How Students Use Whiteboards and Its Effects on Group Work

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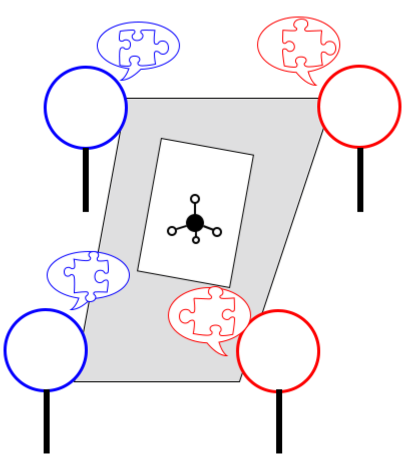
ABSTRACT

Various strategies have been promoted to increase student engagement in collaborative activity in chemistry courses, including the use of small portable whiteboards where students can represent and share ideas. In this paper, we summarize the results of a study designed to investigate how the use of small portable whiteboards during group work affects student engagement. In particular, we paid attention to how the use of whiteboards affected social processing, knowledge dynamics, and student contributions during in-class tasks in a college general chemistry class. Our findings reveal significant differences in student engagement during activities in which whiteboards are used compared to those in which these tools are not used. Although the use of whiteboards correlated with more instances of knowledge construction, overall effects are mixed, as the use of whiteboards more frequently led groups to split in pairs in the observed class. Our results suggest that use of whiteboards should be carefully planned and managed by instructors to maximize benefits and reduce potential hindrances to collaborative work.

GRAPHICAL ABSTRACT



KEYWORDS

First-Year Undergraduate/General, Chemical Education Research, Collaborative/Cooperative Learning, Hands-On Learning, Constructivism

INTRODUCTION

Current reform efforts in science and chemistry education emphasize the need for students to engage in the analysis, discussion, and reflection of relevant questions and problems actively and collaboratively.[1-3] This type of work is facilitated in learning environments where students can easily assemble in small groups and have access to resources that foster and support collaborative activity.[4-5] These resources may be human or technological. For example, teaching and learning assistants can support and guide students as they collaboratively work on in-class tasks; student groups may have access to small portable whiteboards that enable collective representation of ideas, or to computer technologies that facilitate access to and communication of information, as well as collaborative elaboration of products. Nevertheless, research on how students use these different types of resources and their effects on group work are uneven. Thus, this paper seeks to contribute to this body of knowledge by providing insights into how students use small portable whiteboards in a college general chemistry class and its effects on student engagement in group work.

The use of whiteboards in collaborative classrooms has been promoted as a means to facilitate students' representation and sharing of ideas, and to gain insights into student thinking.[4-6] Whiteboards can help make students' ideas more visible and support formative assessment. They can thus be critical tools for monitoring group progress towards the learning goals. Whiteboards create opportunities for students to construct a collective product and generate a unified answer.[6-7] They are expected to support sense-making and provide students with a tangible tool for visually representing their understanding. Unfortunately, to our knowledge there are no studies on how whiteboards are actually used by students working in small groups and their effects on group work. Gaining insights in these areas is important to take better advantage of these resources and for understanding how these tools may enhance or hinder student collaboration and intellectual engagement with course content.

RESOURCES TO SUPPORT STUDENT WORK IN CLASSROOMS

Research on how students use different types of resources in the classroom and how these resources affect their work is varied but somewhat sparse. In this section, we review existing work on the effects of using digital and material resources, such as whiteboards, as it provides insights into educational benefits and challenges of using diverse physical tools. Some authors have explored, for example, the impact of the use of technological resources such as computers on teaching practices and students' perceptions and behaviors[8,9] Access to wireless laptops in the classroom seemed to foster student-centered instruction and students' hands-on and exploratory activity. It also positively affected student-student and student-instructor interactions.[9] Using laptops led some students to spontaneously form small collaborative groups and facilitated social discourse.[8] In addition, technological platforms such as Google Docs have been shown to serve as forums for students to ask questions or provide answers and to foster collaboration inside and outside the classroom.[10] These types of tools often allow students to work collaboratively in real time using their personal devices,[11] and enhance diverse interactions among students and between students and the instructor. Participants in these studies have expressed preference for using these resources because they facilitate real-time collaboration and interaction, and open channels for immediate feedback.[10,11]

Computer technology also gives students direct access to different types of software tools that allow them to explore phenomena, analyze data, apply or build models, test ideas, or run simulations. The combined use of computer-based modeling tools with actual physical models has been shown to improve student understanding and performance.[12] While some instructors hesitate to provide students with access to technological resources in their classrooms, existing research suggests that students' time on-task and productive interactions may actually increase if technology-supported activities are well-designed and managed.[13] These studies also indicate that students tend to engage more actively in well-designed tasks that require the use of technological resources as long as they are perceived as interesting and relevant. Nevertheless, proper instructional use of computer-based resources often requires additional teacher knowledge and training for successful implementation in the classroom.[10-13]

Besides computer technologies, teachers and instructors in student-centered classrooms often provide students with different types of low-tech resources, such as sticky notes, paper pads, or small portable whiteboards, that facilitate the sharing of ideas during sense-making and problem-solving activities in small groups and the communication of results to the whole class. These resources also help make student thinking visible and facilitate and foster formative assessment practices. At the college level, the use of portable whiteboards has been promoted particularly in collaborative learning environments and recitation session.[4-7,14-16] Engaging students in "whiteboarding" has been shown to increase student engagement[4] and improve their performance in conceptual questions in quizzes and exams.[5] Whiteboarding can offer students the opportunity to engage in active retrieval and to co-construct ideas through peer-peer discussions.[6,14] Although there is limited research on how both instructors and students use whiteboards during collaborative group activities, and what the impact of using this tool actually is on students' interactions and group work, some authors have discussed the difficulties that instructors may face in using this tool in an effective manner[1] and the consequences of their instructional decisions on student behavior and anxiety.[7]

STUDENT ENGAGEMENT IN GROUP WORK

Student engagement is a complex and multifaceted construct with diverse meanings to different people. Nevertheless, in collaborative learning environments it often refers to the degree or level of attention, participation, and intellectual engagement of students working in groups while completing in-class activities.[17,18] Higher levels of engagement are expected to result in more meaningful learning and better student performance. Student engagement has been analyzed from different perspectives, paying attention to behavioral, emotional, and agentic factors.[19,20] These studies point to three different dimensions of analysis in the characterization of student engagement in group tasks: Nature of social interactions in the group (social processing),[21] knowledge use and elaboration (knowledge dynamics),[22] and types and degrees of participation.[23]

Student-student interactions in a group affect student engagement and thus it is important to characterize the different types of social relationships in peer groups (social processing). Different modes of social processing have been identified,[21] including individualistic (people work individually on a task), domination (one or more individuals direct the work of others), confusion (participants express lack of comprehension of the task goals or associated concepts), tutoring (some participants assist others while working on a task), and collaborative (the entire group engage to reach a common solution). The types of social processing that emerge are affected by group and task characteristics.

Researchers in the field of knowledge management in groups consider important to also characterize how knowledge is shared, used, and created during collaborative activity (knowledge dynamics).[24,25] When people work in groups, knowledge can be shared between individuals (knowledge sharing) while completing a task without much attention to their origin, interpretation, or evaluation.[22] A group can also apply their shared knowledge in a systematic way (knowledge application) to meet their goals. Thirdly, people in groups can also construct understandings (knowledge construction) as they engage in sharing, testing, and critiquing ideas, interpreting and evaluating information, and seeking to make sense of phenomena. Knowledge construction may result in significant changes in knowledge structure and diversify approaches to problem solving and decision making.[26]

The types and extent of student participation in group work has also been used to characterize student engagement in collaborative activity.[23] In particular, researchers have looked at the contributions that students make in the form of presenting ideas[27] and asking questions.[28] Diversity of ideas and questions in an environment in which students take responsibility and have agency in their own learning are seen as critical for knowledge building and restructuring.[27] High levels of participation in group work also correlate with higher levels of cognitive engagement and increased use of higher-order thinking.[29,30] Increased student participation often leads to a larger number of student-student and student-instructor interactions.[31] The analyses of these different types of interactions is thus also used as a measure of student engagement in active learning environments.

RESEARCH QUESTIONS

The overarching goal of this study was to develop a better understanding of the use of whiteboards during group work and the associated effects on different aspects of student engagement in collaborative activity. Thus, our study was guided by the following research questions:

- How are small portable whiteboards used in a collaborative learning environment by students working in small groups?
- How does the use of whiteboards affect the social processing, knowledge dynamics, and types and extent of student participation in small group work?

METHODS

Context and Participants

This investigation was conducted at the University of Arizona (UA), a large public research-intensive university in the southwest of the USA. Participants in the study were students in a first-semester general chemistry lecture course for science and engineering majors. The observed course section followed an alternative curriculum (Chemical Thinking)[32] that was implemented using evidence-based teaching strategies that created multiple opportunities for collaborative group work. Three to five collaborative activities were interspersed with mini-lectures and whole class discussions every class session (see the Supporting Information for examples of in-class tasks implemented in the course). This course section had an enrollment of 220 students and met 3 times a week for 50 minutes during the semester (15 weeks). The class was taught in a flat collaborative learning space with 66 square tables with four chairs (two pair of chairs in opposite sides of a table). Each of these tables was equipped with two small portable whiteboards (18" x 23"), two markers, and one eraser. The main instructor was assisted by eight learning assistants (undergraduate and graduate students) who interacted with different groups of students during in-class activities. Students were allowed to form groups of their own accord and the instructor did not intervene in group organization (e.g., by requesting that students took on defined roles) nor provided worksheets with carefully structured questions to guide group work as it is common in POGIL or peer-lead team learning environments.[33]

Data Collection

Ten different student groups with four students each were selected and consented to participate in this study. We sought to select groups that included students from diverse genders and ethnicities, that were located in different regions of the classroom, and in which all four members consented to be observed during the entire semester; observations of their work began on the third week of instruction. Four different student groups were observed during weeks 3 through 8 of the academic semester (groups labeled G1 through G4), 2 groups were observed weeks 3 through 15 (labeled G5 and G6), and four other groups were observed weeks 9 through 15 (labeled G7 through G10). This rotation of four groups was done to diversify our data set. The overall composition of the observed group was: 61% women, 40% men; 61% from underrepresented minorities, 31% from represented groups; 56% freshman, 32% sophomore, 12% junior/senior; 54% earned A/B final scores, 46% earned C or lower final scores in the course. These distributions were similar to those of the entire class.

Each group was video recorded for the entire duration of a class session using two tablets mounted on tripods set near to the group's table but far enough to capture all students in the group. Audio recordings were taken using two recorders placed in the center of the table and pointing in opposite directions to best capture conversations in each side of the table. All visual products generated by students on a whiteboard were photographed at the end of each activity. All the data collected in class was synced after each session and pre-analyzed to identify and mark times where students worked on in-class tasks. Data collection was approved by the Institutional Review Board at the UA.

Data Analysis

We began our analysis by first characterizing the different types of in-class tasks in which students engaged in the observed general chemistry course. These activities were classified into five main groups based on the core practice that they targeted: “interpretation” (students analyzed data represented in various forms), “representations” (students build visual representations of different systems and phenomena, “inferences and predictions” (students made inferences about the properties or behavior of a system, “comparisons” (students compared properties or behaviors of substances and processes), and “calculations” (students used mathematical relationships to compute an answer). We completed this analysis because we were interested in characterizing whether the use of whiteboards and student engagement differed depending on the type of task. Specific examples of each type of task can be found in the Supporting Information.

In a second stage, we analyzed video and audio recordings, together with associated photographs of whiteboards, of each observed group during each class activity seeking to characterize different aspects of student engagement in group work. During the analysis of data for each observed group, we found important to separate into different sets those activities in which no whiteboards were used, one whiteboard was used by the entire group, one whiteboard was used by only a subset of students in the group, or two whiteboards were used by pairs of students in each group. This allowed us to identify and characterize similarities and differences in each group’s social processing and knowledge dynamics when working with or without whiteboards, in split (pairs of students working separately in a group) and non-split (all students working together) group dynamics. The characterization of social processing (individualistic, confusion, domination, tutoring, collaboration) and knowledge dynamics (knowledge sharing, knowledge application, knowledge construction) in each of the selected groups for each of the observed activities was done applying existing analytical frameworks described in a previous section. Examples of the application of our coding system are included in the Supporting

Information. Additionally, we also characterized and tracked two types of contributions made by each student in a group during different class activities. In particular, we counted the number of students who engaged in "presenting ideas" while working on a task as well as the number of students who contributed by "asking questions" that helped move a group's conversations forward.

To ensure interrater reliability in all aspects of our analysis, a subset of all in-class tasks (25.9%) and recorded in-class activities (17.4%) were analyzed by at least two individuals who independently applied a common coding system (for types of tasks, social processing, social dynamics, and types of contributions) to the data and then met to discuss, resolve all disagreements, and make modifications to coding descriptions to facilitate their consistent application. The rest of the collected data was analyzed by the first author of this paper using the revised code books. Once all data were coded, Chi-square tests of independence were performed using R studio software[34] to identify significant differences between various conditions of group work. Post-hoc analysis of residuals was used to identify major contributors to statistical significance. Items with standardized residuals greater than 2 occurred at frequencies higher-than-expected, while items with values less than -2 occurred at frequencies lower-than-expected.

MAIN FINDINGS

The core results from our analysis are summarized in this section where we highlight differences in student engagement in in-class tasks when whiteboards were used and when they were not.

Overall use of whiteboards

A total of 116 different in-class tasks were observed as part of our study, which resulted in 460 instances or episodes of group interactions across the observed group. Our analysis revealed that most of these groups primarily used the whiteboard when it was explicitly requested by the instructor either at the beginning of a task or once students were engaged in an activity. The instructor's directions to use the whiteboard were always generic (e.g., "I want to see your work on the whiteboard…") and did not vary between different types of tasks. These types of requests were made in 50 (43.1%) of the tasks corresponding to 202 (43.9%) of observed instances of group work. Several instances of students' spontaneous use of whiteboards were observed (56, 12.2%) in 31 (26.7%) additional tasks. There were also a few tasks (14, 12.1%) in which some groups did not use the whiteboard even when requested by the instructor. Our observations indicated that most of these instances (19, 4.1%) occurred on days in which students worked with the whiteboard on several tasks of the same type or engaged in a sequence of high intensity tasks. In either case, a few groups of students stopped using the whiteboard at some point during the class even when requested.

In-class tasks in the observed general chemistry course engaged students in a variety of activities, including interpretation, representations, inferences and predictions, comparisons, and calculations. As summarized in Table 1, the whiteboard was used in all of these different types of tasks but to different extents. Chi-square analysis of the data revealed a significant difference in whiteboard use for different types of tasks (χ^2 = 75.332, df = 4, p <0.01) but mostly stemming from a more frequent use of whiteboards in “representation” tasks and a less frequent use in “interpretation” tasks.

Table 1. Different types of in-class tasks and instances of group work observed

Type of Tasks	Total Observed		Whiteboard Used*	
	Tasks	Instances	Tasks	Instances
Interpretations	38 (32.8%)	154 (33.5%)	21 (55.3%)	55 (35.7%)
Representations	24 (20.7%)	108 (23.5%)	22 (91.7%)	95 (88.0%)
Inferences and Predictions	23 (19.8%)	98 (21.3%)	18 (78.3%)	48 (49.0%)
Comparisons	20 (17.2%)	69 (15.0%)	12 (60.0%)	38 (55.1%)
Calculations	11 (9.5%)	31 (6.7%)	8 (72.7%)	22 (71.0%)
Total	**116**	**460**	**81**	**258**

*Percentages are calculated in reference to the total number of tasks and instances observed in each category (e.g., whiteboards were used in 21 out of 38 tasks = 55.3% and 55 out of 154 instances = 35.7% during “Interpretation” activities).

Forms of collaboration in the observed groups differed between instances in which students used or did not use whiteboards. When whiteboards were used, students split and worked in pairs rather than as a whole group in 61.6% of the observed instances. In contrast, this splitting was only observed in 18.8% of the instances in which whiteboards were not used during group activities. Nevertheless, this splitting behavior varied across groups. Five of the groups (G1, G3, G4, G7, G9) tended to work together rather than splitting both when using whiteboards (no splitting in 59.8% of these instances) and not using them (no splitting in 89.7% of instances), but the probability of splitting was almost six times higher when whiteboards were in use. The other five groups (G2, G5, G6, G8, G10) often split in pairs when using whiteboards (splitting in 77.9% of these instances) but worked as a whole group when whiteboards were not used (no splitting in 74.6% of these instances). Similar splitting patterns were observed when these two sets of groups worked on different types of in-class tasks. Nevertheless, overall splitting behaviors were significantly different depending on the type of task. When using whiteboards, significance ($\chi^2 = 21.08$, df = 4, $p < 0.01$) mostly stemmed from groups working together (no split) more frequently in “comparison” tasks and less frequently in “representation” tasks. When working without whiteboards, significance ($\chi^2 = 13.082$, df = 4, $p < 0.05$) was mostly due to groups more frequently splitting when working on “calculation” tasks.

When groups split, student pairs were always formed by students sitting by each other rather than across the table. Group splitting when using whiteboards could result in both pairs working independently on their own whiteboard (55.3% of all instances of whiteboard use) or only one pair using a whiteboard (44.7% of all instances of whiteboard use) while the other pair worked together without a whiteboard or completed the task individually. When groups split, student pairs often rejoined to share or discuss their results as a whole group (64.5% of all instances of splitting). When this occurred, students mostly engaged in answer check (65.6%) and less frequently in collaborative discussion (23.5%) or tutoring from one pair to the other (10.8%).

Social Processing

As part of part of our study, we analyzed the different social processes in which students engaged while working in in-class tasks when using and not using whiteboards. The most common type of social processing across all observed groups and types of tasks was collaboration (48.9% of all instances), followed by individualistic (33.3%), tutoring (7.9%), confusion (5.8%), and domination (4.1%). Nevertheless, as shown in Figure 1, the frequency with which these different forms of social processing occurred significantly varied ($\chi^2 = 139.77$, df = 12, $p < 0.01$) between cases when whiteboards were used and were not, and when groups split or not in each of these conditions. In general, instances of individualistic work were more common when using whiteboards than when not, but instances of confusion and domination were higher than expected when whiteboards were not used, particularly when the groups did not split in pairs. Group splitting led to more individualistic work in all circumstances, but more markedly when whiteboards were not in use. Collaboration was always more prevalent when the groups did not split.

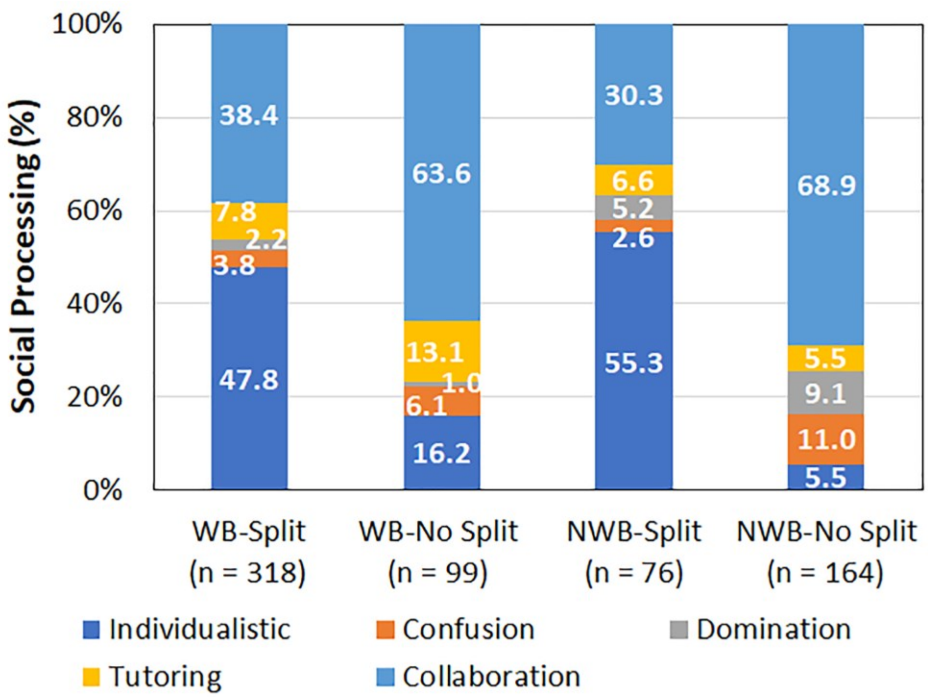


Figure 1. Relative percentages of different types of social processing observed in groups using whiteboards when split (WB-split), using whiteboards without splitting in pairs (WB-No Split), not using whiteboards and split (NWB-Split), and not using whiteboards working together (NWB-No Split). The numbers on the graph correspond to the percentages of instances observed in each category.

Given the observed association between group splitting and social processing, it was found that student groups that split in pairs less often (G1, G3, G4, G7, G9) tended to exhibit more instances of collaboration, while groups that tended to split when using the whiteboards (G5, G6, G8, G10) engaged more frequently in individualistic work, with the exception of G2 which more commonly engaged in tutoring when using whiteboards. For the most part, similar patterns of social processing were observed across all types of tasks, although higher-than-expected instances of tutoring and lower-than-expected instances of confusion were observed when students worked on “representation” tasks. Higher-than-expected instances of confusion were observed when working with whiteboards on “interpretation” tasks and higher-than-expected instances of individualistic processing were observed when working without whiteboards on “calculation” tasks.

Knowledge Dynamics

The analysis of knowledge dynamics indicated that observed groups more frequently engaged in knowledge sharing (56.3% of all instances) than in knowledge construction (19.6%) and knowledge application (2.3%) during in-class tasks. There were instances (21.8%) in which no knowledge dynamic was observable, particularly when students worked individually. As shown in Figure 2, the frequency of different types of knowledge dynamics significantly varied (χ^2 = 103.29, df = 9, p < 0.01) depending on whether groups used whiteboards or not, and whether they split or not in each of these conditions. Given that individualistic work was more common when groups split, instances of not observable knowledge dynamics were higher-than-expected under such conditions. Knowledge sharing occurred at a lower-than-expected frequency when groups using the whiteboard split, and at a higher-than-expected frequency when groups not using whiteboards worked together. On the other hand, knowledge construction was observed more frequently when students using whiteboards did not split and much less frequently when groups not using whiteboards split in pairs.

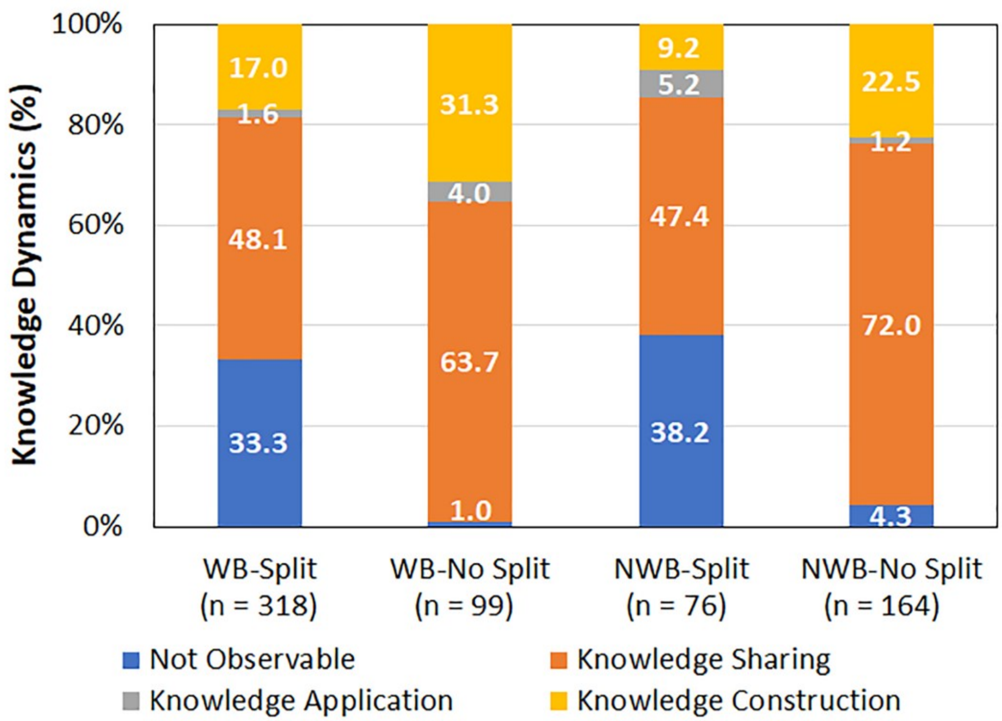


Figure 2. Relative percentages of different types of knowledge dynamics observed in groups using whiteboards when split (WB-split), using whiteboards without splitting in pairs (WB-No Split), not using whiteboards and split (NWB-Split), and not using whiteboards working together (NWB-No Split). The numbers on the graph correspond to the percentages of instances observed in each category.

The more detailed results for knowledge dynamics when groups using whiteboards split in pairs (WB-Split, n = 318 instances in Figure 2) are summarized in Figure 3. As shown in this figure, when groups split and only one side had a whiteboard, the side with a whiteboard more frequently engaged in knowledge sharing (64.8%) while the side with no whiteboard more often had a not observable knowledge dynamic (59.1%). When both sides used a whiteboard, there was an increase in the number of instances of knowledge construction (21.0%) over what was observed when only one side used a whiteboard (12.0% on average). In either case, instances of knowledge construction were the highest when groups used a whiteboard without splitting (31.3%) as shown in Figure 2.

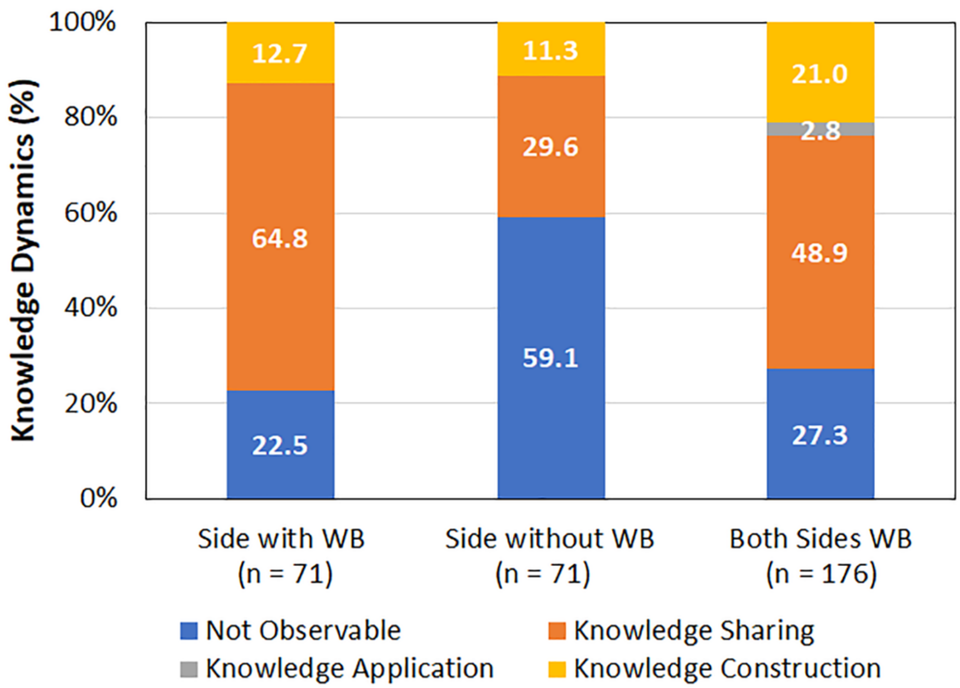


Figure 3. Relative percentages of different types of knowledge dynamics observed in groups using whiteboards when split (WB-split) and only one side or both sides used this resource. The numbers on the graph correspond to the percentages of instances observed in each category.

Our analysis indicated that there was a significant difference ($\chi^2 = 34.22$, df = 3, $p < 0.01$) between the patterns of knowledge dynamics observed in groups that tended to work together (G1, G3, G4, G7, G9) and those that more often split (G2, G5, G6, G8, G10). The former exhibited a higher-than-expected number of instances of knowledge construction and fewer-than-expected episodes with no observable knowledge dynamics, while the opposite was observed in the groups that more often split.

Overall, knowledge dynamic patterns were similar to those described above across all types of tasks (e.g., interpretation, calculation) in which students engaged.

Student Contributions and Interactions with Instructors

Our analysis of students' contributions to group work during in-class activities focused on quantifying the number of students in a group who contributed towards completing the task by either presenting ideas or asking questions. Given that each observed group had four students, we defined the "average level of participation" in any group throughout the semester in the following manner:

$$Average\ Level\ of\ Participation = \frac{\sum_{All\ observed\ tasks} Number\ of\ students\ contributing\ to\ a\ task}{4\ x\ Total\ number\ of\ observed\ tasks}\ x\ 100$$

The levels of participation for presenting ideas and for asking questions calculated across all observed groups when using and not using whiteboards, under split and not split conditions are listed in Table 2. The analysis of these data showed a significant difference in the number of students presenting ideas ($\chi^2 = 32.82$, df = 1, $p < 0.01$) in these various cases, with the significance mostly stemming from a higher-than-expected number of these types of participations when students worked together without whiteboards and a lower-than-expected number of these contributions when students used whiteboards in a split manner. The average number of students contributing ideas to a group conversation exceeded two only in the no whiteboard-no split condition. The average number of students contributing by asking questions was considerably lower in all cases, but significantly higher ($\chi^2 = 10.986$, df = 1, $p = 0.0118$) when whiteboards were not used and the groups did not split.

Table 2. Calculated indexes of participation in in-class tasks across all groups under various conditions

Average Level of Participation	Whiteboard-Split	Whiteboard-No Split	No Whiteboard-Split	No Whiteboard-No Split
Presenting Ideas	37.4%	42.4%	40.1%	55.8%
Asking Questions	12.4%	16.4%	14.5%	19.1%

Whether a group of students used or did not use a whiteboard typically affected the types and level of participation of the various students in a group, although in different manners in each of the observed groups and for each of the students in a group. Figure 4 illustrates this effect for one of the groups (Group 8). In this case, we can see how Student C (S-C) more frequently contributed to group work during activities in which the whiteboards were not used, but the opposite occurred with Student D (S-D). The contributions of Student A (S-A) in terms of presenting ideas (PI) were more frequent in tasks where whiteboards were not used, but this student more frequently asked questions (AQ) when whiteboards were in use. The reverse pattern characterized the participation of Student-B (S-B). The use of the whiteboard also seemed to affect the frequency of interactions between groups of students and instructors in the class (either the main instructor or learning assistants). Interactions between students and instructors were more frequent in activities where whiteboards were used (23.3% of all observed instances; 12.8% of these interactions were initiated by students and 10.5% were initiated by an instructor) than in those where whiteboards were not in use (11.4% of all observed instances; 4.0% of these interactions were initiated by students and 7.4% were initiated by an instructor).

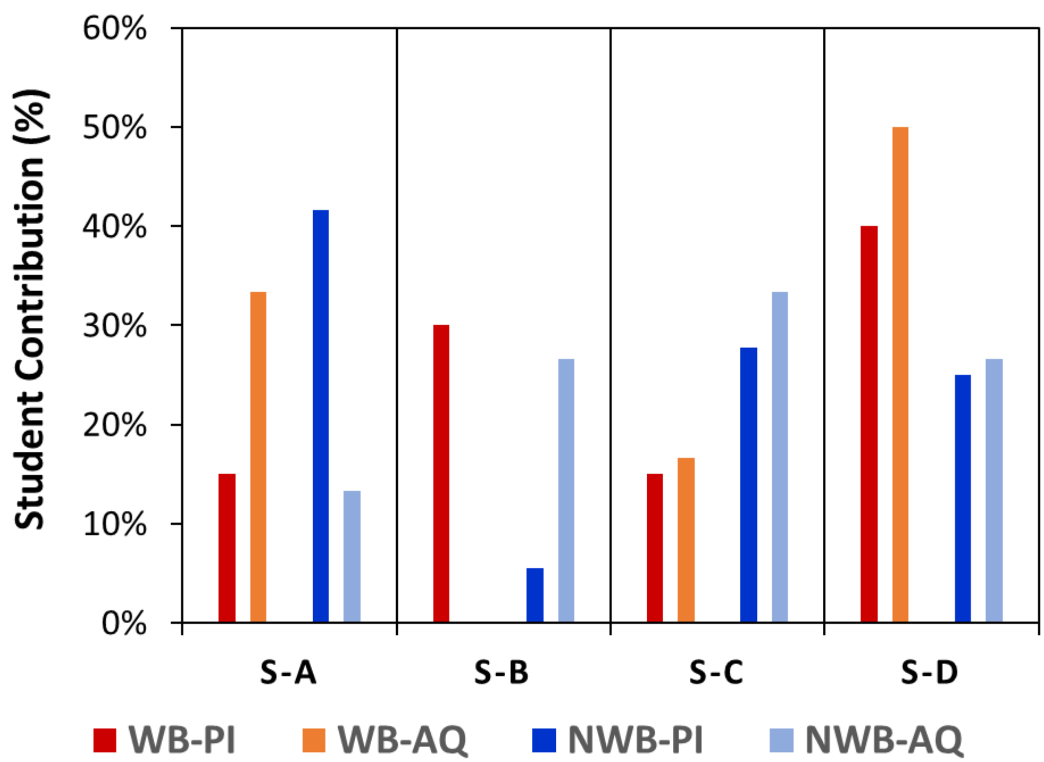


Figure 4. Average percent contribution from each of the four students (S-A, S-B, S-C, S-D) in Group 8 to group work in the form of presenting ideas (PI) or asking questions (AQ) in activities where whiteboards were used (WB) and were not (NWB).

LIMITATIONS

This study was carried out in a single general chemistry classroom with a particular layout: Multiple square tables with two pairs of students in opposite sites who had access to two small portable whiteboards. Only a subset of all student groups in this class were observed that may have not been fully representative of all types of students and group dynamics present in the classroom. Participating students may have had different levels of prior experience using whiteboards, which may have influenced their behaviors and discourse patterns. In the observe class, none of the instructors (main instructor and learning assistants) intervened to direct students on how to use whiteboards during collaborative activity. Student behavior in the observed groups could also have been affected by the presence of video and audio recorders. All of these conditions likely influenced the results of our study and thus our main findings should be taken with caution. The generalizability of studies involving a small subset of potential participants is always limited and further studies with a larger number of groups and in a variety of settings are needed to better understand how small portable whiteboards are used in various conditions and their corresponding effects on student engagement.

DISCUSSION AND IMPLICATIONS

Collaborative learning classrooms are being built in universities across the US seeking to facilitate student interactions and foster intellectual engagement during in-class tasks. The results of our study suggest that closer attention should be paid to how these learning environments are designed and used to best support student learning. Access to small portable whiteboards had mixed effects on various aspects of student engagement in the observed general chemistry class in our study. Students were more likely to split in pairs rather than work as a whole group in those activities in which whiteboards were used. However, in those tasks in which whiteboards were not used, students were more likely to engage in individualistic work when they split in pairs and manifested more instances of confusion and domination when they worked together. The use of whiteboards correlated with a larger number of instances of knowledge construction when groups did not split in pairs while knowledge sharing became more dominant in groups working together without a whiteboard. Overall, the use of whiteboards was more frequently linked to modes of social processing and knowledge dynamics indicative of higher student engagement when groups did not split, but group splitting was more common when using whiteboards in the observed setting.

Student contributions to group work in the forms of presenting ideas and asking questions were more frequent in those activities in which whiteboards were not used. Group splitting in pairs negatively affected the number of both types of contributions in all conditions. Nevertheless, our analysis of individual student behavior in the different observed groups indicated that some students were more likely to contribute to group work when whiteboards were used or contribute in different manners. It was also the case that interactions between students and instructors, both initiated by the students or the instructors, were more frequent during tasks in which the whiteboards were used. One may speculate that the use of whiteboards made student work more visible to instructors and this prompted them to approach groups more frequently.

It is likely that the layout of the observed classroom and its individual square tables, with two whiteboards, markers, and erasers each influenced the splitting behavior of observed groups. However, our observations throughout the semester suggest that splitting was also common when groups had access to only one whiteboard in their table. In these cases, one pair of students used the whiteboard while the other students often worked individually. The square shape of the table may have influenced this behavior as students on the side holding the whiteboard had easier access to it. This suggests that instructors should take a more proactive role in directing students to collaborate as a unit and generate a collective product visible on a whiteboard during group work. In the observed classroom, the instructor did not ask students to take on rotating roles (e.g., facilitator, writer, reflector) during in-class tasks.[42] This strategy could also help reduce the likelihood of group splitting and increase the number of contributions from all students to group work. Overall, our main findings point to the need for instructors to carefully reflect on how students may use the different resources to which they have access in the classroom, and carefully plan and manage group work as to maximize known benefits of using such resources and minimize the constraints they may impose on collaborative activity. The mixed effects of the use of small portable whiteboards observed in our study indicate that the mere presence and suggested use of these tools do not always ensure better outcomes in terms of student engagement.

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ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.XXXXX. The following file includes additional details on methods and results of the statistical analysis: MacrieShuck_Talanquer_Supp_Info.pdf

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