

Research Article

Joy Ballard, Sujani Gamage, Leyte Winfield* and Suazette Mooring*

Cognitive discourse during a group quiz activity in a blended learning organic chemistry course

<https://doi.org/10.1515/cti-2023-0007>

Received February 7, 2023; accepted July 14, 2023; published online August 17, 2023

Abstract: Student-centered approaches are critical to improving outcomes in STEM courses. Collaborative learning, in particular, allows students to co-construct understanding of concepts and refine their skills in analyzing and applying information. For collaborative learning to be effective, groups must engage in productive dialogue. The work reported here characterizes the quality of dialogue during group quizzes in a first-semester organic chemistry course. The group quiz sessions were video and audio recorded. The recordings were transcribed and coded using the Interactive, Constructive, Active, Passive (ICAP) framework. The quiz prompts were analyzed using Marzano's taxonomy. In this study, students within the group demonstrated varying degrees of interactional quality as defined by the ICAP framework. Our data also indicate that the level of constructive and interactive dialogue is highest and most consistent when prompts are at Marzano Level 3 or higher. Marzano Level 3 prompts required students to compare and contrast concepts or extend their understanding of concepts by developing an analogy. Any benefit derived from collaborative learning depends on the quality of dialogue during the group discussion. Implications of these results for research and teaching are offered.

Keywords: classroom discourse; collaborative learning; community of inquiry; ICAP; organic chemistry

1 Introduction

There has been increasing evidence that active learning pedagogies positively impact student outcomes in science, technology, engineering, and mathematics (STEM) courses, as evidenced by improved pass rates and attitudes toward science (Freeman et al., 2014). Additionally, student-centered approaches can decrease the achievement gap of individuals with identities underrepresented in STEM (Theobald et al., 2020). However, the underlying reasons for these positive student outcomes are less known.

In courses structured for active learning, collaborative work is common. Based on learning theories such as social constructivism, it is reasonable to assume that students' ability to dialogue about a subject can deepen their learning (Piaget, 1926; Von Glasersfeld, 1990; Vygotsky, 1978). Nevertheless, putting students into groups and encouraging such discussions may not be sufficient to achieve the type of group discourse that leads to learning gains. To this end, there is a need for empirical data that characterize the components of collaborative course-based activities.

This study utilizes the Interactive, Constructive, Active, and Passive (ICAP) framework to characterize student discussions during a group quiz activity (Chi & Wylie, 2014). The four categories of the ICAP framework are associated with various levels of learning outcomes (Wiggins et al., 2017). The framework can reveal

***Corresponding authors: Leyte Winfield**, Department of Chemistry and Biochemistry, Spelman College, Atlanta, USA; and **Suazette Mooring**, Department of Chemistry, Georgia State University, Atlanta, USA; E-mail: smooring@gsu.edu (S. Mooring), lwinfield@spelman.edu (L. Winfield). <https://orcid.org/0000-0003-3719-5895> (L. Winfield)

Joy Ballard and Sujani Gamage, Department of Chemistry, Georgia State University, Atlanta, USA

characteristics of effective group learning and activities that facilitate beneficial outcomes. Through the lens of this framework, we propose that students' ability to benefit from group activities is related to the extent to which they demonstrate dialogue patterns that are not only accurate, but interactive and constructive for the majority of the activity.

2 Literature review

2.1 Blended learning environments

In blended or flipped learning environments, lectures are replaced by short videos and readings, and class time is used for problem-solving and collaborative group activities (Seery, 2015). Blended environments allow students to be self-paced learners and facilitate skill-building during the synchronous class period. Research on flipped organic chemistry courses has shown that students achieve at higher rates in this environment (Flynn, 2015; Liu et al., 2018; Mooring et al., 2016; Shattuck, 2016). Mooring, Mitchell, and Burrows also found that students in a flipped organic chemistry course had more positive attitudes toward chemistry (2016). Specifically, students in the course were more emotionally satisfied and felt that the content was more intellectually accessible than students in the traditional course. The organization of course materials and exposure to guided problem-solving has often impacted students with identities underrepresented in STEM (Theobald et al., 2020). Despite this knowledge, the research literature does not fully address the factors that drive students' success in such courses. To expand such knowledge, herein, we present an analysis of student dialogue during a collaborative quiz administered as a component of a blended learning environment.

2.2 Collaborative testing in higher education

Collaborative testing is supported by social interdependence theory (Johnson et al., 1989, 2007), which is under the umbrella of social constructivism. In this theory, the group's outcomes depend on students working together to achieve common goals. Therefore, the interactions among group members lead to co-constructed knowledge (Bloom, 2009; Zhao & Kuh, 2004). Like blended learning environments, collaborative learning activities enhance students' beliefs in their agency as learners (Mahoney & Harris-Reeves, 2019). Collaborative testing is a student-centered, active learning approach where two or more students discuss the content of a written assessment (i.e., an exam or quiz) before submitting individual or group solutions. The rationale for the implementation of such activities not only includes reduced test anxiety (Bloom, 2009; Kapitanoff, 2009), but also has the added benefit of improving students' interpersonal skills (Dallmer, 2004; Scager et al., 2016). Similar outcomes have been demonstrated in STEM and non-STEM courses (Russo & Warren, 1999).

In a controlled study, undergraduate students in a collaborative testing environment performed better (Gilley & Clarkston, 2014) when comparing pre- and post-outcomes on individual assessments. Other studies have shown that group exams resulted in increased learning and, more impressively, higher scores on the exam when readministered, signaling knowledge retention (Bloom, 2009; Cortright et al., 2003). A more recent study of group assessments in a statistics course has shown that scores on exams taken as a group were significantly higher than on exams taken individually (Kapitanoff & Pandey, 2018). The result was more pronounced for students with lower GPAs and higher test anxiety. Arguably, low-performing students or those without the knowledge needed to complete the assessment would benefit from group engagement that promotes understanding of the concepts. High-performing students might benefit from having their knowledge confirmed. Therefore, this notion of benefit needs to be better defined. Further, some studies have indicated no difference in test scores resulting from student engagement in collaborative testing (Gilley & Clarkston, 2014; Giuliadori et al., 2008; Harton et al., 2002; Johnson et al., 2007; Leight et al., 2012; Springer et al., 1999). These contradicting results suggest that there is still much to understand about the conditions under which group testing lead to increased learning.

A study by Mahoney and Harris-Reeves attempted to address this gap in the literature by exploring the effect of collaborative testing on higher-order thinking skills of undergraduate students enrolled in a sports and exercise psychology course in Australia (2019). Three examinations were part of the course; however, only the second examination was delivered independently and collaboratively. Students had 45 min to complete the multiple-choice exam independently during the testing scenario. The students were then given 30 min to complete the same assessment in groups. All students taking the collaborative test did better overall on the higher-order questions than those who took the independent tests. The result was observed for all learners regardless of their typical level of performance. While the authors noted that the performance could be related to the discussion and deliberation of the exam content, this engagement was not characterized. The authors remarked that not having this information limited their ability to address: (1) how interactions among the students lead to better answers to higher-order questions and (2) the quality of the interaction between higher and lower performers.

3 Theoretical frameworks

3.1 Community of inquiry (CoI)

The CoI framework is based on a constructivist approach to learning (Swan et al., 2009) that posits that learning occurs when the learner is actively involved in creating meaning and constructing knowledge. CoI accomplishes this by facilitating a rich educational experience (Garrison, 2013) that emphasizes the interrelationships between teaching, cognitive, and social presences and the collective influence of the presences on the student learning experience, Figure 1 (Garrison, 2019). In this way, the framework informs critical elements needed for learning and has been used to characterize student engagement in online and in-person components of the blending learning format (Garrison, 2013, 2019; Swan et al., 2009).

Studies have found a relationship between students' retention in science and their positive social presence, the learner's ability to inject their personality into the learning environment and learn through engagement with others in the environment (Akyol et al., 2009; Arbaugh & Benbunan-Finch, 2006; Richardson & Swan, 2003). Social presence has impacted students' motivation and participation, actual and perceived learning, and course and instructor satisfaction. Also, participants actively contributed when students enjoyed the group dynamics (Garrison, 2019).

Cognitive presence can significantly influence the teaching and social presences (Molinillo et al., 2018) and is, therefore, critical to the function of the CoI as it informs how students and instructors co-create meaning and confirm understanding in a learning environment. The teaching presence includes direct instruction and instructional management. This component of the CoI also includes selecting, organizing, and presenting course content and developing learning activities (Rahim, 2022).

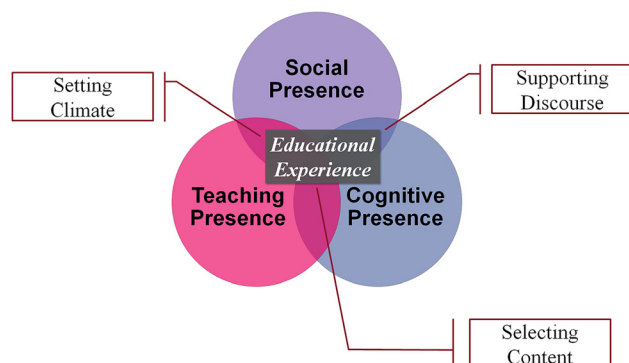


Figure 1: Community of inquiry framework.

Adding to the use of the framework described above, CoI shaped the design and structure of the Organic Chemistry course that is the focus of this study. The course introduces concepts through online lecture videos and required readings (Fullilove et al., 2017; Sanders-Johnson et al., 2020; Sanders-Johnson et al., 2021; Sanders et al., 2019; Winfield et al., 2019). Collaborative and active learning strategies are prominent features of the course, along with instructor-created content and learning strategies. The current study is primarily situated at the intersection of the cognitive and social presences in that we are examining student discourse during group activities.

3.2 The interactive, constructive, active, passive (ICAP) framework

The ICAP framework is a taxonomy that characterizes students' overt behaviors during learning activities. The framework categorizes learning behaviors as interactive, passive, active, or constructive. It hypothesizes that students become more engaged in learning as they progress from passive to interactive, Figure 2 (Chi & Menekse, 2015; Chi & Wylie, 2014). In *passive* engagement, the student receives information but contributes little or superficially to the discussion. For this study, passive engagement is further divided into *negative passive* and *active passive*, according to work by Chen (2018). Negative passive refers to instances in which the student indicates disagreement/agreement or understanding/confusion without further elaboration (Chi & Menekse, 2015; Chi & Wylie, 2014). Active passive dialogue, in contrast, occurs when a student demonstrates a level of listening that enables them to describe or summarize what another student stated. In this case, no new information is added to the dialogue. Passive, whether active or negative, results in shallow understanding. However, passive engagement does not necessarily constitute disengagement or off-task behaviors. When students actively engage in the learning process, they can cycle through each phase of the ICAP model.

During active engagement, no new information is added by the student. However, students are physically involved in something related to the learning activity (Chi & Menekse, 2015; Chi & Wylie, 2014). Some examples of active engagement during discourse include reciting a memory line, reading the problem aloud, asking a question for clarification, and repeating what is heard. Constructive engagement involves a higher level of cognition and produces new information relevant to the activity (i.e., textbook, problem set, or verbal and written instructions). Such instances include self-explaining, creating a concept map, and filling-in knowledge gaps while dialoguing. Therefore, an instance of constructive engagement reflects a student's reasoning. This level of independent knowledge generation is associated with greater understanding and learning gains.

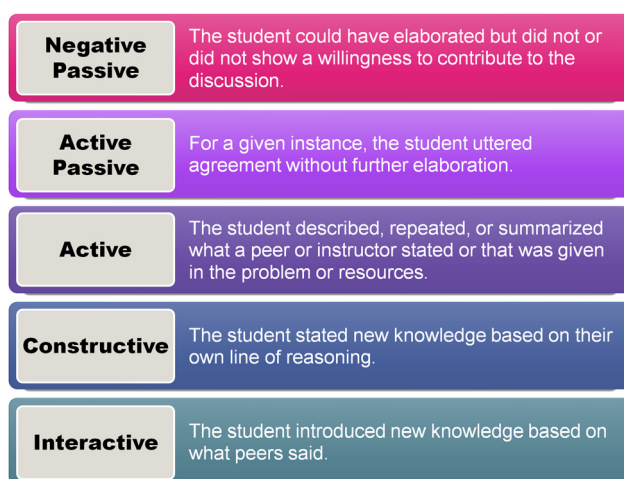


Figure 2: Interactive, constructive, active, passive (ICAP) taxonomy for overt learning activities. Each level demonstrates students' engagement at a given moment in the discussion.

Finally, interactive engagement is evident in a student's contribution to new information in response to another peer's input (Chi & Menekse, 2015; Chi & Wylie, 2014). An instance of dialogue can be interactive only if it directly responds to a comment from another student in the group. Otherwise, that dialogue is constructive. Interactive engagement involves the co-creation of knowledge with peers. In this case, the student makes a substantive contribution to the discussion through new lines of thinking, deliberation, and feedback. Interactive dialogue leads to the deepest level of understanding since the group gains new understanding based on their collective contribution of new ideas.

In chemistry, researchers have used the ICAP framework to qualify engagement during various learning activities. For example, El-Mansy used the framework to examine peer-peer interactions in general chemistry, finding that cognitive engagement was often impaired by students' flawed understanding of the concepts (2022). In a physical chemistry course, the framework allowed faculty to define a correlation between faculty facilitation strategies and the quality of group engagement (Liyanage et al., 2021). The ICAP taxonomy was used in conjunction with Bloom's taxonomy and cognitive load theory to illustrate that an interactive desktop tool leads to a deeper understanding of fluid dynamics in a chemical engineering course (Kaiphanliam et al., 2021). In the study, researchers created activities that were purposefully passive (i.e., students constructing a basic pump) or interactive (i.e., students completing a desktop activity and discussing outcomes in a group). In the latter case, students were provided with a worksheet to prompt interactive or constructive engagement, but the extent to which students demonstrated either was not addressed.

Similarly, biochemistry instructors applied the ICAP framework to create impactful learning experiences (Hilton et al., 2022). The authors have employed PeerWise in a biochemistry course to encourage constructive and interactive engagement by authoring and answering questions. Their work found that the exercise promoted cognitive gains and engagement at the higher levels of the ICAP framework. However, the findings did not provide insight into the characteristics of that engagement. In an essay by Linda Hodges, the author evaluates utilizing the ICAP framework for improving the implementation of the learning strategy in science classrooms (Hodges, 2018). Hodges highlights work by Sandi-Urena et al., which shows a correlation between students' ability to explain their choices in a chemistry laboratory and their metacognitive abilities. In follow-up work, Hodges emphasizes the alignment of constructive engagement to higher levels of Bloom's taxonomy (Leupen et al., 2020).

Each study described illustrates the use of the ICAP framework to understand the level of cognitive engagement students demonstrate during learning activities. The studies quantify students' overt physical and verbal behaviors at specific intervals. Specifically, Chi and Wylie (2014) and later Chi and Menekse (2015) utilized the framework to analyze conversations during active learning. Likewise, the study described herein utilizes ICAP functions as a theoretical and methodological framework. When applied as a theoretical framework, it explains the underlying cognitive processes related to students' overt behaviors as a function of their dialogue patterns. As a methodological framework, it allows us to apply the four levels of engagement in coding students' overt verbal behavior during the group activity, Figure 2 (Chi & Menekse, 2015).

4 Research questions

Published studies demonstrate the positive impact of group activities on student outcomes. However, they do not dive deeply into the nature and quality of students' contribution to dialogue during the exercise or the resulting benefit of that contribution. Additionally, no research studies investigate discourse during collaborative testing in organic chemistry courses. The study reported herein examines the discourse between students completing a group quiz. The research questions are as follows:

- (1) What is the observed interactional quality when students participate in a group quiz activity?
- (2) How does the level of question difficulty (as defined by Marzano's taxonomy) affect the observed engagement of students involved in a group quiz activity?

5 Methods

5.1 Setting and participants

Spelman College is a fully accredited baccalaureate institution historically established for women of African descent. The College has a total enrollment of 2100 students, all of whom identify as Black women. Less than 10 % of these students major in the natural sciences and mathematics (Office of Institutional Effectiveness, 2022). Nevertheless, the College is the top producer of Black women graduates who earn doctorates in these fields (Hrabowski & Henderson, 2021). The study includes observational data from three unique groups completing two different group quizzes. The current study was implemented in a second year, college-level course (age group 18–20) in the United States. The course spans a 16-week semester with three 50-min weekly in-person meetings. All students enrolled in the first-semester organic chemistry lecture in Fall 2017 were required to participate in the group quizzes described herein. The study was approved by the IRB boards of the associated institutions.

5.2 Course structure

Course content and resources were available on the learning management system, which included lecture videos and pre- and post-assessments students completed. Pre- and post-assessments were administered for each topic and contained 10–15 multiple-choice questions varying in difficulty. To reinforce online content, the instructor reviewed the main points from the topic during the first 15–20 min of the in-person class period. The instructor also used this time to answer questions about the previous class period. Students used the think-pair-share model (Kaddoura, 2013; Marzano & Pickering, 2005) to complete the problem set during the remainder of the period (20–30 min). Problems not finished in a given class period were completed as homework, used to start the discussion during the following class, or selected for random grading. A post-quiz was administered at the end of a topic to assess students' concept mastery.

5.2.1 Group quiz format: The course had an enrollment of 19 students allowing for four groups of four and one group of three. Students self-selected their groups and remained in the same groups throughout the semester. During the group quiz sessions, the students could not use supplemental information. Students were instructed to discuss the prompts with group members to find a solution. Students were given the topic before the quiz and were expected to review relevant concepts. The instructor was available to answer questions.

Group Quiz 2: The assessment covered alkane conformations. The topic required students to process structural information about the three-dimensional spatial relationship of groups or atoms represented by the rotation around a carbon–carbon single bond. Students responded to a series of prompts, see Supplementary information, to demonstrate their ability to correctly draw staggered and eclipsed conformations and utilize the drawing to describe the relative stability of two molecules. Lastly, groups were asked to develop an analogy to describe the relationship between the stability of a conformation and the size of two interacting substituents.

Group Quiz 3: The assessment covered nucleophilic substitution reactions involving alcohols as nucleophiles, see Supplementary information. Groups were asked to compare the reactivity of the electrophile based on leaving group ability when considering bond length and acidity. In addition, groups demonstrated their ability to predict and draw the product for a given reaction scheme and describe the underlying mechanisms.

5.3 Data collection

Regarding the physical classroom workspace, student groups were situated around rectangular tables configured to allow students to communicate face-to-face. Each group had a dedicated camera, short-throw projector, whiteboard, and iPad. The cameras were set at fixed angles allowing the groups to be video and audio recorded. iPads, equipped with the screen-capturing app Explain Everything (Explain everything for IOS devices), were used to record group responses to the quiz prompts. We only analyzed recordings where all group members could be seen and heard on camera. Therefore, observational data for groups A and B were analyzed for quiz 2, and observational data for groups B and C were analyzed for quiz 3. The pseudonyms for students in the selected groups are shown in Table 1.

Table 1: Pseudonyms for group quiz participants. Group quiz 2 was completed by students in groups A and B. Group quiz 3 was completed by students in groups B and C.

Group A	Group B	Group C
Ashley	Brittany	Nicole
Candice	Dawn	Morgan
Tiffany	Farrah	Lisa
	Jasmine	Michelle

5.4 Data analysis

The recordings were transcribed, and the transcripts were separated into excerpts. Each excerpt ranged in length and consisted of a single group's response to one quiz prompt. Each excerpt was then divided into speaking turns, with each line representing when a different student began speaking. Since this is a group discussion, it is expected that student discourse may vary throughout the discussion in response to other group members as the conversation evolves. Characterizing engagement based on speaking turns allows us to take a holistic view using natural breaks in the discussion. On the other hand, coding based on timed intervals could inhibit the meaning of a student's statement if the designated time ends while the student is speaking and therefore may not accurately capture a student's level of cognitive engagement. Each speaking turn was coded as interactive, constructive, active, active passive, or negative passive using the definitions indicated by the ICAP framework, Figure 2. Speaking turns unrelated to the group quiz were coded as "off-task."

After the first round of collaborative coding by authors SG and SRM, a third individual coded a sample of transcripts to establish interrater reliability. This coder used the codebook to analyze two sections of the transcript from quizzes 2 and 3. Disagreements were discussed, and the codes were adjusted or refined accordingly. Coding continued until satisfactory interrater reliability was reached between coders. Cohen's kappa for interrater reliability was calculated as 0.78, which indicates a good agreement between coders (Watts & Finkstaedt-Quinn, 2021). The rest of the data was then coded by SG.

The percent of each type of dialog (interactive, constructive, active, or passive) present was calculated as the number of each type of dialog out of the total number of all dialog types. For example, if there were 20 speaking turns in the excerpt and 10 were coded as active, that excerpt is 50 % active dialogue. The count for interactive, construction, active, or passive codes were also determined for each student in each group analyzed. Off-task dialogue was not included in the total code count. In this way, dialog patterns were determined for periods when students were intentionally engaged in the learning activity.

5.5 Interaction quality

The interaction quality of each excerpt was classified as high, medium, or low using a modification of a scheme by Chi, see Supplementary information (Menekse & Chi, 2019), in conjunction with the ICAP percentages and other factors (i.e., the number of group members engaged in dialogue). Dialogues were coded overall as *low interaction* if the dialogue is mainly passive or active, has little input from group members, or if one student suggests a solution that the others agree to without discussion. *Medium interaction* occurred when the discussion was primarily active. In this scenario, one student provides most of the ideas, and the dialogue among the group is discontinuous; that is, students' speaking turns were not in response or related to the previous idea. An excerpt was coded as *high interaction* if there were a substantive number of student statements that were constructive and interactive, and most students in the group contributed to the discussion.

5.6 Characterizing the cognitive level of quiz prompts

A critical feature in the group learning activities is the design of the quiz prompts used to facilitate discussion. Therefore, Marzano's Taxonomy was used to define the cognitive level of each prompt in the group quizzes (2001). The levels from lowest to highest are retrieval, comprehension, analysis, and knowledge utilization, Figure 3.

6 Results

6.1 Outcomes for research question 1: what is the observed interaction quality when students participate in a group quiz activity?

The dialogue excerpts provided in Tables 2–5 illustrate the dialogue observed among the groups that completed quizzes 2 and 3. Below, we assess the interaction quality of the excerpts. These cases are presented as a comparison between groups working on the same quiz prompt in order to highlight the characteristic differences in interactional quality. That is, we present cases of low versus medium interaction quality and medium versus high interaction quality.

Tables 2 and 3 compare low to medium interaction quality on the same prompt. These excerpts are taken from the discussion of quiz 2, prompt 2: Draw a template to illustrate the anti-conformation of an alkane." For this prompt, students had to choose any alkane and draw a Newman projection in the anti-conformation.

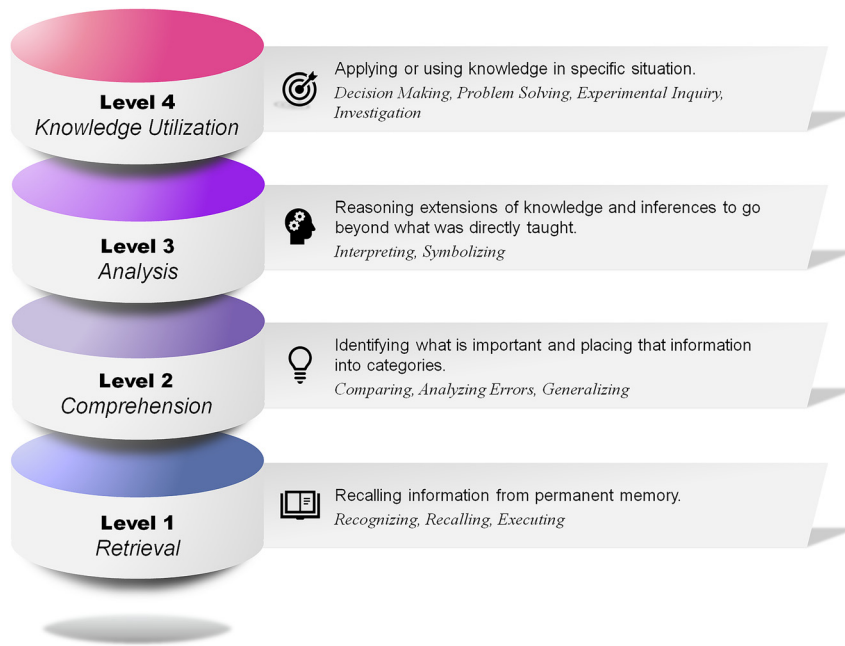


Figure 3: Definition of Marzano levels.

Table 2: Excerpt of dialogue for group B, quiz 2, prompt 2.

ICAP code	Speaking turns
A	1. Jasmine: (Reads prompt partially) ooohhhhh!
C	2. Farrah: I think we just need an example of an alkane. We can just do butane.
AP	3. Brittany: Yeah, that's the easiest one.
A	4. [Jasmine looks at Farrah's paper to write the answer on the iPad]

Table 3: Excerpt to dialogue for group A, quiz 2, prompt 2.

ICAP code	Speaking turns
A	1. Tiffany: So ... draw a template to illustrate the anti-conformation of an alkane. An adjacent group acquired help from the instructor about anti-conformation, and each member of group A observed.
C	2. Candice: It's the Newman projection, right?
AP	3. Tiffany: Yeah
C	4. Candice: So ... draw an alkane, count CH ₂ , CH ₃ , and hydrogens on the ...
A	5. Ashley: I thought we were supposed to draw like the chair
A	6. Candice: Oh, I'm so stuck on Newman projections
A	7. Ashley: I don't know. That's what I was thinking
A	8. (Tiffany looks around for help). Oh, okay. So if it's the chair (begins to draw the chair)
A	9. Ashley: Is that it flipped? That's not it? Flipping?
A	10. Tiffany: That's regular. Flipped would be (Drawing on iPad)
AP	11. Ashley: You drew it good
AP	12. Tiffany: So that's it?
A	13. Candice: Are we allowed to come back to it? Or you can't go back once you go to the next question
A	14. Tiffany: I hope not. Let me see Wait, hold up, hold up, hold up, Nope, can't change it ...

For group B, the discussion was concise, consisting of only four speaking turns, Table 2. There was no interactive discussion of ideas. In this excerpt, one student, Farrah, offered a solution (turn 2), which is copied to the iPad as the group's final answer. No one asked for further explanation of how Farrah arrived at her answer.

Table 4: Excerpt of dialogue for group B, quiz 3, prompt 1c.

ICAP code	Speaking turns
A	1. Brittany: We did not talk about how pKa relates to bond length and leaving group ability and reactivity, did we?
A	2. Farrah: We talked about three of them but not the first one bond length, pKa we know that
C	3. Jasmine: Is it possible that the longer the bond, the stronger? Let me think ...
I	4. Brittany: Uh, un. It's the shorter the bond, the stronger
A	5. Jasmine: The weaker?
NP	6. Brittany: (Shakes head no)
A	7. Farrah: Well, just looking at what they gave us
C	8. Jasmine: Oh! That's with like triple bond
I	9. Farrah: Yes, so the shorter bond, the stronger the acid, the more acidic it is
A	10. Brittany: Yeah, the more acidic
C	11. Farrah: In terms of leaving groups, leaving groups deal with ah acids and bases, right?
AP	12. Brittany: Yeah
I	13. Farrah: So, we said that the strong base is a bad leaving group, then a weak acid is also a bad leaving group
I	14. Brittany: Um, huh, so the shorter the bond length, the lower the pKa that makes it better yeah, that makes it a better leaving group
I	15. Dawn: And the lower the pKa, the stronger the acid, the weaker the base
AP	16. Farrah: Yeah
A	17. Brittany: Yeah. So the smaller the bond length,
OT	18. Jasmine: I hate this pencil thing
OT	19. Brittany: I think it would be better if it was like an actual pin like a ballpoint
A	20. Jasmine: Yeah, if this could come off, it would be better, but I don't know, okay so smaller bond length
I	21. Brittany: Um, the smaller the pKa and just write another equals sign, equals um more acidic and better leaving group
I	22. Farrah: I'm thinking about reactivity. Since we said although OH is a great nucleophile, it's a bad leaving group, so would that apply to all things that are strong acids, or are they all?
A	23. Brittany: I don't know, I don't think so because, um, I'm trying to remember that list, off the top of my head
A	24. Farrah: I just remember that alcohols are on this side, the ether is on this side
A	(Pointing to the opposite side from alcohols)
C	25. Brittany: I just know that strong acids are good leaving groups because they dissociate, and if they're weak, they're going to stay together. You won't get a reaction
I	26. Farrah: So, are they strong acids are more reactive?
I	27. Brittany: Yeah, cause they will dissociate in whatever you put it in, and you will get a reaction ... If they're weak, they won't break apart
C	28. Farrah: Weakly dissociate, got it.
A	29. Jasmine: So, a better leaving group equals
A	30. Brittany: Um, more reactive
A	31. Dawn: The greater the reactivity,
A	32. Jasmine: Anything else were missing?
AP	33. Brittany: Nope

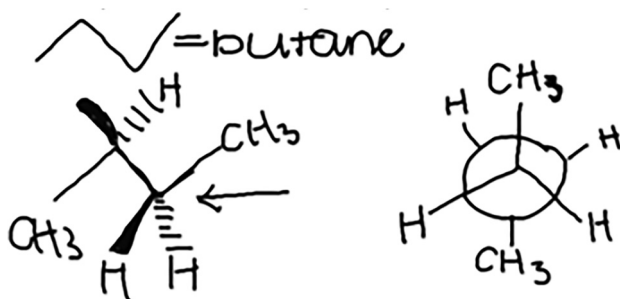
ICAP Code Codes: NP, negative passive; AP, active passive; A, active; C, constructive; I, interactive.

Although the group provided a reasonable answer to the prompt (Figure 4), the lack of interactive or constructive dialogue likely prevented the group members from gaining additional understanding of these concepts. The observation is similar to findings by Chi that assert that non-contributing partners may have little meaningful gains from the discussion (Chi & Menekse, 2015). It is also possible that the prompt did not encourage deeper interrogation of the concept; therefore, the group did not think any further discussion was necessary (Leupen et al., 2020).

In contrast to group B, we qualify group A's response to the same prompt (Table 3) as *medium interaction* since the dialogue is primarily active and is 64 % of the dialogue; however, all group members participated in the discussion. Also, students' responses are discontinuous because each student makes assertions independent of the other. That is, "why" or "how" questions are absent, and the students are not expanding each other's comments. Group A drew a cyclohexane chair in equatorial and axial conformations instead of a Newman

Table 5: Excerpt of dialogue for group C, quiz 3, prompt 1c.

ICAP code	Speaking turns
A	1. Nicole: Reading prompt 1c
A	2. Morgan: I know larger bonds are ...
C	3. Nicole: Well, looking at this, it has a longer bond length, and it has umm smaller pKa that last one
AP	4. Morgan: Yeah
A	5. Lisa: So, the stronger the bond ...
I	6. Morgan: No, the larger the bond, the easier it is to break, I believe, because when it's like because single bonds are stronger than double bonds
AP	7. Nicole: Yeah
A	8. Nicole: The larger the bonds ...
A	9. Morgan: Longer. This is length, not strength
A	10. Nicole: The longer the bond (restating the answer as she writes), the lower the pKa, this makes. (Nicole repeats answer for Lisa to write on the iPad)

**Figure 4:** Group B's final answer to quiz 2, prompt 2, "Draw a template to illustrate the anti conformation of an alkane".

projection (Figure 5). Candice mentions Newman projections twice (turns two and 6). However, the group did not address her question and apparent confusion. She did not have an opportunity to further discuss her ideas, which may have led the group in a different direction. Perhaps, this prompt triggered the students to remember the idea of conformations in general since both Newman projections and chair structure are representations of conformations, the former for alkanes and the latter for cycloalkanes. The students seemed to conflate these two types of conformations.

According to Chi's assertions through research studies using the ICAP framework, the excerpts from group A and B (Tables 2 and 3) on this prompt primarily falls within the passive and active dialogue categories that lead to shallow learning outcomes and limited learning gains. When comparing the two excerpts, it is interesting that the quality of dialogue does not necessarily lead to a correct answer. Although group A (Table 3) qualifies as medium interaction dialogue, their final answer is considered incorrect. Also, group B had a correct answer, but the dialogue was minimal (Table 2).

Tables 4 and 5, describe cases of medium and high interaction dialogue, respectively. Here, the dialogue for groups B and C are compared for quiz 3 prompt 1c: "Describe the relationship between bond length, pK_a , leaving

**Figure 5:** Group A's answer to quiz 2, prompt 2, "Draw a template to illustrate the anti conformation of an alkane."

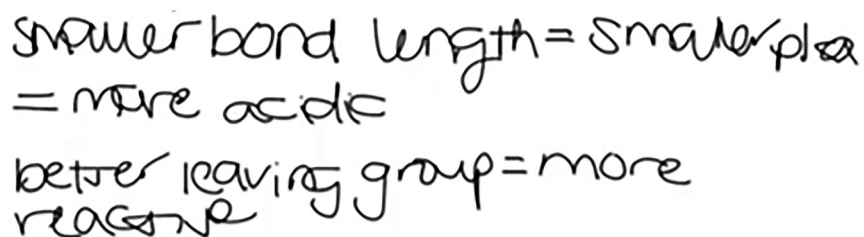
group ability, and reactivity.” To respond to this prompt, students had to understand the meaning of each term and determine how the concepts were related.

Group B’s dialogue reflects high interaction, Table 4, and group C’s conversation reflects medium interaction, Table 5. There was a significant difference in the percentage of interactive and constructive statements between the groups. Constructive and interactive talk accounted for 45 % of group B’s conversation and only 20 % of group C’s conversation for the same prompt.

Group B’s dialogue for this prompt qualifies as high interaction since all the students engaged in the dialogue and built upon each other’s statements. In fact, every student in this group contributed at least twice to the discussion. Students in the group asked each other questions as they co-constructed their ideas to come to a mutual answer. Group B had long sections of constructive or interactive dialogue (Table 4, turns –11 –22), particularly between Brittany and Farrah. The students worked together to make sense of the relationship between bond length, pK_a , leaving group ability, and reactivity. Farrah asked questions for clarity several times throughout the problem (turns 11, 22, 26). Farrah’s questions helped to move the group forward in their thinking. Also, Dawn helped the group to formulate the answer to this problem by contributing interactive dialogue in response to Brittany and Farrah’s statements (turn 15). Brittany then organized and repeated the information for the group’s scribe (turn 21). The group summarized their conclusions in turns 29–32. Their final written answer is shown in Figure 6. This group discussed several aspects of the prompt and concluded that shorter bonds are stronger (turns 4 to 9) and that a lower pK_a is a better leaving group (turn 14). Although Brittany’s contribution that shorter bonds are stronger acids was incorrect, the group had a rich discussion on all aspects of the prompt and the relationship between these concepts.

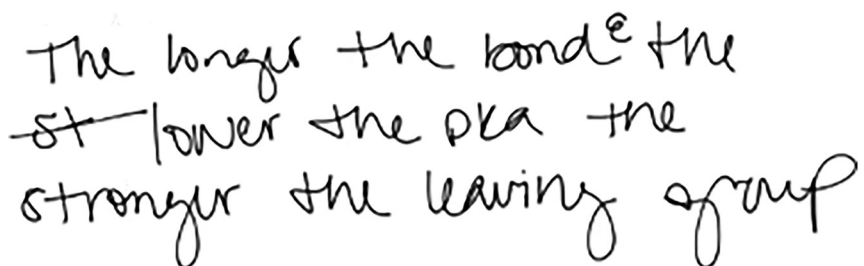
In contrast, group C primarily used active dialogue to discuss the solution (Table 5) and, therefore, qualifies as medium interaction. Morgan proposed some initial reasoning to explain the relationship between bond length and strength (turn 6). However, after Morgan’s input, the constructive or interactive dialogue did not continue and the group did not examine why this was the solution. Instead, the group summarized Morgan’s initial answer to form a response, Figure 7. Although, the final answer was more accurate than group B’s, the dialogue in group C may not have led to enhanced learning outcomes among all the group members based on the ICAP framework.

Individual Contributions to Group Dialogue or quiz 3, prompt 1c. An additional analysis of the individual contributions to the dialogue for quiz 3, prompt 1c, was conducted. Note that active passive (AP) and negative passive (NP) are combined into just Passive (P) in Figure 8. From this analysis, we can observe that every student in group B contributed to the group’s dialogue on this prompt. Although the number of contributions by each group member is different, each student in the group participated in either constructive or interactive talk or



smaller bond length = smaller pK_a
= more acidic
better leaving group = more reactive

Figure 6: Group B’s answer for quiz 3, prompt 1c, “Based on the data from the table completed for problem 1, describe the relationship between bond-length, pK_a , leaving group ability, and reactivity.”



The longer the bond the
st lower the pK_a the
stronger the leaving group

Figure 7: Group C’s answer for quiz 3, prompt 1c, “Based on the data from the table completed for problem 1, describe the relationship between bond-length, pK_a , leaving group ability, and reactivity.”

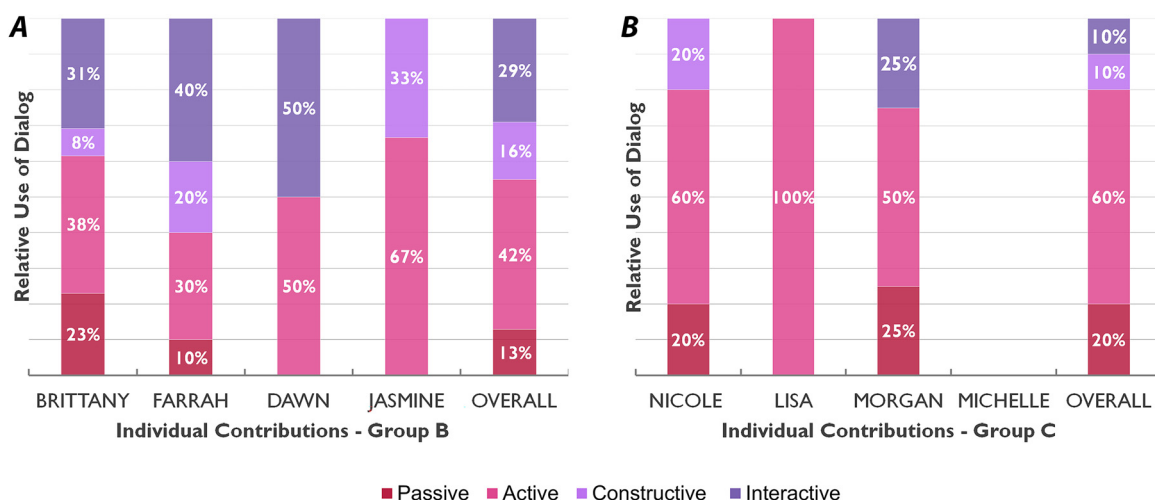


Figure 8: Individual contributions to dialogue quiz 3, prompt 1c for (A) group B and (B) group C.

both constructive and interactive talk during this discussion. For group C, we observed that one group member, Michelle, did not participate in the discussion and only two students, Nicole and Morgan, participated in constructive or interactive dialogue for group C. This more detailed analysis is another indicator of the quality of the group's dialogue and the implied differences in learning opportunities between groups B and C.

6.2 Outcomes for research question 2: What is the relationship between the cognitive level of the quiz prompt and the ICAP level of dialogue?

Given the variability in the interactive quality of the groups' dialogue, we wanted to examine if the cognitive level of the prompt, defined by Marzano's taxonomy, influenced dialogue quality. Each prompt was assigned a Marzano level, Table 6.

There was an increasing amount of constructive and interactive dialogue as you move from prompt 1 through prompt 6 for quiz 2. Prompt 1 was at Marzano level 1. Prompts 2 and 3 were Marzano level 2. Prompts 4, 5, and 6 were at Marzano level 3. We observed that the level of constructive and interactive dialogue was highest and most consistent when prompts were at Marzano level 3, Figure 9. In fact, for quiz 3, all the prompts are at a Marzano level 2 or 3. Chi-squared statistical analysis was used to compare the differences in high-level dialogue (constructive and interactive) and low-level dialogue (passive and active) between Marzano level 2 and 3 prompts. The chi-squared analysis was statistically significant at $p < 0.05$ (chi-square statistic = 4.34; $p = 0.037$).

Table 6: Marzano levels with definitions and prompt examples from quiz 2.

Marzano level	Prompt examples
Level 1 – retrieval	P1. Define anti-conformation.
Level 2 – comprehension	P2. Draw a template to illustrate the anti-conformation of an alkane.
Level 2 – comprehension	P3. Draw the most stable anti-conformation of heptane for the rotation around the C3 C4 axis.
Level 3 – analysis	P4. Compare the most stable anti and the least stable eclipsed conformations of heptane for the rotation around the C3 C4 axis.
Level 3 – analysis	P5. Explain the stability of the least stable eclipsed conformations of butane defined for the rotation around the C2–C3 axis compared to that of octane defined for the rotation around the C4–C5 axis.
Level 3 – analysis	P6. Develop an analogy explaining why a molecule's stability will change as substituent size increases.

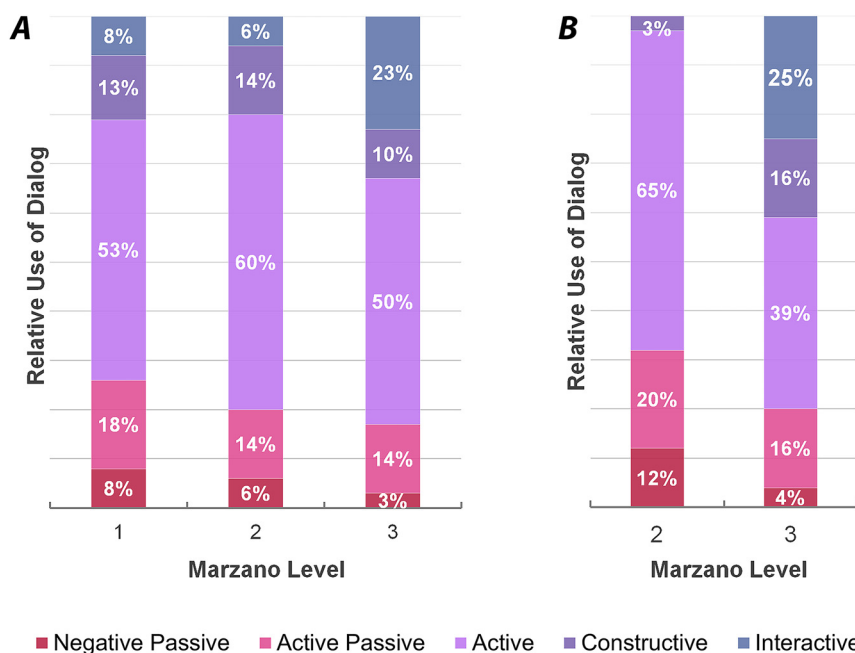


Figure 9: Marzano level and cognitive engagement. Percentages of ICAP categories versus Marzano level for (A) quiz 2 and (B) quiz 3.

Marzano level 3 prompts required students to compare and contrast concepts (prompts 4 and 5) or extend their understanding of concepts by developing an analogy (prompt 6). In comparison to Marzano levels 1 and 2, level 3 prompts were more likely to provoke students to ask questions and engage in interactive and constructive dialogue. The level 3 Marzano prompt also promotes higher interaction quality, suggesting that students collaborate and build on each other's statements and responses. Higher interactional quality also indicates that students ask more "why" and "how" questions. This type of interaction typically leads to deeper learning among all group members (Chi & Menekse, 2015).

7 Discussion and conclusion

This study investigated the interactional quality among students engaged in a group quiz activity as part of a blended-learning course in organic chemistry. We have shown that groups demonstrate varying degrees of engagement – low, medium, and highly interactive dialogue. When comparing groups on the same prompt, groups engaging in high-quality dialogue may not necessarily lead to accurate answers and *vice versa*. However, groups that were characterized as high interaction had discussions that included constructive and interactive talk that were likely to benefit the learning of all students in the group. That is, high-quality dialogue allows students to think about and explain the course concepts to one another in ways that benefit both the students giving and receiving the explanations (Chi & Wylie, 2014). For example, studies in classes taught using peer instruction suggest that students benefit from the discussion even if none of the discussants initially answers the prompt correctly (Smith et al., 2009). Other studies have shown that students who initially provided incorrect solutions demonstrated improved comprehension of the concept after discussing the solution with another student (Versteeg et al., 2019).

Additionally, we have shown that the cognitive level of the group quiz prompts, as characterized by Marzano's taxonomy, impacted the quality of dialogue based on the ICAP framework. Researchers previously cautioned that shallow prompts are not sensitive to intervention efforts since shallow prompts that require only recall of information can be answered with passive, low-level activities (Chi & Menekse, 2015; Chi & Wylie, 2014). Work by Leupen et al. (2020) also suggests a relationship between students' constructive engagement and higher levels of Bloom's taxonomy. We observed that quiz prompts with at least level 3 allowed students to ask

more “why” and “how” questions of each other as they responded to the prompts and increased the likelihood of students contributing their explanations of the material to the group.

Overall, our findings contribute to the current knowledge on productive engagement in group-based discussion activities that are a critical component of many active learning classrooms in chemistry and other STEM disciplines.

8 Limitations

The data herein is from a single course at a single institution, which can affect the generalizability of the results. We also present data from a limited number of groups selected based on the usability data collected as some recordings were not used due to audio quality or some group members not appearing on camera. Other dialogue patterns may have been observed if more groups were included. However, we have provided a detailed description of group dialogue that sheds light on students’ interaction when completing group activities in organic chemistry courses. Our data analysis of the dialogue was facilitated through the ICAP framework that captures the cognitive level of student dialogue. Other factors at work, such as the influence of social presence, teaching presence, and students experience with group quizzes, were not captured by the ICAP framework.

9 Implications

Learning during collaborative group activities is not guaranteed. Any benefit derived from collaborative learning depends on the quality of the group discussion. The goal of group activities is to engage students in discussion that ensures understanding of the concepts. Such discussion should be constructive and interactive, exploring various perspectives and conflicting ideas. This type of high-quality discussion is likely to lead to the best learning opportunities for students. It is clear from this study that the design of the activity prompts is critical to the quality of dialogue. That is, prompts at higher cognitive levels produce higher-quality dialogue.

These results point to the need for scaffolding activity prompts to include questions at Marzano levels 1 and 2 that would induce active dialogue for students to retrieve relevant prior information and concepts. These can be followed with prompts at levels 3 and 4 of Marzano’s taxonomy in which students can engage in dialogue that leads to more co-constructed knowledge. Also, one study by Aleven and Koedinger (2002) provided embedded prompts for students to explain their solutions when solving geometry problems. They found that prompting students to explain was especially useful when they had more challenging problems.

In addition, we also observed that high-quality dialogue does not always result in a correct final answer. As such, the final answer may not accurately reflect the level of dialogue that occurred during the group activity. Therefore, inserting guiding prompts that encourage students to engage in critical thinking and explain their reasoning would give instructors more insight into what occurred during the group activity. Rewarding these activities with points may also motivate students to interact at higher levels. Prompts can be used to encourage students to ask each other questions, as Farrah and Dawn demonstrated in Table 4. As another example, Candice (Table 3) questioned the group’s direction by mentioning Newman projection twice. Including a prompt in the assignment to trigger students like Candice to ask questions and explore additional ideas before ending the discussion may give them a chance to voice their concerns and create an environment where engaging in scientific argumentation is safe and rewarded.

One aspect not considered, as mentioned in limitations, is the teaching presence. Although we did not compare group B’s performance on quiz 2 to that on quiz 3, we notice that the interaction quality improved. More insight is needed on the reason for that improvement. Particularly, it is of interest to understand how instructors can be more intentional in training students to engage in productive dialog, and how students gain agency to do so.

Finally, in this study, we have demonstrated the feasibility of using the ICAP framework to gain insight into students’ dialogue during group activities. As such, instructors should consider occasionally observing and/or

recording students during group work, as the insights gained can be invaluable in helping instructors make changes to group dynamics and prompts to further improve student learning from these activities. We did not directly explore the impact of interactional quality on student learning outcomes. Future research is needed in this area to test the hypothesis that high-level interactional quality leads to deeper learning for students.

Author contributions: All the authors have accepted responsibility for the entire content of this submitted manuscript and approved submission.

Research funding: This work was funded by National Science Foundation (no. 1332575, no. 1625414)

Conflict of interest statement: The authors declare no conflicts of interest regarding this article.

References

- Akyol, Z., Garrison, D. R., & Ozden, M. Y. (2009). Online and blended communities of inquiry: Exploring the developmental and perceptual differences. *International Review of Research in Open and Distance Learning*, 10(6), 65–83.
- Aleven, V. A., & Koedinger, K. R. (2002). An effective metacognitive strategy: Learning by doing and explaining with a computer-based cognitive tutor. *Cognitive Science*, 26(2), 147–179.
- Arbaugh, J. B., & Benbunan-Finch, R. (2006). An investigation of epistemological and social dimensions of teaching in online learning environments. *The Academy of Management Learning and Education*, 5(4), 435–447.
- Bloom, D. (2009). Collaborative test taking: Benefits for learning and retention. *College Teaching*, 57(4), 216–220.
- Chen, J. (2018). *Dialogue patterns and peer social relationships during collaborative small-group discussions: A multiple methods approach*. The Ohio State University. http://rave.ohiolink.edu/etdc/view?acc_num=osu1531955704880496
- Chi, M. T. H., & Menekse, M. (2015). Dialogue patterns in peer collaboration that promote learning. In L. B. Resnick, C. Asterhan, & S. N. Clarke (Eds.), *Socializing intelligence through academic talk and dialogue* (pp. 263–274). American Educational Research Association.
- Chi, M. T. H., & Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist*, 49(4), 219–243.
- Cortright, R. N., Collins, H. L., Rodenbaugh, D. W., & DiCarlo, S. E. (2003). Student retention of course content is improved by collaborative-group testing. *Advances in Physiology Education*, 27(1–4), 102–108.
- Dallmer, D. (2004). Collaborative test taking with adult learners. *Adult Learning*, 15(3–4), 4–7.
- El-Mansy, S. Y., Barbera, J., & Hartig, A. J. (2022). Investigating small-group cognitive engagement in general chemistry learning activities using qualitative content analysis and the ICAP framework. *Chemistry Education: Research and Practice*, 23(2), 335–347.
- Explain everything for IOS devices*. <https://explaineverything.com/about/> [Accessed 5 Mar 2021].
- Flynn, A. B. (2015). Structure and evaluation of flipped chemistry courses: Organic & spectroscopy, large and small, first to third year, English and French. *Chemistry Education: Research and Practice*, 16(2), 198–211.
- Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, 111(23), 8410–8415.
- Fullilove, F., Hibbard, L., & Winfield, L. L. (2017). *Engineering course success through interactive engagement. Teaching a new generation of students: A national symposium*, New York, NY.
- Garrison, D. R. (2013). Theoretical foundations and epistemological insights of the community of inquiry. In Z. Akyol & D. R. Garrison (Eds.), *Educational communities of inquiry: Theoretical framework, research and practice* (pp. 1–11). IGI Global.
- Garrison, D. R. (2019). Online community of inquiry review: Social, cognitive, and teaching presence issues. *Online Learning*, 11(1), 61–72.
- Gilley, B. H., & Clarkston, B. (2014). Collaborative testing: Evidence of learning in a controlled in-class study of undergraduate students. *Journal of College Science Teaching*, 43(3), 83–91.
- Giuliodori, M. J., Lujan, H. L., & DiCarlo, S. E. (2008). Collaborative group testing benefits high- and low-performing students. *Advances in Physiology Education*, 32(4), 274–278.
- Harton, H. C., Richardson, D. S., Barreras, R. E., Rockloff, M. J., & Latané, B. (2002). Focused interactive learning: A tool for active class discussion. *Teaching of Psychology*, 29(1), 10–15.
- Hilton, C. B., Goldwater, M. B., Hancock, D., Clemson, M., Huang, A., & Denyer, G. (2022). Scalable science education via online cooperative questioning. *CBE-Life Sciences Education*, 21(1), ar4.
- Hodges, L. C. (2018). Contemporary issues in group learning in undergraduate science classrooms: A perspective from student engagement. *CBE-Life Sciences Education*, 17(2), es3.
- Hrabowski, F. A., & Henderson, P. H. (2021). Nothing succeeds like success. *Issues in Science & Technology*.
- Johnson, D. W., Johnson, R. T., & Smith, K. (2007). The state of cooperative learning in postsecondary and professional settings. *Educational Psychology Review*, 19(1), 15–29.
- Johnson, D. W., Johnson, R. T., & Stanne, M. B. (1989). Impact of goal and resource interdependence on problem-solving success. *The Journal of Social Psychology*, 129(5), 621–629.

- Kaddoura, M. (2013). Think pair share: A teaching learning strategy to enhance students' critical thinking. *Educational Research Quarterly*, 36(4), 3–24.
- Kaiphanliam, K. M., Nazempour, A., Golter, P. B., Van Wie, B. J., & Adesope, O. O. (2021). Efficiently assessing hands-on learning in fluid mechanics at varied Bloom's taxonomy levels. *International Journal of Engineering Education*, 37, 624–639.
- Kapitanoff, S. H. (2009). Collaborative testing: Cognitive and interpersonal processes related to enhanced test performance. *Active Learning in Higher Education*, 10(1), 56–70.
- Kapitanoff, S., & Pandey, C. (2018). Collaborative testing in statistics: Group interaction, anxiety, and class performance. *Statistics Education Research Journal*, 17(2), 51–67.
- Leight, H., Saunders, C., Calkins, R., & Withers, M. (2012). Collaborative testing improves performance but not content retention in a large-enrollment introductory biology class. *CBE-Life Sciences Education*, 11(4), 392–401.
- Leupen, S. M., Kephart, K. L., & Hodges, L. C. (2020). Factors influencing quality of team discussion: Discourse analysis in an undergraduate team-based learning biology course. *CBE-Life Sciences Education*, 19(1), ar7.
- Liu, Y., Raker, J. R., & Lewis, J. E. (2018). Evaluating student motivation in organic chemistry courses: Moving from a lecture-based to a flipped approach with peer-led team learning. *Chemistry Education: Research and Practice*, 19(1), 251–264.
- Liyanage, D., Lo, S. M., & Hunnicutt, S. S. (2021). Student discourse networks and instructor facilitation in process oriented guided inquiry physical chemistry classes. *Chemistry Education: Research and Practice*, 22(1), 93–104.
- Mahoney, J. W., & Harris-Reeves, B. (2019). The effects of collaborative testing on higher order thinking: Do the bright get brighter? *Active Learning in Higher Education*, 20(1), 25–37.
- Marzano, R. J. (2001). *Designing a new taxonomy of educational objectives. Experts in assessment*. Sage Publications.
- Marzano, R. J., & Pickering, D. J. (2005). *Building academic vocabulary: Teacher's manual*. ERIC.
- Menekse, M., & Chi, M. T. H. (2019). The role of collaborative interactions versus individual construction on students' learning of engineering concepts. *European Journal of Engineering Education*, 44(5), 702–725.
- Molinillo, S., Aguilar-Illescas, R., Anaya-Sánchez, R., & Vallespín-Arán, M. (2018). Exploring the impacts of interactions, social presence and emotional engagement on active collaborative learning in a social web-based environment. *Computers & Education*, 123, 41–52.
- Mooring, S. R., Mitchell, C. E., & Burrows, N. L. (2016). Evaluation of a flipped, large-enrollment organic chemistry course on student attitude and achievement. *Journal of Chemical Education*, 93(12), 1972–1983.
- Office of Institutional Effectiveness (2022). *Fact book series*. Spelman College. <https://www.spelman.edu/academics/office-of-the-provost/institutional-research/fact-book> [Accessed 23 Nov 2018].
- Piaget, J. (1926). *The language and thought of the child*. (M. Gagnin & R. Gabain, Trans.). Routledge.
- Rahim, A. S. A. (2022). Mirror mirror on the wall: Escape a remote virtual stereochemistry lab together. *Journal of Chemical Education*, 99(5), 2160–2167.
- Richardson, J., & Swan, K. (2003). Examining social presence in online courses in relation to students' perceived learning and satisfaction. *Online Learning Journal*, 7(1), 68–88.
- Russo, A., & Warren, S. H. (1999). Collaborative test taking. *College Teaching*, 47(1), 18–20.
- Sanders-Johnson, S., Gaines, M. K., Van Vleet, M. J., Jackson, K. M., Barrett, C., Camp, D., Mancía, M. D. L., Hibbard, L., & Rodriguez, A. (2020). Unleashing our chemistry superpowers: Promoting student success and well-being at a Black women's college during COVID-19. *Journal of Chemical Education*, 97(9), 3369–3373.
- Sanders-Johnson, S., Winfield, L., & Sung, S. H. (2021). Integrating iSpartan into a classic organic chemistry laboratory experiment. *Journal of Chemical Education*, 98(3), 982–985.
- Sanders, S., Thrill, C., & Winfield, L. L. (2019). Self-regulated learning in organic chemistry: A platform for promoting learner agency among women of african descent. *Critical Conversations and the Academy*, Miami, FL.
- Scager, K., Boonstra, J., Peeters, T., Vulperhorst, J., & Wiegant, F. (2016). Collaborative learning in higher education: Evoking positive interdependence. *CBE-Life Sciences Education*, 15(4), ar69.
- Seery, M. K. (2015). Flipped learning in higher education chemistry: Emerging trends and potential directions. *Chemistry Education: Research and Practice*, 16(4), 758–768.
- Shattuck, J. C. (2016). A parallel controlled study of the effectiveness of a partially flipped organic chemistry course on student performance, perceptions, and course completion. *Journal of Chemical Education*, 93(12), 1984–1992.
- Smith, M. K., Wood, W. B., Adams, W. K., Wieman, C., Knight, J. K., Guild, N., & Su, T. T. (2009). Why peer discussion improves student performance on in-class concept questions. *Science*, 323(5910), 122–124.
- Springer, L., Stanne, M. E., & Donovan, S. S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. *Review of Educational Research*, 69(1), 21–51.
- Swan, K., Garrison, D. R., & Richardson, J. C. (2009). A constructivist approach to online learning: The community of inquiry framework. *Information technology and constructivism in higher education: Progressive learning frameworks* (pp. 43–57). IGI Global.
- Theobald, E. J., Hill, M. J., Tran, E., Agrawal, S., Arroyo, E. N., Behling, S., Chambwe, N., Cintron, D. L., Cooper, J. D., Dunster, G., Grummer, J. A., Hennessey, K., Hsiao, J., Iranon, N., Jones, L., 2nd, Jordt, H., Keller, M., Lacey, M. E., Littlefield, C. E.,... Freeman, S. (2020). Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. *Proceedings of the National Academy of Sciences of the U S A*, 117(12), 6476–6483.
- Versteeg, M., van Blankenstein, F. M., Putter, H., & Steendijk, P. (2019). Peer instruction improves comprehension and transfer of physiological concepts: A randomized comparison with self-explanation. *Advances in Health Sciences Education: Theory and Practice*, 24(1), 151–165.

- Von Glasersfeld, E. (1990). An exposition of constructivism: Why some like it radical, constructivist views on the teaching and learning of mathematics. *Journal for Research in Mathematics Education - Monograph*, 4, 19–29.
- Vygotsky, L. S. (1978). *Mind in society*. Harvard University Press.
- Watts, F. M., & Finkenshaedt-Quinn, S. A. (2021). The current state of methods for establishing reliability in qualitative chemistry education research articles. *Chemistry Education: Research and Practice*, 22(3), 565–578.
- Wiggins, B. L., Eddy, S. L., Grunspan, D. Z., & Crowe, A. J. (2017). The ICAP active learning framework predicts the learning gains observed in intensely active classroom experiences. *AERA Open*, 3(2), 1–14.
- Winfield, L. L., Hibbard, L. B., Jackson, K. M., & Sanders-Johnson, S. (2019). Cultivating agency through the chemistry and biochemistry curriculum at spelman college. *Broadening participation in STEM*. Emerald Publishing Limited.
- Zhao, C.-M., & Kuh, G. D. (2004). Adding value: Learning communities and student engagement. *Research in Higher Education*, 45(2), 115–138.

Supplementary Material: This article contains supplementary material (<https://doi.org/10.1515/cti-2023-0007>).