
Investigating English Learners' Engagement Challenges in a Process Oriented Guided Inquiry Learning (POGIL) Based General Chemistry Classroom.

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ABSTRACT

10 Active learning approaches in introductory chemistry classrooms have improved students' course performance and decreased achievement gaps between underrepresented groups and non-underrepresented groups. With the English Learners (ELs) population increasing steadily in the U.S., finding inclusive learning strategies for those facing language barriers in STEM classrooms is essential. This study focused on the engagement of nine students in a university level active learning introductory chemistry course and their perspectives on possible challenges faced as English Learners (ELs). Data
15 were collected during the Spring 2021 and Fall 2021 semesters in General Chemistry courses each with an enrollment of 24 students using a hybrid (online/in person) format. The participants were interviewed, and the interviews were analyzed using thematic analysis. The results indicate that English learners commonly encountered challenges when participating in small groups. These challenges
20 included feeling overwhelmed, dealing with time constraints while responding to models with extensive reading, comprehending unfamiliar scientific terms, and lacking language proficiency skills. Accommodations tailored to ELs' needs during instructor and facilitation while the ELs are working in small groups with native English speakers are considered.

KEYWORDS

25 Active learning, POGIL, Engagement, Introductory Chemistry, English learners, Inclusive learning strategies, small group participation, Language barriers.

INTRODUCTION

In chemistry education, the integration of active learning methodologies, particularly those grounded in collaborative approaches like Process-Oriented Guided Inquiry Learning (POGIL), has demonstrated significant efficacy in enhancing student outcomes.¹ However, the successful execution of these strategies relies on various factors, including class size, instructor expertise, and the diversity of the student body.¹ As the educational landscape in the United States undergoes a substantial transformation, English learners (ELs) are emerging as the fastest-growing student population, compared to native English-speakers, with an estimated enrollment of 4.9 million students in public schools.^{2, 3} Providing quality education for EL students ultimately prepares scientifically literate citizens and diversifies the STEM workforce.^{4, 5, 6} ELs face distinct challenges in collaborative learning settings, including language barriers,⁶ fear of being judged by their peers,⁷ and a lack of a sense of belonging to the class social community.⁸ Despite the acknowledged effectiveness of POGIL, a notable gap exists in the literature, with few studies investigating the experiences of underrepresented minorities, including ELs, in these active learning environments.^{9, 10}

The primary goal of this study is to examine challenges encountered by a group of English learners (ELs) enrolled in POGIL-based general chemistry classes. Once challenges are identified, ways to tailor the learning environment to meet the needs of ELs more effectively will be considered. Through this exploration, the intention is to guide institutions and professors in promoting inclusivity, ultimately enhancing the learning experience for all students, irrespective of their linguistic or cultural backgrounds. The following research question guides this study: What are challenges regarding engagement and small-group interactions of nine English Learners (ELs) enrolled in POGIL-based general chemistry classrooms?

Active Learning

Active learning, as defined by Brent & Felder,¹¹ entails students participating in brief, course-related activities, either individually or in small groups. These activities are interspersed with instructor-led intervals aimed at analyzing responses and constructing knowledge. Active learning strategies prompt students to establish connections between new and existing knowledge, fostering collaborative problem-

solving. The advantages of employing active learning in STEM classrooms includes; heightened critical thinking abilities,¹² improved student performance,¹³ increased attendance,¹⁴ and greater inclusivity.¹¹ Nevertheless, the efficacy of active learning strategies relies on their proper implementation, considering factors such as class size, instructor facilitation approaches, and student diversity.¹ This study delves into the experience of ELs in POGIL-based chemistry classrooms, analyzing nine interviews post their engagement in an active learning setting facilitated by a trained POGIL instructor.

POGIL as an Active Learning Approach

Process Oriented Guided Inquiry Learning (POGIL) is a widely used active learning method in undergraduate chemistry courses. It provides guided opportunities for collaborative learning, task completion, knowledge construction, and application.¹⁵ POGIL is rooted in cognitive development, collaborative learning, and instructional design principles.¹⁶ Moreover, it aligns with a social constructivist framework, influenced by Vygotsky's ideas,¹⁷ where learning is a social process. Within this framework, students engage in social interaction to interpret and comprehend new concepts, emphasizing collaborative elaboration for collective understanding.^{18, 19}

The social constructivist framework is applied in a cyclical manner with seven stages: prior knowledge, internalization, transformation/habitation, externalization, objectivation, legitimation, and reification (see figure 1).¹⁷ The cycle begins with students utilizing prior knowledge to explore and interpret POGIL activity models. Through habituation and transformation, students construct new knowledge individually. Following internalization, the cycle progresses to invention, encompassing externalization and objectivation. Here, students express and share new knowledge, engaging in group interactions to form a shared understanding. The final part of the cycle involves implementing the new knowledge, comprising legitimation and reification, where the instructor serves primarily as a facilitator rather than a lecturer.¹⁶

Despite POGIL's popularity as an active learning approach and extensive research on its effectiveness,^{9, 10} there is limited exploration of the experiences of underrepresented minorities, including English Learners (ELs), in these environments.²⁰ This study focuses on the invention stage of the learning cycle (externalization and objectivation) aiming to uncover the challenges and barriers ELs

encounter while articulating their understanding of concepts in group settings. Invention represents a pivotal stage within the learning process where verbal engagement and knowledge construction are paramount. In this stage, students actively express and share their newly acquired understandings, engaging in dialogue and group interactions to collectively shape their comprehension of concepts. While ELs may encounter difficulties in comprehending tasks and content during the exploring stage, the invention stage is particularly significant as they are involved in collaborative interactions and peer engagement, which can highlight challenges related to language proficiency and expression.²⁰

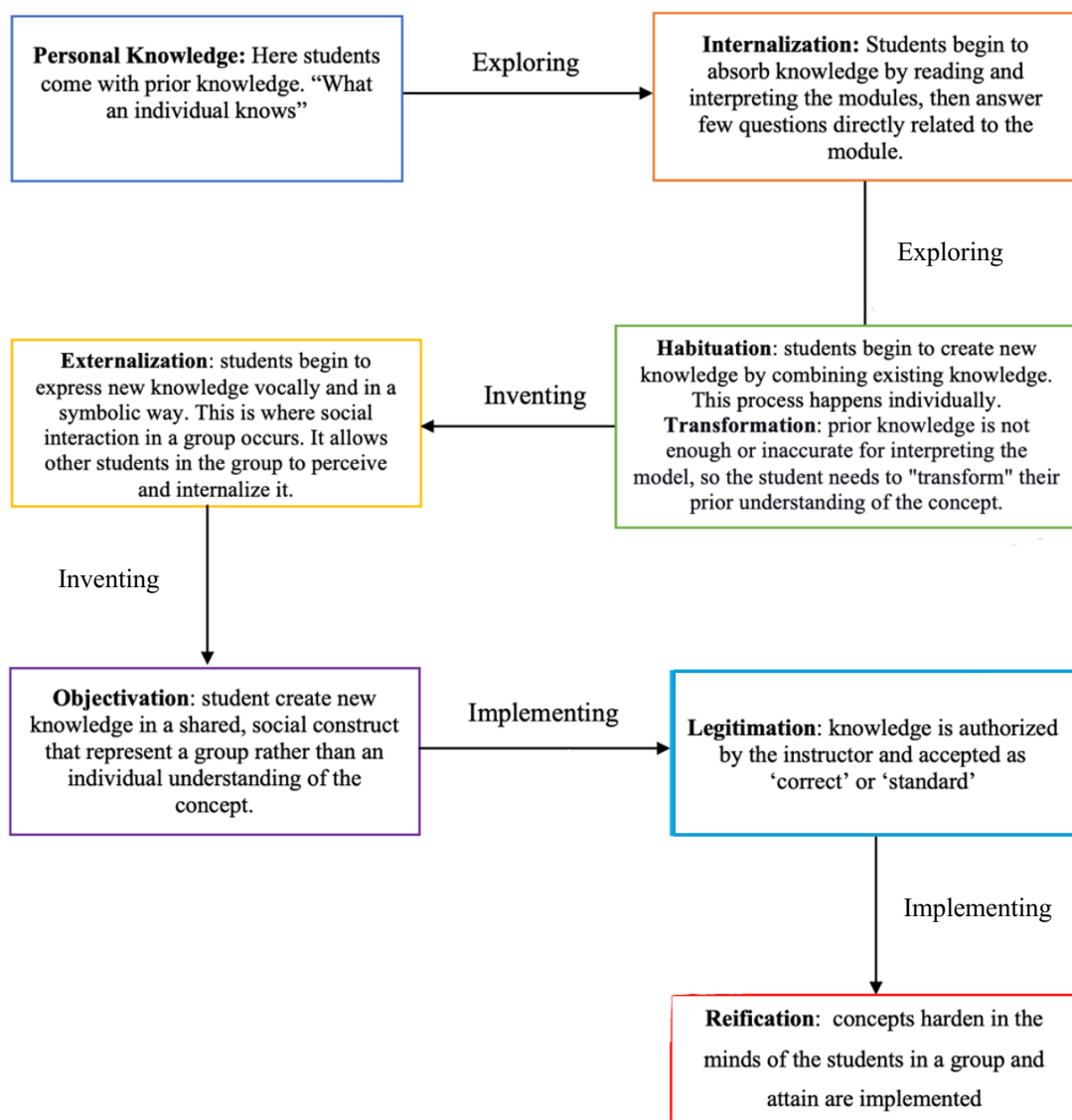


Figure 1. Conceptual framework on knowledge construction in a POGIL-based classroom based on social constructivism.

Barriers and Challenges Faced by ELs

The efficacy of teaching and learning in educational settings is influenced by the motivation of students, who may encounter various types of barriers such as personal, emotional, financial, psychological, situational, or organizational.²¹ These challenges exist for students in many classrooms, emphasizing the need for a comprehensive understanding of factors affecting students' academic endeavors. This study focuses specifically on English Learners (ELs), an underrepresented group in STEM, to identify and comprehend the barriers they face. By addressing these challenges, educators aim to provide quality education, contribute to creating scientifically literate citizens, and foster diversity in the STEM workforce.^{5, 6}

Recent research has revealed that language proficiency significantly impacts the reasoning students demonstrate in chemistry, necessitating tailored academic support.²² EL students face unique challenges, such as difficulty in connecting new scientific information with prior knowledge due to language and cultural differences, the need for extra cognitive steps to interpret and respond to questions in English, and potential biases in assessments that might undervalue their scientific understanding. These barriers can create a less comfortable academic experience for EL students, particularly those with limited English exposure, ultimately affecting their performance and confidence in science.²²

In a study conducted by Lee and her colleagues, it was revealed that ELs often encounter difficulties with the lecture-centric teaching methods commonly employed in introductory science courses.²³ While 34% of native English speakers report a strong grasp of lecture content, only 9% of ELs share the same level of understanding. This significant gap underscores the difficulty ELs face in following and engaging in lectures, leading to lower comprehension and participation rates. In addition, ELs must achieve academic literacy in science, which involves mastering basic conversational English, content-specific vocabulary, and the complex language structures used in scientific inquiry.²³ These language difficulties can lead to potential misinterpretations of their understanding by instructors, highlighting the need for more effective instructional strategies and support mechanisms to ensure ELs can succeed in their academic pursuits.

Deng and Flynn looked at chemistry graduate students and postdoctoral researchers from English-as-an-additional-language (Eng+) backgrounds highlighting that these trainees face significant barriers in their academic environments.²⁴ These barriers include avoidance of interactions due to linguistic insecurities, feelings of imposter syndrome exacerbated by language challenges, the need for extra time for learning and communication, and limitations in fully expressing their scientific knowledge. The study underscores the importance of empathetic supervision and institutional support tailored to the needs of Eng+ students to help them overcome these challenges.

Recognizing the need for innovative approaches, active learning emerges as a promising solution to bridge this gap. Departing from traditional lecture formats, active learning engages students in interactive and participatory learning experiences.¹⁰ . Martin and Graulich's investigation addresses this gap by proposing the use of translation tools and multilingual machine learning models to support ELs in postsecondary chemistry classes.²⁵ They suggests that tools like Google Translate or ChatGPT can assist in translating students' reasoning from their preferred language into the instructional language, making it easier for instructors to assess their understanding. Additionally, multilingual machine learning models offer a more inclusive assessment approach by handling diverse linguistic inputs, though they must be carefully designed to avoid potential biases that favor majority languages.

Lee and her colleagues delve into the difficulties ELs face, especially in mastering both conversational and scientific language in introductory science courses.²⁶ Their research underscores the compounded nature of these challenges and the necessity for instructors to address both linguistic and academic hurdles that ELs encounter in STEM disciplines. In particular, the study investigates the experiences of Chinese-speaking ELs in a virtual chemistry lab course during the COVID-19 pandemic using a phenomenographic approach. It explores how these students navigated virtual learning environments and employed language-learning tools to overcome linguistic barriers. The findings indicate that virtual labs offered a safe, low-pressure

environment that allowed students to repeat experiments and alleviate anxiety. However, the study
145 also identifies challenges related to trans-language and the need for advanced metacognitive
strategies. Additionally, Lee and her colleagues examined how modifying general chemistry assessment
items can help alleviate language barriers for ELs while maintaining the difficulty of the content.²⁷ By
applying the Equitable Framework for Classroom Assessment (EFCA), three assessment items on
limiting reactant and percent yield were revised for linguistic simplification. The results demonstrated
150 that EL students significantly improved their comprehension and problem-solving abilities with the
modified versions of these assessments. The modified items, designed to be less dependent on complex
language, were more accessible to EL students, highlighting the effectiveness of linguistic adjustments
in enhancing their performance and engagement in chemistry. Furthermore, issues such as a sense
of belonging within the class social community and stereotype threat exacerbate feelings of
155 inadequacy related to language proficiency, potentially affecting engagement and achievement.^{7, 28}
Washburn suggests strategies, such as relating classwork to students' home countries, to enhance
sense of belonging.⁸

Building on these findings, our research delves deeper into the specific challenges faced by
ELs in small group settings, where collaboration and discourse are critical for knowledge
160 construction. Small group environments, such as those found in POGIL classrooms, require
students to actively engage in discussion, share ideas, and build on each other's contributions. For
ELs, this setting can be challenging due to language barriers that complicate their ability to fully
participate and benefit from these interactive learning experiences. By focusing on the dynamics of
small group settings, our study aims to identify the specific challenges ELs face in active learning
165 environments and to develop effective strategies to support them, enhance their learning
experiences, and ensure they thrive in collaborative academic contexts.

METHODOLOGY

This research adopts a comparative case study design, an in-depth examination of a single unit,
such as a nation-state, revolution, or person, observed at one point in time or over a specific period of

170 time.²⁹ By focusing intensively on individual cases, we can uncover patterns and generate insights that
might be overlooked in broader, less detailed studies. The comparative aspect enables us to draw
connections and contrasts with other similar units, enhancing the transferability and relevance of our
findings to a larger class of similar cases. The data collection methods were tailored to the needs of the
case study, focusing on capturing descriptive information about English Learners' (ELs) student-student
175 interactions in general chemistry classrooms. All research methods and forms underwent IRB approval
(protocol #19-2253). Data were collected in General Chemistry classes at a large public university in the
southeastern United States over the course of two semesters, Spring 2021 and Fall 2021. The courses
involved small collaborative groups (3-4 students per group) working on Process Oriented Guided Inquiry
Learning (POGIL)-based activities. The instructor, who has over twenty years of chemistry teaching
180 experience and has served as a POGIL trainer, led the course. Due to COVID-19, students were divided
into two groups and alternated between meeting in-person and joining the class via Zoom (e.g., hybrid
format). For small group conversations, the instructor sent the students to pre-assigned breakout rooms
consisting of up to two students who were present in the class and up to two students who were online
that day. Students did not have assigned roles in their groups and group composition was random.
185 Usually, the group conversations took ten to twenty minutes, depending on the time the instructor
provided for students to work on each POGIL question. While students were working on the POGIL
handouts in their small group, the instructor checked in with groups and answered their questions.
Each group had an iPad to share the screen while working on the POGIL handout. For confidentiality,
all student names mentioned in this study are pseudonyms.

Data Collection

The data for this study were collected from multiple sources to gain a comprehensive understanding of English Learners' (ELs) experiences in introductory General Chemistry classrooms. First, a Qualtrics survey was administered to gather demographic information and identify EL students based on their self-reports.³⁰ This survey played a key role in selecting participants for further study. Next, Zoom recordings of breakout room sessions were analyzed to observe EL students' interactions within small groups, which also guided the development of targeted interview questions. Notably, this data was collected during the spring semester only. The primary data source, however, was in-depth interviews conducted with both EL students and the course instructor. These interviews were central to our study, providing rich qualitative data that formed the foundation for most of our findings. By integrating data from surveys, classroom observations, and interviews, we aimed to capture a comprehensive view of the challenges ELs face in collaborative learning environments.

Spring 2021 Semester

In the 2021 Spring semester, 22 out of 24 students (comprising 6 males and 16 females) agreed to participate in the research study and shared their demographic information through a brief survey.³⁰

Among these participants, six self-identified as English Learners (ELs) (one male, five females), with one female EL later dropping the course after three weeks. Through careful examination of the dynamics present in these conversations, we identified key areas of interest and potential challenges faced by ELs. Our observation protocol included watching the small group recordings to note the types of interactions and topics discussed, the students' non-verbal cues, and the overall group dynamics after the discussion took place. The observer responsible for setting up the recording equipment was the sole person present during these sessions; no additional observers were present during class. In our observation, we paid close attention to how EL students initiated or responded to conversations, their use of academic language, and their comfort levels in expressing ideas. For instance, we supposed that some ELs may engage less due to discomfort stemming from language barriers. This observation informed the development of interview questions tailored to directly address these interpretations, ensuring that the interviews effectively captured the perspectives and insights of ELs. By aligning the interview protocol

with our firsthand observations, we aimed to delve deeper into the unique experiences and needs of ELs in active learning environments, thus enriching the depth and relevance of our research findings.

Meet the Students Spring 2021

220 Rachel

Rachel, an EL student, was a part of a group composed of two ELs and two non-ELs. Born in North Carolina, she learned English through interactions with her neighbors and was enrolled in an English as a Second Language (ESL) program early in her education. Arabic is her native language.

Luna

225 Luna, an EL student, was a part of a group composed of two EL and one non-EL students. She came to the United States when she was five years old, primarily speaking Spanish. She described herself as bilingual and mentioned teaching herself English. She faced a prolonged mid-semester absence due to a family health issue in El Salvador, impacting participation and ultimately her success in the course.

230 Faith

Faith is an EL student from Kenya who identified herself as an international student on the consent form. She was a part of a group composed of two ELs and two non-ELs. Faith came to the US for her undergraduate degree with a student visa as a member of the university track and field team

Fiona

235 Fiona, an EL student, was a part of a group composed of two ELs and two non-ELs. She began her education in Iran, continued in Turkey, and started first grade in the United States. Fiona experienced culture shock upon arriving in the US as a child of immigrants. She's trilingual, with Farsi as her first language, Turkish as her second, and English as her third. Fiona shared how COVID affected her mental health and learning. She had frequent absences in the semester.

240 Henry

Henry is an EL student from Kenya who identified himself as an international student on the consent form. He was a part of a group composed of two ELs and two non-ELs. Henry came to the US for his undergraduate degree with a student visa recruited to run track for the university and he was a

second-year student at the time of the study. His group interacted through the chat feature of zoom
rather than out loud.

ELs Interviews

Pilot interviews were conducted with two EL students enrolled in a different general chemistry course taught by a different instructor. These pilot interviews' main aim was to assess the clarity and effectiveness of the questions formulated. By engaging in this preliminary phase, we sought to ensure that the interview questions were comprehensible and appropriately targeted to elicit meaningful responses from ELs.³¹

After confirming the clarity of the interview questions through the pilot interviews, we conducted formal interviews with our five ELs participants from the spring 2021 semester, with each participant being interviewed once. The interview questions were not changed after the pilot interviews. The interviewees received compensation in the form of electronic gift cards, at a rate of \$10 per hour. These interviews were conducted via Zoom and recorded, featuring questions aimed at understanding participants' views on classroom dynamics and needed improvements. Topics included educational background, group interactions, POGIL activity experiences, language proficiency, and student-instructor interaction. Each interview lasted 30-60 minutes based on respondents' detailed responses. All interviews were conducted in English and each participant was interviewed once. Transcriptions of all interviews were generated using Otter.ai or Temi transcription services.^{32, 33} These interviews were conducted during the third month of the Spring 2021 semester to ensure that students had gained sufficient experience working in small groups.

Following the Spring 2021 semester, we aimed to extend this research project to further explore the experiences of English Learners (ELs) in small group settings. To achieve this, we sought to compare our findings with data collected from the Fall 2021 semester. By analyzing experiences across multiple semesters, we aimed to track any changes or consistencies in EL engagement patterns across different cohorts and academic periods. This comparative approach would provide valuable insights into the dynamics of EL participation in active learning environments over time, informing the professor to develop potential strategies for enhancing ELs educational experiences and outcomes.

Fall 2021 Semester

In the Fall 2021 semester, 22 out of 24 students (8 males and 14 females) provided their consent for research participation and shared their demographic information through a short survey.³⁰ Among these participants, four students (2 males and 2 females) identified as English Learners (ELs) and completed the consent process. Like the previous semester, students were divided into six small groups (G, H, I, J, K, and L). Notably, two of those groups included English Learners (ELs) and were the primary focus of our study. One of these groups consisted entirely of ELs (group L), while the other group comprised a mixture of ELs and non-ELs (group G) (See table 1). Special attention was given to the group comprising solely ELs to ensure that their conversations pertained to the class material. This was particularly crucial as they primarily communicated in Arabic. While the instructor did not speak Arabic, one of the authors of this paper was fluent in Arabic and was able to confirm that their engagement was related to the course content, particularly in the context of POGIL activities. Subsequently, all four ELs were invited via email to participate in interviews, following the same interview procedure as in the Spring 2021 semester.

Unlike the Spring 2021 semester, no recordings were transcribed this semester. Instead, we opted to employ the same interview questions utilized in the previous semester. However, we expanded upon this framework by incorporating a couple of additional questions focused on the students' preferred methods of learning. These inquiries delved into whether students engaged in group chats with their peers outside of scheduled class times to discuss course material. This addition was motivated by a desire to investigate the influence of students' sense of belonging and their interpersonal relationships on their participation in small group discussions. Recognizing the significance of these dynamics, particularly in fostering active engagement within collaborative learning environments, was central to our research objectives.

Meet the students from Fall 2021

295 Sarah

Sarah is an EL student originally from Egypt who came to the US in eighth grade. She was placed in a group with three other EL students, all from Egypt and Arabic speakers. Sarah knew her group peers from high school. Group engagement was excellent as they conversed in their native language. However, when a non-EL student temporarily joined the group, the engagement declined significantly, and Sarah did not engage in the conversation at all.

Casey

Casey is an EL student originally from Egypt, who arrived in the US during middle school with Arabic as her first language. She was part of Sarah's group. Among her group members, Casey had lived in the United States for the longest period.

305 Kevin

Kevin is an EL student from Egypt who came to the US in eighth grade. Arabic is his first language, and he was part of Sarah's group.

Paul

Paul is an EL student originally from Egypt and lived in New Jersey for a couple of years before moving to Tennessee. Paul moved to the United States when he was in high school. He was part of a group composed of two non-ELs students and he was the only EL in his group. Arabic is his native language.

Table 1. Demographic Information

Participants name	Gender	EL	International Student	First language	Semester	Group
Luna	Female	Yes	No	Spanish	Spring 2021	Group C
Rachel	Female	Yes	No	Arabic	Spring 2021	Group D
Henry	Male	Yes	Yes	Unspecified	Spring 2021	Group D
Faith	Female	Yes	Yes	Unspecified	Spring 2021	Group F
Fiona	Female	Yes	No	Farsi/Turkish	Spring 2021	Group F
Sarah	Female	Yes	No	Arabic	Fall 2021	Group L
Kevin	Male	Yes	No	Arabic	Fall 2021	Group L
Casey	Female	Yes	No	Arabic	Fall 2021	Group L
Paul	Male	Yes	No	Arabic	Fall 2021	Group G

Table 1. Demographic Information of Participants in POGIL-Based Chemistry Classes over two semesters.

315 Instructor Interview

The instructor responsible for teaching both the Spring 2021 and Fall 2021 semesters was interviewed to provide insights into their perception of English Learners' (ELs) experiences and engagement within small group settings. With over two decades of experience in teaching chemistry and specialized training in POGIL, the instructor brought valuable expertise to the discussion. The interview
320 protocol resembled that of the ELs, focusing on the perceived challenges encountered by ELs in the classroom and exploring potential adaptations of POGIL to address these challenges. This interview's main objective was to compare the instructor's observations and the responses provided by students during their individual interviews. For instance, the instructor was queried regarding the class expectations and norms, a question that was also posed to the ELs. This allowed a direct comparison to
325 ascertain the level of familiarity ELs had with the classroom expectations in relation to the instructor's perspective.

Interviews Analysis

Initially, analytical memos were crafted to document emerging ideas and questions observed during the transcription of each interview. Drawing upon previous research on obstacles encountered by
330 English Learner (EL) students,^{22, 23, 24, 25, 26, 27} initial codes were developed to identify specific topics in the interview transcripts. For instance, discussions about English proficiency were categorized separately. Following this initial categorization, thematic analysis was used, adhering to the framework outlined by Xu and Zammit (2020), to identify recurring themes in the dataset. Employing a constant comparative analysis method consistent with case study techniques, we incorporated students' own
335 words (*in vivo* codes) to fully understand their perspectives. Subsequently, our focus shifted to presenting individual cases before identifying broader themes and trends spanning both semesters. Throughout this process, four coders were engaged for the thematic analysis, and any discrepancies in their interpretations were resolved through discussion and consensus.

Positionality Statement

As researchers, we recognize that our backgrounds, experiences, and identities shape our perspectives and interactions with the research process. This positionality statement serves to acknowledge these influences and ensure transparency in our study.

The first author identifies as an immigrant and English Learner (EL), bilingual in Arabic and English. Navigating the educational system in a new language has profoundly influenced their commitment to supporting EL students. This author's experiences have heightened their awareness of the challenges and barriers faced by ELs and their resilience and potential. This background drives their passion for the research and informs an empathetic approach to understanding EL students' perspectives.

Also, two of the authors are international students, further enriching the collective understanding and sensitivity towards EL students' experiences. The diverse backgrounds of the authors contribute to a comprehensive approach in the research, aiming to authentically capture and advocate for the voices of EL students.

RESULTS AND DISCUSSION

This section pertains to the analysis of interviews conducted during the Fall 2021 and Spring 2021 semesters, with the use of pseudonyms to maintain the confidentiality of the participants. Key findings from our data and interview analyses encompass: 1) the redefinition of the ELs population to acknowledge distinct subgroups 2) heightened engagement of K-12 ELs students in small group discussions, 3) ELs students' lack of familiarity with class expectations and norms, 4) limitations in English fluency hindering ELs' expression in scientific tasks, 5) scientific terminology posing a barrier for EL students, 6) ELs' experiences with POGIL activities, and 7) the instructor's perspective on ELs' engagement and experiences.

Initial Findings

This study focused on the experiences of ELs collaborating within their small groups to answer POGIL handouts questions. These handouts encompassed a range of content, such as definitions, tables, graphs, background information, or equations, all of which students were tasked with reading before attempting to answer questions. When delving into the individual experiences of ELs through

analyzing interviews and transcripts, it becomes evident that they had similar and diverse experiences as they worked on POGIL handouts. Rachel described her experience as relatively smooth but pointed out the potential benefit of having a lecture before engaging in group work. Although Luna found the POGIL approach to be helpful, she mentioned the significance of prior knowledge to successfully answer the POGIL questions. The obstacle of feeling like they had a lack of prior knowledge was commonly mentioned by Kevin, Sarah, and Luna. Faith faced the challenge of time constraints and expressed her wish for more time to work on the handout. Casey also emphasized time constraints as her primary issue with POGIL along with language being a major barrier. Moreover, she felt pressured by her group's expectations of her knowledge level, given her longer residency in the United States compared to her group members. Sarah shared similar sentiments, expressing difficulties in articulating her thoughts due to language barriers, stating,

“so I know the answer sometimes, but I forget or I don't know how like to put in complete sentences or in a way that makes sense. Like I will know, like, a point to the answer. And I couldn't like type it or say it to make sense.”

At the inception of this study, we initially categorized the classroom population into two broad groups: English Learners (ELs) and non-English Learners (non-ELs). However, upon a more thorough examination of the data, we uncovered that the EL population was more heterogeneous than expected. This realization prompted us to divide the ELs into specific subgroups based on the similarities in their experiences and the challenges they encountered within their small groups. This reclassification allowed us to gain a deeper understanding of how these subgroups navigate POGIL activities, providing more targeted insights and information to develop recommendations to enhance ELs learning experiences.

Redefining the ELs population

Through collecting educational background information during interviews and consent forms, it was discerned that the number of years in which a person has been a student in the US education system had an impact on that student's experience and engagement in a POGIL-based class. Therefore, we categorized ELs in this study based on this criterion. Students born in the United States or educated here from pre-school through college had similar experiences and outlooks on the class and so they were labeled K-12 EL students, exemplified by Rachel, Luna, and Fiona. Students who arrived in the

United States on student visas, lacked prior U.S. educational experience, and self-identified as International Students in the consent form were designated as EL-I (EL-International) students, exemplified by Faith and Henry. Finally, individuals who immigrated to the United States at an older age with limited exposure to the American education system were termed EL-SE students (English Learners-Secondary Education Students). Data indicated that these students, classified as EL-SE students in the Fall 2021 semester, encountered greater English language proficiency challenges than K-12 students. Those students were Kevin, Sarah, Casey, and Paul (See Table 2).

Table 2. ELs Subgroups

Participants name	EL Subgroup
Rachel	K-12
Luna	K-12
Faith	EL-I
Henry	EL-I
Fiona	K-12
Sarah	EL-SE
Kevin	EL-SE
Casey	EL-SE
Paul	EL-SE

Table 2 illustrates the subgroup classification for each EL student included in the study.

Engagement in small group conversations

The analysis of interviews revealed distinct engagement patterns among different subgroups of EL students. K-12 EL students exhibited a high level of comfort and active participation in small group discussions, expressing the benefit of working with peers who could help them understand and remember course content. Their high level of comfort and peer interaction supported rather than impeded their development in the externalization and objectivation stages of the learning cycle (see figure 1). Fiona and Rachel emphasized the comfort and effectiveness of small group collaboration in facilitating their learning. Rachel articulated her experience in her interview, stating:

“I like working in small groups because you know, if there's something that like, I don't understand, usually my partner will. Or if maybe my partner understands something, it gives me a chance to think through it because I feel like when you when you're teaching it to somebody else, you're thinking through it more, remembering it more for the exam. So, it's really helpful to me.”

Fiona provided real-life example of why she feels comfortable in her group, expressing:

415 *"I remember a girl in my group was like, like, I don't understand what's going on. And then a guy like, was like, that's okay. Like, I know, it's complicated. He just kind of went through it step by step. So, it's comfortable when like, everybody's kind of like, paying attention and like trying to work through the problems...small groups let you like, ask questions to your peers. And it's kind of like, less vulnerable. Like, you can just ask like, Okay, I have no idea what this is like, Can you explain it to me, and they'll*
420 *explain instead of feeling like it's like a high pressure situation with a professor...I just think small groups are really helpful in making people feel more comfortable asking questions.."*

Luna's experience was unique as she faced the challenge of traveling abroad due to a family health emergency. However, despite this unexpected circumstance, her participation in small groups proved to be beneficial. Within her group, Luna found a supportive environment where she could communicate
425 about the concepts and POGIL handouts she had missed. Reflecting on her experience during the interview, Luna shared,

"So when I told my breakout room that I was going out of the country, because it was so last minute, like, we bought tickets, and then that same night, or in the morning, I emailed all of my professors. And then I went to class. And then I told the breakout room. And they were all really supportive of me. And
430 *they told me that, because I thought I'd have internet over there, but I don't have any. But they were like, okay, we'll send you our notes to help you get back on track. They were very supportive, and they wished me the best with my family and everything that I was going through. And I know that just hearing like, those sweet sentiments from them. It just made... it just reassured me about how I felt in the breakout room is very, very sweet of all of them to check in on me"*

435 The diverse experiences shared by K-12 ELs in the small group setting underscore the importance of collaborative learning environments in supporting academic success and well-being. While students like Rachel, Fiona, and Luna highlight the positive impact of peer interaction, it's essential to recognize that not all ELs feel equally comfortable within their small groups, as evidenced by some contrasting experiences. For instance, EL-I students recognized the value of small groups but encountered
440 challenges related to discomfort and the fear of not being understood when contributing to discussions. Faith articulated this sentiment, stating:

"everyone can contribute ideas...you can ask your fellow group members to at least elaborate for you...At first, it was so hard for me, but, you know, as the time goes, you adapt you...you know, it's sometimes it's not effective actually, because sometimes you can type and somebody doesn't understand that."

Henry also expressed his comfort in small group settings. However, he mentioned that his accent could potentially pose a challenge when expressing himself, particularly in situations where he might need to repeat himself. Nonetheless, as mentioned earlier in the paper, Henry's group engaged mainly through the chat feature of zoom, so this obstacle didn't significantly hinder his participation.

Henry: *"well yeah accent remember like once you like where you grow where you stay like back home for a long time so whenever like you stay with someone maybe from a different place like American you know and I'm from Kenya you will be able to know that this accent is a little bit different"*

Interviewer: *"yeah definitely I have the same experience I mean I'm an international student too I have sometimes they make me repeat what I'm saying because of my accent because they cannot understand me."*

Henry: *"Exactly"*

For EL-I, discomfort stemming from language proficiency issues and the fear of being misunderstood can significantly impact their experiences during the externalization and objectivation stages of the learning cycle (see figure 1). In the externalization stage, where learners articulate their understanding and apply their knowledge, EL-Is might hesitate to express their thoughts fully due to concerns about making errors or being judged. This reticence can limit their ability to engage deeply with the material and interact effectively with peers. Similarly, in the objectivation stage, where learners reflect on and analyze their knowledge, EL-Is may struggle to contribute meaningfully to discussions and activities if they feel their contributions will be misunderstood or dismissed. The resulting anxiety and self-doubt can impede their ability to integrate and solidify their learning, potentially affecting their overall academic performance and engagement. Similar to the K-12-ELs, EL-SE students felt at ease participating in small group, highlighting the opportunity to share ideas and collaborate. Paul mentioned in his interview,

" It's good. It's, it's really good. It's such it's something different than anything I've done before...

470 like, none of my classes had that, like group work. I would say like always, like, every class, we meet, we had the group work together. And so, it was it was helpful like asking questions if I don't know something, or if they don't know something they asked me, so it was it was good...The first day was uncomfortable, of course, because you don't know that person. But when you get to know them, it gets comfortable with them. And you ask them, you laugh, literally make jokes. You do like problems."

475 In another interview, Kevin stated,

"I'm confident and comfortable because I know these people, so it's fine. If I got something wrong, it's fine to discuss with them what's right, what's wrong. What's what we have to do? And this step? Yeah. Because... I just know them, like, from three years ago... So, we all from Egypt in my group, so that this is easier that we take we talk Arabic, most of the time. Not English, "

480 It's noteworthy to mention that this experience might have been unique since three of the EL-SE students engaged in their native language, Arabic, as they all came from the same country and knew each other prior to this course.

An interesting observation indicates that some ELs could be less inclined to participate in discussions when their groups' composition changes throughout the semester. We believe that as students become more engaged with each other over the course of the semester, their willingness to share ideas would naturally increase. However, if the composition of the groups were to change, they might not feel as comfortable expressing their thoughts due to a lack of connection with new group members. This observation is drawn from statements made by some ELs during their interviews. Kevin, for instance, shared in his interview:

490 "One time, they all were absent. So, I went to work in another group. I didn't feel comfortable because they were talking together. Like, they didn't ignore me. But they weren't comfortable with me because I hadn't talked to them before. Yeah. So, I was working by myself."

Kevin's discomfort might have arisen from the need to communicate in English rather than Arabic with the other group members, or simply from the unfamiliarity of the new group composition, placing him in an environment he was not accustomed to. Fiona also expressed,

495

"I think, toward the beginning, so like, the first couple of times, we were in the groups and like, people were kind of quiet. It's kind of like, we don't know who's gonna take over what role. So, I just kind of like broke the silence."

Hence, we understand that maintaining consistent group compositions is crucial for ELs to feel at ease and engage in meaningful small group conversations. This allows them to become accustomed to their peers and foster relationships over time.

ELs aren't familiar with the expectations and norms of the class

Our data indicates that the majority of EL students lacked familiarity with the class expectations. During the instructor's interview, the instructor was asked about her expectations and norms for students in the class. Concerning expectations, she underscored the significance of class attendance, active participation, taking initiative in learning the material, and being responsive to questions. The instructor articulated,

"There's an expectation that you participate, that you play the game, you know—if there's a question, you try to answer it, if there's a problem, you tackle it. If you're working in a group, you participate, stay awake, and engaged. But I don't expect that you've read the chapter before coming to class. I think it would be silly of me to expect it. I think you should do your homework, but I treat the book as a supplement to class. I expect people to take responsibility for their understanding, meaning if you don't get it, you should let me or your group know, rather than sitting there suffering in silence. The only person who knows how much you understand is you."

Regarding norms, she noted that it is common for some students to deprioritize homework under the assumption that attending class suffices. Additionally, she mentioned that certain students may not value group work, presuming that the instructor will provide answers post small group discussions. She perceives these behaviors as typical, attributing them to the unfamiliarity of many students with active and collaborative learning environments.

Based on ELs' interviews, two out of nine ELs, both of whom were K-12 ELs, exhibited some understanding of these expectations. Rachel and Fiona, K-12 EL students, acknowledged the importance of class attendance, preparation, and participation. It is possible that their prior experience within the American education system may contribute to their familiarity. In contrast, EL-I students,

exemplified by Faith and Henry, displayed limited awareness of the class norms. Their perception was primarily centered on relying on peers to ask questions rather than directly approaching the instructor; this was the only expectation or norm mentioned in their interviews. Some EL-SE students faced a challenge in grasping class expectations and norms. According to Kevin and Casey, they were overwhelmed by their perceived expectation to have a deeper understanding of chemistry concepts and possess prior knowledge to answer questions in the POGIL handouts and participate in their small groups. Therefore, it is likely that if ELs are not familiar with the class expectation, they may reduce their interaction frequency.

Instructor interview analysis

The instructor's interview served as a tool to highlight the challenges faced by ELs through the perspective of the classroom instructor. One prominent challenge is the disparity between ELs' receptive and expressive language skills. Many ELs understand English well enough for classroom instructions and discussions but struggle to articulate their thoughts effectively. This difficulty in expression can impede their full engagement in class activities and hinder the communication of their learning needs to the instructor.

Another critical challenge for ELs is the reluctance to participate actively in class interactions. The instructor noted instances where ELs may avoid speaking up in class or within their groups due to concerns about being misunderstood or feeling socially marginalized. This hesitation can stem from anxieties related to their accent or language fluency, which may lead them to perceive themselves as less accepted by their peers.

"I think for most of the ELs I've had, their receptive language is stronger than their spoken language. So, I don't think they have as much trouble understanding me as they do expressing what they don't understand. That's a constant issue. It's hard for me to know what they know, not because they don't know anything, but because they can't tell me as easily as other students. When they're stuck, it takes longer to figure out the problem. I worry that some of them won't ask questions in class or even in their groups, worried about being misunderstood. Some ELs don't mind talking at all, but others may feel less accepted, especially depending on their language of origin."

Moreover, the instructor pointed out the complex dynamics of group work for ELs. While some may thrive in collaborative settings and take leadership roles within their groups, others may withdraw and become passive participants. The composition of the group and the acceptance within it play crucial roles in determining ELs' comfort levels and participation rates.

555 In addressing these challenges, the instructor emphasized the importance of providing ELs with sufficient time to formulate their responses. This accommodation acknowledges the additional cognitive effort required for ELs to process information in their second language and to construct coherent verbal responses. Small group settings, according to the instructor, can sometimes offer a more supportive environment where ELs feel less pressured and more encouraged to contribute compared to larger class
560 settings. The instructor stated,

*"I guess the thing I worry about the most is giving them enough time, to formulate a response, because if I if I were having to translate. Students sometimes see that delay as 'I don't know,' instead of 'Give me a minute.' The groups can help with that. I know not everyone on the research team agrees, but I think small groups are more comfortable for ELs than speaking in front of 48 people. Some come to my
565 office, which I'm okay with, but I worry about the ones who don't speak in class, in groups, or send emails."*

However, despite these accommodations, the instructor acknowledged the ongoing difficulty in accurately assessing ELs' understanding and proficiency. Balancing the need to provide ELs with adequate time during assessments while ensuring fairness remains a persistent challenge for instructors. Recognizing these challenges and implementing supportive strategies are essential steps
570 toward creating inclusive learning environments where all students, including ELs, can thrive and succeed.

Language proficiency and scientific terminology

Language proficiency posed various challenges for different subgroups of EL students. K-12 EL students, such as Luna and Rachel, primarily struggled with listening, as their thoughts sometimes
575 switched involuntarily between languages, hindering comprehension. EL-I students, represented by Fiona and Henry, encountered difficulties in speaking, driven by a fear of being judged or misunderstood (see figure 3). In contrast, EL-SE students acknowledged the need for improvement in multiple language skills but found that it didn't significantly affect their group participation, mainly because they

communicated in their native language (Arabic). However, language proficiency did impact their learning, as illustrated by Casey's struggle with writing, which slowed down group tasks. It is important to note that the use of their native language in groups hindered the instructor's ability to assess their knowledge construction and comprehension, a crucial aspect of the learning process. An analysis of students' self-evaluations showed that K-12 students rated their English proficiency higher than EL-I and EL-SE students, indicating differences in language confidence among these subgroups (see figure 2).

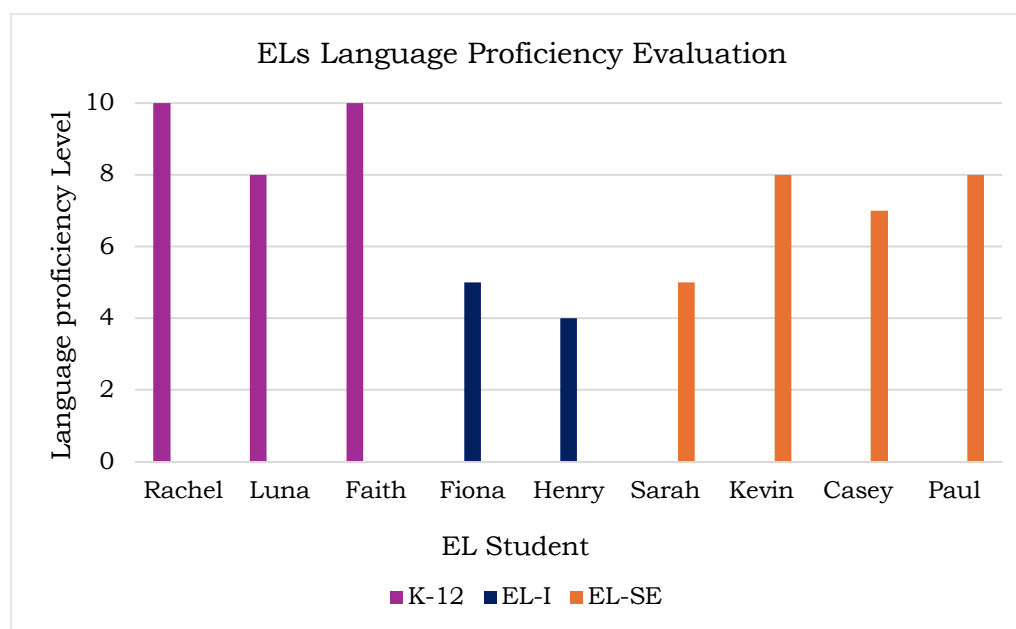


Figure 2 ELs Self-Reported Language Proficiency Evaluation from Interviews on a Scale from 1-10

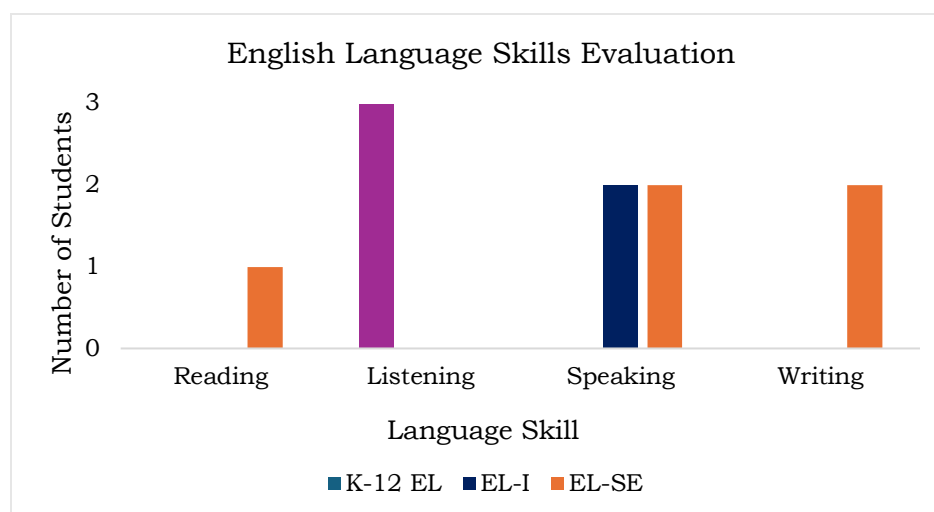


Figure 3. Self-Reported English Language Skills Evaluation by ELs from Interviews

In conclusion, the analysis of interviews conducted during the Fall 2021 and Spring 2021 semesters shed light on the diverse experiences and challenges faced by EL students in small group based POGIL activities. Through the reclassification of EL students into distinct subgroups based on their educational backgrounds and language proficiency, we gained a deeper understanding of their unique needs and barriers. These findings offer valuable insights for educators and institutions seeking to support EL students effectively in similar educational settings.

CONCLUSION AND IMPLICATIONS

Previous research has consistently highlighted the benefits of employing active learning methodologies in introductory chemistry classrooms. These approaches have been found to enhance student performance,¹³ foster critical thinking skills,¹² and contribute to narrowing achievement disparities between various demographic groups.⁵ Amidst the increasing enrollment of English Learners (ELs) in the U.S., there is a pressing need to develop inclusive strategies tailored to their needs. ELs often encounter difficulties in fully engaging with course materials and participating in classroom activities due to language barriers.²² In the context of general chemistry classrooms utilizing Process Oriented Guided Inquiry Learning (POGIL), understanding the engagement levels and obstacles faced by ELs during small group interactions became crucial. This study sought to delve into the experiences of ELs in POGIL-based general chemistry classrooms, examining their levels of engagement and the challenges they encountered when working in small groups. By gaining insights into these dynamics, educators could better understand the specific needs of ELs and develop targeted interventions to support their learning journey in STEM disciplines.

This research concluded that ELs face common obstacles and challenges when engaging in their small groups. Some challenges include feeling overwhelmed while working in a group, answering models with heavy reading portions due to time, learning new scientific terminology and concepts, and language proficiency. Consequently, it is beneficial to consider specific accommodations to facilitate ELs' learning experiences, taking into account their English language proficiency levels and the unique challenges encountered in group settings. For example, during the initial observation of small group discussions in the fall 2021 semester, Arab students, while learning to name polyatomic ions, struggled to understand

that "Penta" is the prefix for five. Throughout the discussion, they referred to it as "benta" because the letter "p" does not exist in the Arabic alphabet. While this might seem like a simple example, such misunderstandings can hinder ELs' performance in the class.

To better support ELs, instructors might consider incorporating several strategies. These could include clarifying terminology, addressing phonetic differences, and offering visual aids to enhance understanding.³⁴ Additionally, writing key terms and concepts on the board more frequently can be particularly helpful. This practice ensures that students who struggle with listening skills have a visual reference, aiding in their comprehension and retention of the material.³⁴ By incorporating these strategies, instructors can create a more inclusive and supportive learning environment that addresses the specific needs of ELs, helping them to engage more effectively and achieve better educational outcomes.

Educators play a crucial role in enhancing the learning environment by fostering a culture of active participation and verbal interaction among students. While active listening can facilitate learning, verbal engagement often leads to higher-quality interactions. Instructors are encouraged to create a friendly and low-stress atmosphere where ELs feel comfortable interacting and discussing with their peers. To achieve this, instructors could begin each class with icebreakers or team-building activities. These activities not only help break the ice among students but also encourage them to communicate and collaborate from the outset. It's also essential to set clear communication expectations. ELs benefit from knowing what is expected of them in terms of participation and interaction. By clearly communicating these expectations, instructors can reduce anxiety and create a sense of predictability in the classroom environment.

Recognizing that EL students may require additional time to articulate their thoughts effectively, instructors could provide ample time for ELs to organize their ideas and contribute to group discussions. Instructors can facilitate preparation time by providing ELs with discussion prompts or questions ahead of group sessions. This allows them to organize their thoughts and formulate responses more confidently. Assigning formal roles within the group can also promote active participation, ensuring that each member has a meaningful contribution to make towards the group's collective learning goals.³⁵

645 This inclusive approach fosters a supportive learning environment where all students, including ELs, have the opportunity to actively engage and succeed together.

Our data indicate that while the number of EL students in our undergraduate STEM courses is increasing, there may be complexities to their contribution in a small group discussion. This observation can help researchers understand that classifying ELs with other minorities and asserting that all minorities have similar needs—or just relying on the fact that their native language isn't English—won't be sufficient for enhancing the learning of this population. To understand ELs' experiences, further background knowledge is required. Researchers and instructors should be aware that the demographic of EL students may need to be redefined and that there are several subgroups with various needs within this population. Given the challenges associated with EL students in POGIL based classrooms, it might be tempting to assume that this active learning cooperative group structure is not good for EL students. Many of the challenges discussed here are observable because students are asked to participate in class, revealing struggles that exist in other class settings as well. In this cooperative group setting the opportunity for the challenges to be addressed is much greater than in a strictly lecture based course. When instructors interact with the groups, they have the opportunity to respond to the challenges. For example, if the vocabulary is unfamiliar, instructors are also encouraged to integrate analogies into their explanations to illustrate the concepts in a more relatable way which, can significantly enhance the learning experience for ELs.³⁶ These students can find analogies easier to grasp than straightforward definitions. An instructor working with ELs is also encouraged to leverage visual models that can illustrate complex concepts in a way that bypasses some of the language issues.³⁴ Embracing these approaches not only addresses some of the challenges for ELs but also enriches the learning experience for all students. However, further research is essential to evaluate the efficacy and effectiveness of the proposed recommendations, particularly given the current gaps in the literature regarding accommodations and supports for English Learners (ELs) in STEM education.

LIMITATIONS

670 While this study provides valuable insights into the challenges encountered by English Learners (ELs) in POGIL-based general chemistry classrooms, it's crucial to acknowledge the specific context

within which these findings were obtained. The study was conducted in a particular educational environment, and variations in classroom dynamics, instructor approaches, and institutional support structures across different settings may influence ELs' experiences differently. Additionally, the study
675 relied primarily on qualitative data from interviews and observations, offering in-depth insights into participants' experiences but possibly lacking the breadth of quantitative data that could provide a more comprehensive understanding of ELs' engagement in POGIL-based learning environments. Future research could explore a wider range of methodologies to capture a more diverse spectrum of perspectives. Furthermore, the exclusive focus on ELs' experiences might overlook the viewpoints of
680 other student groups. Conducting a comparative analysis between ELs and non-ELs or among different subgroups of ELs could provide a more comprehensive understanding of engagement dynamics within POGIL-based classrooms. Lastly, the study's sample size was relatively small and limited to EL students from a single institution, which may restrict the transferability of the findings. Expanding the sample to include a more diverse population of ELs from various educational contexts would enhance the relevance
685 and applicability of the results. Future research endeavors could explore targeted interventions aimed at enhancing ELs' engagement and success in POGIL-based STEM classrooms.

A notable limitation of this study is the reliance on self-reported measures of language proficiency, as shown in Figures 3 and 4. Participants rated their own proficiency and identified challenging skills without the use of a standardized measure. This reliance on subjective self-assessment may constrain
690 the validity of the data, suggesting that future studies could benefit from incorporating standardized tools to improve the reliability and validity of language proficiency measurements.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI:
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- Interview questions; Qualtrics consent form.

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