty. Teacher: Excellent. You have to have – what you actually said the first time was this – you have to have air and water together to make the iron go rusty – and I think that's an excellent way of describing this. **(Mortimer & Scott, 2003, p. 64)** **2. Episode: The basic ham and cheese sandwich will be defined here as 2 slices of bread (B), a slice of ham (H), 2 slices of cheese (C) and a slice of tomato (T). (You may not agree with me but humor me in the name of an example). Write a "chemical reaction" for making a ham sandwich using the symbols given in the recipe.** Ryan: And cheese is limiting reagent. **Instructor:** Blue cheese. How do you all feel about cheese? Ryan: We think it's diatomic. **Instructor:** You think cheese is diatomic? Ryan: Yes, and so is bread. **Instructor:** Okay, well, so let's, let's talk about that. What does that mean? It comes in pairs. So

		does your cheese come in pairs? Well, I think you always need two slices of cheese. Dyne: Apparently in your formula it you always need two slices of cheese. **Instructor:** For this sandwich. But when I go to get it, do they come conjoined? **(from MTSU transcript)**
Noninteractive/Authoritative	Teacher presents a specific point of view. (Mortimer & Scott, 2003, p. 39)	**1. Episode: Examining Ideas of Cold and Hot Heat** Teacher: So, there are two things. The first relates to what we call "cold," or "the cold." There is nothing which is absolutely cold is there? For example, melting ice. . . we think it is really cold, but is it compared to ice plus salt? Is it cold? Student?: No. Teacher: No, it's warm. It's a source of heat. If you put both in contact, pure melting ice will pass heat to the ice with salt. What is cold? I can say that it is less hot and the opposite is also true, hot is less cold. Cold and hot are relative ideas, aren't they? It's a matter of comparing things. So, does it help to think about two kinds of heat, one associated with hot objects and the other with cold? There is a second point, an important one. . . . **(Scott, Mortimer, & Aguiar, 2006, p. 617)** **2. Episode: Calculate the number of moles in 75.0 grams of iron.** Instructor: That's good.

		Drake: Would that mean there's no percent size yet? Instructor: Am I happy that there's no percent size? Instructor: This one's okay. Yeah, that's number… **(from MTSU transcript)**

Appendix B: Inquiry-oriented Discursive Move (IODM) Coding Definitions

Inquiry Oriented Discursive Moves Coding Definitions.
Definitions adapted from Rasmussen, Kwon, and Marrongelle (2008).

Revoicing. Revoicing is defined as reuttering or saying again (this could be verbal, symbolic, or gestural) – of someone else's utterances.

Revoicing Category	Description	Example
Repeating	Teacher repeats a student's utterance using (essentially) the same words or a portion thereof.	S: As the reaction occurs the piston moves up because there is an increase in moles. I: my volume is gonna go up because our moles is going up
Rephrasing	Teachers states a student's utterance in a new or different way	S: dS, dV, and dU are exact differentials. I: all of these variables are state functions.
Expanding	Teacher adds information to a student's utterance	S: Volume is a state function because you can use the final volume and the initial volume. I: So my change in volume doesn't depend on the path I use to get there, just what it is.
Reporting	Teacher attributes an idea, claim, or argument to a specific student.	I: So when the weight's removed, like Mary said, it's gonna expand till I can restore equilibrium.

Questioning. We used questioning codes in cases when there was an expectation that students actually respond or take action (as opposed to rhetorical questions).

Questioning Category	Description	Example
Evaluating	The intention is to check for understanding against what the teacher sees as an expected response.	I: What does dH equal at constant pressure? S: dH = dU + PdV
Clarifying	Purpose of the request is to seek clarification of detail what a student is saying. a. Request for clarification is directed to the speaker b. Request for clarification is direction to someone other than the speaker	I: We're going to have reactions that have a negative entropy change. The substances won't, and for it to be spontaneous what has to be true? S: It's positive? I: What's positive? S: The entropy? I: The entropy of what? S: Of the reaction? Of the substance?
Explaining	Intention is for student(s) to share ideas however tentative. (Could be in question or request form.) a. Requests to explain your/group's thinking b. Requests to explain or comment on another student's/ group's thinking	I: Ok, so what are some first impressions? You don't have to be right. Just kind of what are your first impressions about what's going on here. S1: Well, we said that because there is constant motion for, it must be a positive for it to move S2: we said that things are always moving, things always move from order to disorder.
Justifying	Requests to provide warrants or backing for a some conclusion	I: Why are all entropies positive? S: Because you can't go lower than zero degrees Kelvin, and at zero degrees there's no movement so the entropy's zero.

Telling. Telling is an important, but often underemphasized, part of a teachers' repertoire

Telling Category	Description	Example
Initiating	a. Describing or presenting a *new* concept, representation, procedure, solution method, etc. b. Telling students what problem they are to work on next. Involves some contextualization of task. c. Reminding students of conclusions from a previous problem.	I: So in our first model we have our system here, our piston/cylinder thing that we've been analyzing as we go through. We've made one change now, we have indicated the surroundings because when we look at energy exchange, we're looking at the exchange between the system and the surroundings.
Facilitating	a. Providing information that students need, for a task that students are in the midst of working on. b. Reminding students of a conclusion or a way to think about a problem for which there has already been some agreement or public voicing.	I: So I should clarify that, we're not talking about the entropy of a reaction, we're talking about the entropy of a substance.
Responding	a. Answering a direct student question. b. Evaluating a student utterance, can add additional reasoning	S: You can substitute in nRT/V for P because we are working with ideal gas. I: That correct.
Summarizing	This discursive move summarizes ideas, highlights particular mathematics of importance, and/or points to next steps related to the summary.	I: So when we look at heats of formation, you have to do it from the elements. And so when you look at the table in the back of your book that gives you all of those heats of formation, they calculated what the heat of reaction for this, and then we can just add all of those reactions together.

Managing. Teachers, like a general manager at most any company, typically engage in actions that organize their workers in both structural and affective ways.

Managing Category	Description	Example
Arranging	Classroom management of physical space or arrangement of work space or work tasks.	I: Let's look at the focus question for T2. You guys have got a minute to come up with an answer in your small group.
Directing	Mathematical management that directs students to carry out a particular mathematical action.	I: Take the total differential for H = H(T,P)
Motivating	Provides encouragement or motivation for students	I: That's a really good question.
Checking	Check on current status of student progress	I: Does this make sense? Yes, no, maybe?

Appendix C: Analytical Framework for Analysing Student Discourse (SIDM)

Type of interaction:
describes students' interaction during small group activities

Category	Definition
On-task (On)	Students are actively conversing with each other on the assigned task
Independent work (Ind W)	Students are not conversing with each other but are actively working through the problem (ex. no feedback from peers, writing stuff down, using calculator)
Instructor interaction (Inst I)	Asking assistance from the instructor regarding class content or administrative matters
Off-task content related (Off)	Students engaging in conversation that deviates from their assigned task but is still related to class content
Off-task personal (Off P)	Students engaging in conversation not related to class content (ex. personal experiences)
Unengaged (U)	Not participating in classroom activities or engaging with peers (ex. sitting, using phone)

Primary intent:
describes for what purpose the student is speaking

Discourse move	Definition
Initiating (I)	Students begin to work on the activity prompt
Questioning (Q)	Utterances that require member(s) to respond during the activity (does not include questions regarding management of time or work tasks)
Contributing to discussion (RC)	Responses that contribute to the completion of activity
Concluding (C)	Statements that serves as a consensus and ends the question answering process
Commenting (CM)	Personal remarks, judgement of activity/class, or utterances of how students understand the material or future plans to work on material
Managing (MG)	Management of time, works tasks, and student roles or utterances related getting started to begin the activity
Active listening (AL)	Acknowledging a stated utterance that does not meaningfully contribute to the conversation
External Interaction (EI)	Interactions that take place with someone who is not a member of the group or instructor

Nature of utterance:
describes the manner at which students engage in a specific discourse move

Discourse move	Definition	Key Features	Example
Activity	Reading the	• repeating given text	Students begin working

prompt (AP)	activity prompt out loud	at any point during discussion	on activity. S1: ***In the following words, cross out those compounds that do not belong to the category Type I binary ionic compound.***
Agreeing (A)	Voicing agreement to a previous utterance	● does not just include repeating an utterance ● clear indication of agreement to another's utterance ● Confirmation to a question	S2: *I think it would just go to 1400. It's fine. Because you don't need to convert to scientific notation because it already…* S1: ***Okay, yeah you're right.***
Assessing (AS)	Determining if the strategy addresses all aspects of the problem/task and is functional or if an answer makes sense	● Reflecting on the degree to which strategy is addressing the question/task ● Provides evidence of determining whether a strategy or response is functional/correct ● not related to analyzing answer options	S2: ***I don't think it can be a, because you can't have one and a half of an element***
Clarification Seeking (CL)	Requesting to seek clarification of what another student said or what is being stated or confirming their interpretation is correct	● Asking to repeat an utterance ● Asking for more information on a previous utterance ● asking for a reworded statement ● States an idea followed by request for feedback/agreement	S2: *13 has 6* S3: ***Which one has 6?***
Building (B)	Completing and incomplete utterance or expanding on an utterance with more detail or adding additional claims. (this is coded along with another code to describe the nature	● finishing an incomplete thought ● Can be done by self or another student ● Descriptor code does not have to be the same as the original utterance that is being built upon	Prompt: What do all the three carbon atoms have in common? S2: *Um, they all have…* S1: ***Six protons***

	of the building utterance)		
Explanation Seeking (E)	Requesting to share ideas, seeking an initial answer to a question or how to think about a problem or requesting backing to a claim	● Seeking the process for how to complete/solve a problem ● Why/How questions ● Asking for rationale/reasoning for an utterance	Prompt: Iron (Fe) is a transition metal and can form two possible ions. What is the charge on iron in Fe_2O_3? S1: *What is the charge on the iron.* ***How do we even know?***
Information processing (IP)	Evaluating, interpreting, or transforming given information (students trying to make sense of given information)	● Includes the information that is being processed related to the task ● Does not include one-word phrases (um, so, uh, then)	Prompt: What is 6.35 ounces expressed in grams? S3: ***So we're starting with 6.35 ounces and then want to get****...*
Information seeking (IS)	Requesting for more information needed to solve the problem such as conversion factors, definitions, or rules	● Asking for pieces of information to complete a procedure to solve a problem ● Does not include asking for the process of how to solve a problem ● Does not include asking for the answer ● what questions	Prompt: The daily dose of ampicillin for the treatment of an ear infection is 115 mg ampicillin per kilogram of body weight (115 mg/kg). What is the daily dose of the drug for a 27-lb child? S2: ***Oh, oh, okay. So what's the conversion between pounds and kilograms?***
Motivating (M)	Providing encouragement to group members	● Positive reinforcement ● Appreciating group collaboration or individual ideas	***Good job. Woohoo!***
Organizing (O)	Getting ready to work on the task, making sure members are working on the correct task, keeping up with discussion, or assignment of student roles/tasks	● Can happen at any point in discussion ● Does not have to be related to question content ● Utterances are related to the whole group and not oneself	S2: ***You're on the wrong page.*** S1: ***What page? Which ones are we doing? Are you the spokesperson? What did I put? Did I put b?***
Past experiences	Describing experience(s) with	● does not have to be academic/class related	***I remember that one from chemistry***

(PE)	science	● Should be in past tense	***engineering because it was the fun one.***
Personal remarks (PR)	Describing current state of being,or how they feel about the activity, prompt, something they need to complete or other comments not related to completing the task	● Can be on task ● not related to solving the focus of the problem	***I'm so confused…. If you're wrong about this, I'm going to be angry.***
Presenting a claim (PC)	Suggesting an answer that may be tentative in nature	● Does not have to be the final answer ● Cannot be framed as a question	S3: *What weighs more, a ton of bricks, or a ton of cotton balls?* S1: ***They weigh the same.***
Procedural (P)	Describing how to solve the problem. This can include the calculational process	● Calculation or conceptual process ○ not just stating a formula ● Does not have to be the entire process ● Can be stating how an individual solves a problem	Prompt: Gold has a specific heat of 0.128 J/g°C. Determine the amount of heat required to raise the temperature of a 153 g bar of gold from 25.0°C to 75.0°C. S2: ***I did q=mcat. So q=153*.138*50.*** *I can't remember what I put, I think I got 979.*
Providing information (PI)	Providing information that is needed to solve the problem (ex. conversion factors, definitions, rules, formulas, data) or move the conversation forward	● presenting pieces of information to help solve a problem that are not provided ● Is not the answer to a problem ● response to an utterance that does not have to be scientific	S2: *Oh, oh, okay. So what's the conversion between pounds and kilograms?* S3: ***One kilogram is two point two o five lbs.***
Reasoning (RS)	Thinking through the problem/scenario or justifying or supporting an idea with scientific reasoning	● Evidence of thought process in reaching a conclusion ● Presenting a rationale to explain why a claim is true ● Does not have to be about the answer to the	Prompt: How does the size of one Celsius degree compare to one Kelvin? S2: *They're the same?* S1: ***Because the only difference is that, what number they designate***

		task ● Does not have to be requested	***to be zero. Zero in Kelvin is absolute zero, so as cold as possible, and zero in Celsius is the freezing point of water.***
Rebutting (RB)	Rejecting an assertion supported with reasoning	● Clear indication of disagreement of a previous utterance ● Must include a clear rationale for why the utterance was incorrect or reasoning for alternate claim ● does not include rebutting the ideas from oneself	S2: *That's multiplication, this one has one sig fig.* S3: ***Isn't it two because it's one point zero?***
Rejecting (RJ)	Explicitly voicing disagreement with an utterance	● Clear indication of disagreement of a previous utterance ○ Statement of disagreement or ○ Statement of alternate claim/response ● Does not include rationale	S2: *2s squared 2p squared.* S1: ***2p is to the six.***
Repeating (RP)	Repeating an utterance because there was a lack of attention to the conversation	● Restating an utterance, information that the person has previously uttered ● Due to lack of hearing or understanding ● repeating oneself or what someone else has said	Girl 4: Okay I got 4.73 times 10 to the 18th molecules of CO2 in a normal breath. Girl 3: What did you get sorry I wasn't listening what did you say? Girl 4: I got 4.73 times 10 to the 18th.
Reporting (RT)	Repeating an idea or feedback to move the conversation forward	● Restates a claim, information, or reasoning that was provided previously (text, instructor, peer, etc.) ● Should be attributed to the source ● Would not be a restatement due to lack	DS3A: *So we have twenty two cookies, 120 calories for one serving, one serving is two cookies. But then there's nothing under (inaudible).* DS3C: ***Yeah she said not to. She said that this cancels out because there is***

		of hearing or understanding.	***nothing there.***
Summarizing (SM)	Summarizing ideas or steps to solve a problem that arose from the conversation	● Represents a consensus process that typically incorporates ideas from multiple respondents ● Clearly wrapping up how an answer was arrived at ● Appears at the conclusion of the dialogue for a particular task ○ Can be a final answer or an intermediate step	Prompt: Calculate the charge for a chlorine (Cl) ion if a chlorine atom gains an electron to become an ion. S1: *It's, you said negative one, right?* S2: *Mhm... Because it has one extra electron.* S1: ***Oh, because the number of protons is, hold on, 17, the number of electrons if you gain one is 18; the charge is negative one.***
Non-verbal interaction (NVI)	Contributing to the completion of activity by engaging in conversation without words	● seen in video data ● clear indication that a student is pointing towards something	Students pointing at something in the periodic table.
Not audible or applicable (N/A)	Utterances that are inaudible due to static or are not appropriately described by any of proposed codes	● Audio cannot be heard to code properly ● Cannot fit into any other nature codes	

Appendix D: MTSU IRB 19-2253

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Thursday, October 21, 2021

Protocol Title	*Collaborative Research: Investigating classroom discourse in active learning environments for large enrollment chemistry courses*
Protocol ID	**19-2253**
Principal Investigator	**Gregory Rushton** (Faculty)
Co-Investigators	Shaghayegh Fateh, Jonah Schiavone, Amy Phelps, Demer Kirbulut, Anika Chowdhury, Marzea Akter, Steven Berryhill, Oluwatobiloba Ayangbola (ota2g), Joshua Reid, and Fatima Kaya
Investigator Email(s)	*gregory.rushton@mtsu.edu and sf3u@mtmail.mtsu.edu*
Department	Tennessee STEM Education Center, MTSU

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(7) Research on individual or group characteristics or behavior*. A summary of the IRB action and other particulars in regard to this protocol application is tabulated below:

IRB Action	**APPROVED for ONE YEAR**				
Date of Expiration	**6/30/2022**	Date of Approval	6/11/19	Recent Amendment	10/21/21
Sample Size	100 (ONE HUNDRED)				
Participant Pool	Primary Classification: **Healthy Adults - 18 years or older** Specific Classification: **College students**				
Type of Interaction	☒ Virtual/Remote/Online Interaction ☐ In person or physical Interaction – Mandatory COVID-19 Management				
Exceptions	1. Contact information allowed. 2. Audio or/and video recording are permitted for data collection. 3. Approved to use informed consent for verbal recruitment				
Restrictions	**1. Mandatory ACTIVE informed consent using MTSU tempate; the participants must have access Part A of the informed consent.** **2. All identifiable data/artifacts that include audio/video data, photographs, handwriting samples, and etc., must be used only for research purpose and they must be destroyed after data processing.** **3. This study is NOT approved for online data collection.**				
Approved Templates	MTSU Informed Consent				
Funding	National Science Foundation (NSF 1914813)				
Comments	This notice is updated to the 2021 Format (08/20/2020)				

IRBN001 Version 2.0 (overlay) Revision Date 08/20/2020

Post-approval Requirements

The PI must read and abide by the post-approval conditions (Refer "*Quick Links*" in the bottom):

- ***Reporting Adverse Events:*** The PI must report research-related adversities suffered by the participants, deviations from the protocol, misconduct, and etc., within 48 hours from when they were discovered.
- ***Final Report:*** The PI must close-out this protocol by submitting a final report before 6/30/2022 **(Refer to the Continuing Review section below)**; REMINDERS WILLNOT BE SENT. **Failure to close-out or request for a continuing review may result in penalties** including cancellation of the data collected using this protocol and/or withholding student diploma.
- ***Protocol Amendments***: An IRB approval must be obtained for all types of amendments, such as: addition/removal of subject population or investigating team; sample size increases; changes to the research sites (appropriate permission letter(s) may be needed); alterations to funding; and etc. The proposed amendments must be clearly described in an addendum request form. The proposed changes must be consistent with the approval category and they must comply with expedited review requirements.
- ***COVID-19:*** Regardless whether this study poses a threat to the participants or not, refer to the COVID-19 Management section for important information for the PI

Continuing Review **(Follow the Schedule Below)**

This protocol can be continued for up to THREE years (6/30/2022) by obtaining a continuation approval prior to 6/30/2022. Refer to the following schedule to plan your annual project reports and be aware that separate **REMINDERS WILL NOT BE SENT**. Failure in obtaining an approval for continuation will result in cancellation of this protocol. Moreover, the completion of this study MUST be notified by filing a final report in order to close-out.

Reporting Period	Requisition Deadline	IRB Comments
First year report	Progress report received (06/25/2020). A CR conducted on the protocol determined the study is in good condition and the PI may continue the protocol for an additional year. Minor amendment is also done as described later (IRB ID IRBCR2020-059). Current investigators: Rushton (PI), A Phelps, S Fateh, D Kirbulut, A. Chodhury, J Shiavone, M Akter, S Berryhill and J. Reid.	
Second year report	Progress report received (05/26/2021. A CR conducted on the protocol determined the study is in good condition and the PI may continue the protocol for an additional year (IRB ID IRBCR2021-097). Current investigators: Rushton (PI), A Phelps, S Fateh, D Kirbulut, A. Chodhury, J Shiavone, M Akter, S Berryhill, J. Reid, S. Zakher, O. Ayangbola and K. Aboulyamin.	
Final report	5/31/2022	NOT COMPLETED

Post-approval Protocol Amendments:

Only two procedural amendment requests will be entertained per year. *In addition, the researchers can request amendments during continuing review. This amendment restriction does not apply to minor changes such as language usage and addition/removal of research personnel. .*

Date	Amendment(s)	IRB Comments
08/30/2019	Shaghayegh Fateh (sf3u - CITI28917043) is an approved co-investigator	IRBA2020-040
09/27/2019	Grace Millican (gem3h - CITI 33398256) is an approved co-investigator	IRBA2020-055
10/09/2019	Jonah Shiavone (jas2ta - CITI33000069) and Johann Mejia (adb2ev - CITI 33642204) have been approved to join the research team	IRBA2020-060
10/16/2019	Amy Phelps (amy.phelps CITI31797802) and Demet Kirbulut	IRBA2020-066

Date	Amendment(s)	IRB Comments
	(CITI33739947) are added to the investigating team.	
12/06/2019	Anika Chowdury (atc4g - CITI8683231) is an approved co-investigator	IRBA2020-078
04/10/2020	Marzea Akter (ma2ey: CITI8951155) is added to the protocol	IRBA2020-130
05/11/2020	An interview protocol to interview the course instructor has been approved An updated informed consent template to add the interview protocol (IRBA2020-139) has been added.	IRBA2020-139 IRBA2020-143
05/27/2020	Steven Berryhill (steven.berryhill@mtsu.edu; CITI7776875 is an approved co-investigator.	IRBA2020-145
		IRBCR2020-059
06/25/2020	Joshua Reid (jwr4k: CITI5610010) is added to the protocol.	
07/30/2020	Permitted to continue data collection with modified class structure that includes "hybrid" class sections with virtual interactions involving the platform Zoom.	IRBA2020-161
08/20/2020	The informed consent will be administered via a Qualtrics link (on file). The investigating team is updated.	IRBA2021-173
02/03/2021	Changes to data collection to allow hybrid methods are approved. This was done to address challenges due to COVID-19.	IRBA2021-212
02/16/2021	Student worker Sylvia Zakher (swz2a - CITI9879058) is added to the protocol.	IRBA2021-216
02/24/2021	Student worker Oluwatobiloba Ayangbola (ota2g - CITI8211312) is added to this protocol.	IRBA2021-220
03/09/2021	Karolin Abouelyamin (ka6f - CITI9959130) is added to this protocol.	IRBA2021-225
q04/06/2021	A new student interview protocol is added.	IRBA2021-231
07/23/2021	A new interview protocol is added.	IRBA2022-266
10/04/2021	Fatima Kaya (CITI575996) is added to the protocol.	IRBA2022-296
10/21/2021	A new instrument is approved.	IRBA2022-306

Other Post-approval Actions:

Date	IRB Action(s)	IRB Comments
NONE	NONE.	NONE

COVID-19 Management:

The PI must follow social distancing guidelines and other practices to avoid viral exposure to the participants and other workers when physical contact with the subjects is made during the study.

- The study must be stopped if a participant or an investigator should test positive for COVID-19 within 14 days of the research interaction. This must be reported to the IRB as an "adverse event."
- The MTSU's "Return-to-work" questionnaire found in Pipeline must be filled by the investigators on the day of the research interaction prior to physical contact.

- PPE must be worn if the participant would be within 6 feet from the each other or with an investigator.
- Physical surfaces that will come in contact with the participants must be sanitized between use
- **PI's Responsibility:** The PI is given the administrative authority to make emergency changes to protect the wellbeing of the participants and student researchers during the COVID-19 pandemic. However, the PI must notify the IRB after such changes have been made. The IRB will audit the changes at a later date and the PI will be instructed to carryout remedial measures if needed.

Data Management & Storage:

All research-related records (signed consent forms, investigator training and etc.) must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data must be stored for at least three (3) years after the study is closed. Additional Tennessee State data retention requirement may apply (*refer "Quick Links" for MTSU policy 129 below*). The data may be destroyed in a manner that maintains confidentiality and anonymity of the research subjects.

The MTSU IRB reserves the right to modify/update the approval criteria or change/cancel the terms listed in this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

Quick Links:

- Post-approval Responsibilities: http://www.mtsu.edu/irb/FAQ/PostApprovalResponsibilities.php
- Expedited Procedures: https://mtsu.edu/irb/ExpeditedProcedures.php
- MTSU Policy 129: Records retention & Disposal: https://www.mtsu.edu/policies/general/129.php