The Journal for Research and Practice in College Teaching 2017, Volume 2, Number 1
http://journals.uc.edu

A Tale of Two Classrooms: Active Learning in STEM Classes using Whiteboards

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Introductory STEM courses are traditionally considered gateway classes that introduce difficult concepts and often have significant retention challenges. Students taking these STEM classes are challenged to develop higher-level critical thinking skills, but at the same time, research has shown that they often exhibit negative affective responses to traditional teaching. This article describes using small-group whiteboards to create collaborative classroom communities in introductory Physics and Anatomy and Physiology courses. Having students solve problems and describe processes in small groups, using a whiteboard to facilitate interaction, makes visible students' conceptions and misconceptions about course material. Faculty can then scaffold new material based on where students have demonstrated mastery. By working this way, students participate in a collaborative classroom atmosphere that encourages peer-to-peer learning. Data from student perception surveys, presented here, indicated that students felt comfortable with this mode of instruction, prepared in advance for classes, and gained a better understanding of experimental design as a result of the entire whiteboarding process.

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Students taking introductory science, technology, engineering, and math (STEM) classes are confronted by unfamiliar terminology and new, challenging content. Instructors teaching these classes are challenged to identify student misconceptions and provide a framework to scaffold learning. In addition to helping students master the language of the discipline, instructors strive to help students become active, self-directed learners, develop critical thinking skills, learn to analyze and then verbalize the classical problems of their discipline, and work in groups to achieve new understandings about the content.

This article describes how two STEM professors used small-group whiteboards to create collaborative classroom communities. By utilizing whiteboards to make thinking visible, students created shared understanding of concepts while practicing the language of the discipline. Instructors used this “visible thinking” to uncover student difficulties and scaffold learning. Furthermore, working in a group environment allowed students to tackle more challenging concepts and problems than students could typically conquer on their own.

Theoretical Framework - Distributed Cognition

The theoretical framework for the pedagogical technique described here is distributed cognition. Traditional cognition can be viewed as a solo event where the student interacts with the material in isolation. They passively listen to a lecture, watch a video, or read material, etc. These activities are mostly the result of a two-way exchange between the instructor, who transmits knowledge, and the learner, who accepts or gains knowledge. In contrast, distributed cognition can be described as social learning

(Bandura, 1977). Distributed cognition involves not only the processes that occur in our brains, but also extends to the social and physical environment in which these cognitive processes occur (Dillenbourg & Traum, 1997). Within this social and physical environment, students engage in a process of clarifying, developing, and refining ideas (Nielsen, 2012). Because distributed cognition is shared, students build on each other's understanding (Dillenbourg & Traum, 1997). In the technique described here, students use a whiteboard as a central space of interaction that facilitates the distributed cognition.

Active Learning

Active learning is defined as instructional strategies that engage students in meaningful learning activities and forces them to reflect on the process (Prince, 2004; Michael, 2006). Essentially, active learning requires that students take responsibility for their own learning by immersing them in the language of the discipline and the process of building their own mental models. This student-centered instructional strategy involves active construction of meaning and articulation of explanations that contribute to meaningful student learning (Michael, 2006).

Active learning has been shown to be more effective than passive, traditional instruction (Hake, 1998; Meltzer & Manivannan, 2002: Michael, 2006), including in settings with underprepared students (Lasry, Mazur, & Watkins, 2008) as measured by concept inventories. Freeman et al. (2014) found active learning improved student performance across STEM disciplines and class sizes, although the greatest effect appeared in smaller classes with less than fifty students.

Description of the Teaching Problem

In introductory STEM courses, we expect students to begin developing critical thinking and reasoning skills. This requires that students take responsibility for their own learning. In both Physics and Anatomy & Physiology, students typically begin with naïve conceptions and need to develop correct scientific interpretations, as well as strong problem solving skills. An instructor needs a way to see what students are thinking in order to scaffold correct scientific thinking.

In Physics, students often enter the classroom with a fear of physics and a realization that physics is the obstacle between them and their educational goals. Changing fear to engagement and the obstacle to an achievable challenge is no small feat! Most students develop a more negative attitude towards physics after a semester of introductory physics (Brewe, Kramer, & O'Brien 2009). To overcome this negative perception and break down the fear, the instructor must build a sense of community among students (Desbien, 2002). In a collaborative classroom atmosphere, which encourages peer-to-peer learning, students have the opportunity for a more positive classroom experience. Brewe, Kramer, and O'Brien (2009) first reported a positive attitudinal shift for students in an introductory physics course using whiteboarding and, more specifically, modeling instruction (Jackson, Dukerich, & Hestenes, 2008).

Likewise, Anatomy & Physiology (A&P) can be daunting for new college students. The organ systems that make up the human body are complex, and interrelationships between the systems are not always intuitive. Students often have preconceived misunderstandings about the human body and struggle to put multiple facts about a physiological process together into a coherent sequence of events. Added to that, understanding biology requires students to work at multiple levels of scale at the same time (i.e. how molecular interactions effect cellular function, and how that translates to changes in the entire organism) (Michael, 2006).

It has been shown that individuals learn more when working in groups than when working alone (Michael, 2006). Therefore, we believe that the challenges of these complex topics, which students approach with negative attitudes and preconceived ideas, can be overcome by using community building activities that create a culture of cooperation, effective communication, shared meaning, clarified assumptions, and a method of representing student understanding.

Teaching Solution

In our STEM classes, we used whiteboarding to promote improved classroom dynamics and student learning. We utilized discourse management (Desbien, 2002) that moves the classroom focus from teaching to learning—from instructor to student— in a classroom management process designed to get students thinking deeply about course content through student-to-student discourse guided by the instructor, as needed. We created collaborative learning communities where students developed shared inter-individual meaning utilizing whiteboards to make their thinking visible. Students were able to develop, clarify, and present new ideas. Because student thinking became visible on the whiteboards, instructors were able to better scaffold student learning by guiding struggling students and pushing better students to think deeper.

Whiteboarding—A Process of Creating of Shared Inter-Individual Meaning

Whiteboards are a tool to foster student-to-student discussion. In the physics classes, students were presented with a problem and worked in small groups (about 4 students each)(see Figure 1) to represent a scenario and agree on terms, concepts and methods of representing their understanding. Students were expected to use appropriate representational tools including identifying givens with appropriate variables, sketching the physical scenario, creating graphs or free body diagrams, as needed, and demonstrating mathematical solutions. In Physics Lab, students designed controlled experiments to answer research questions and displayed their designs and predictions on whiteboards. Their design included identifying independent, dependent, and control variables, determining the experimental procedure and describing how they planned to represent their findings. In Anatomy & Physiology, students were asked to diagram or explain a physiological process, showing appropriate interrelationships with various body systems (see Figure 2). This could include a sequence of events as it moves from one body region to another (i.e. blood flow) or a temporal sequence that produces a molecular or cellular change (such as a neuronal action potential).

Figure 1. Small group preparing whiteboard

In both Physics and A&P, students collaboratively created a whiteboard with

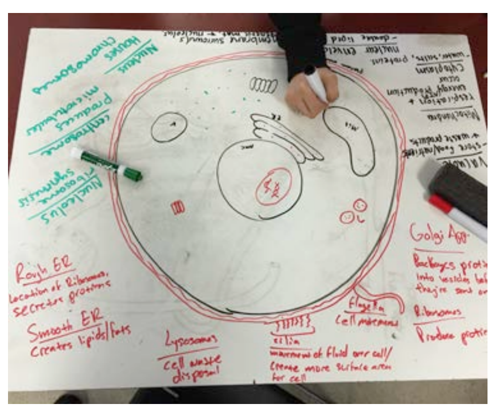

Figure 2. Representation of cell structure

their shared understanding and/or solution to the problem. In other disciplines, representation could involve flow charts, graphic organizers (concept maps), Venn diagrams, even words; whatever is appropriate to the discipline and class goals. Regardless of the method of representing the knowledge or problem solution, the keys are collaborative work and visual explanations of the group's process.

Seeding to Clarify and Extend

During the small group time, the instructor circulated through the room to question groups in order to guide their thinking or introduce new ideas–a process known as seeding (Desbien, 2002). For groups who needed support, instructor questions guided them towards the appropriate understanding. For groups who needed additional challenge, instructor questions provided areas to which the concepts could be applied or transferred to a new scenario. Seeding (Desbien, 2002) was also the mechanism through which the instructor introduced new ideas to a few of the small groups who then worked through the details and developed a representation of the new idea on their whiteboards.

Board Meetings —Whole Class Discussions

When the small groups had compiled their understanding on their whiteboards, the class formed a circle (Board Meeting) so that each student could see all the whiteboards and all their class members (see Figure 3). The instructor stayed outside the circle and observed. (In physics, the class of 32 students was divided into two board meetings, which were more conducive to student discussions. Other instructors who used this method use one board meeting for classes up to 30 students.) One group would begin by explaining their reasoning and representational tools. Peers asked questions and identified areas where the representation needed improvement or correction. The groups in which new ideas were seeded brought these concepts to the whole class. This process focused on students teaching each other and placed the authority figure (instructor) on the outside. Students developed a deeper understanding by explaining concepts to their peers and verbalizing their understanding. They were more willing to ask peers questions, whereas they were hesitant to ask an instructor what may appear as a stupid question.

Figure 3. Board meeting

During board meetings, the instructor intentionally stayed out of the circle and remained silent to promote student discussion. It was critical that the instructor had objectives for each activity to make sure the goals were achieved during the small group discussions and board meetings. If the board meeting was not producing the correct understanding, the instructor needed to join the circle and more intentionally guide the discussion. As students developed familiarity with the whiteboarding process and class expectations, the need for instructor intervention became less frequent.

Analysis of Effectiveness of Solution

The authors of this study assessed the use of the small-group whiteboard technique in introductory STEM classes. Preliminary data was collected using surveys to assess student attitudes and perceived effectiveness of whiteboard activities. The Physics class had 32 students in lecture (4 hours per week) who worked in groups of four students on whiteboard problems. The Physics lab had 31 students in three sections of lab (2 hours per week) who worked in groups of three using whiteboards to design experiments to answer research questions and present claims based on evidence. Data is included for twenty-seven students who completed the survey in Physics Lab. The Anatomy and Physiology (A&P) class had 24 students in lecture and lab (3 hours each, per week). The whiteboarding activities occurred in A&P lecture. A&P Lab also encouraged group work (lab tables of four), but whiteboards were not used there. Ten of the A&P students completed an anonymous online survey about attitudes towards, and effectiveness of, the whiteboarding activities. While whiteboarding was used in previous terms in physics, this was a first implementation of whiteboarding in A&P.

Three specific aspects were surveyed: were students comfortable with the process of whiteboard groups, did the whiteboard activities change their study or preparation habits, and did they feel they understood material better as a result of these activities? Surveys were conducted online, anonymously, at or towards the end of the term. Survey questions utilized a Likert-type scale where students were presented with a statement to which they either Strongly Agreed (SA), Agreed (A), were Neutral (N), Disagreed (D) or Strongly Disagreed (SD).

When looking at student's comfort level with whiteboard activities, most students were comfortable with this type of group work, even from the first day of class (see Figure 4a-d). Only 26% of physics students strongly agreed or agreed with the statement that whiteboard meetings were intimidating to some students, while 74% of students were neutral or disagreed with that statement (see Figure 4a). For A&P students, 90% strongly agreed/agreed that they were comfortable sharing in their groups on the first day of class (see Figure 4b), 80% were comfortable sharing in groups overall (see Figure 4c), and 70% said it helped them to get to know fellow classmates more quickly (see Figure 4d).

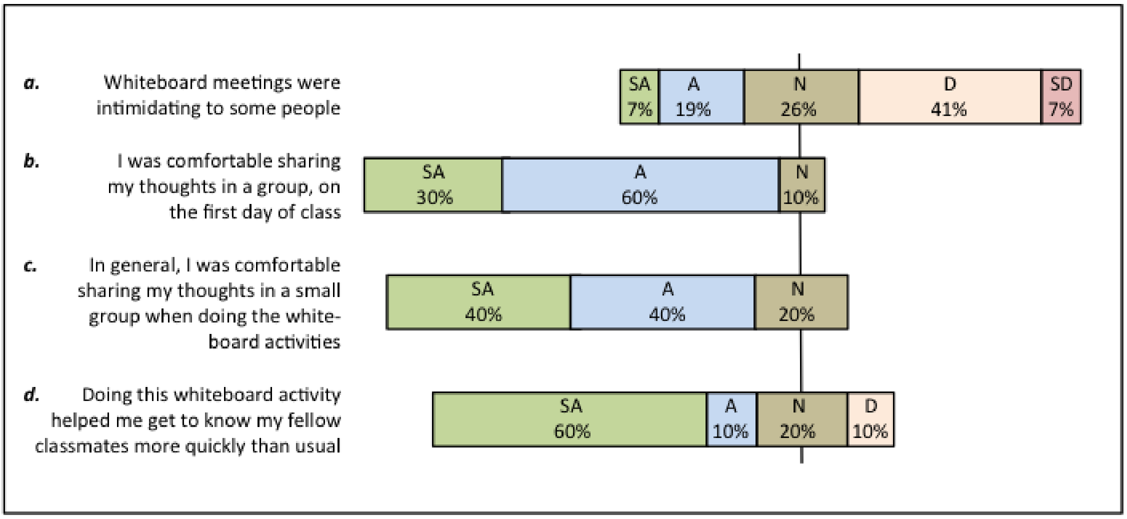

Figure 4. Comfort level with small group whiteboard activities

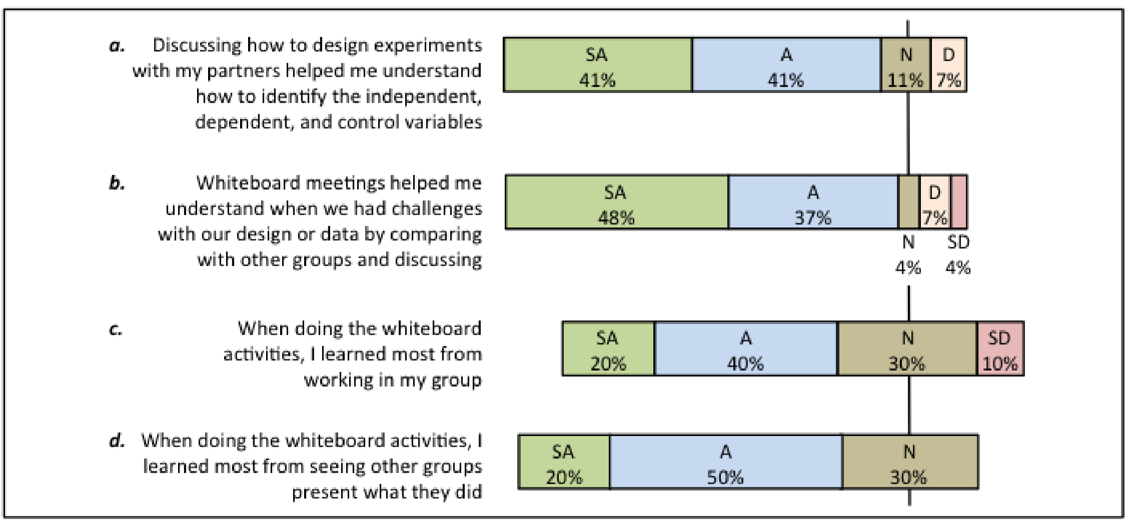

Figure 5. Perceived learning from small group whiteboard activities

In physics labs it was clear that the process of discussing experimental design in a small group, coupled with diagraming potential solutions to problems helped students better understand the scientific process. A majority (82%) of these students strongly agreed/agreed that group discussions of experimental design helped with identifying independent, dependent and control variables (see Figure 5a), and 85% strongly agreed/agreed that the presentation process helped them identify problems with their experimental design or data collection by comparing their work with other groups (see Figure 5b). For A&P students, 60% strongly agreed/agreed that they learned most from working in their own groups (see Figure 5c), while 70% said they learned most from seeing other group presentations (see Figure 5d).

One goal for the use of whiteboard activities is to encourage student preparation before class. The A&P activities instructed students to watch an assigned video and/or read a textbook passage prior to class, and to take notes from these resources. During class, the whiteboard activities then required them to draw on this information to describe or explain physiological phenomena. Most A&P students did prepare for class by watching or reading the assignment, (90% Strongly Agreed/Agreed, see Figure 6a) although only 40% Strongly Agreed/Agreed that they had taken notes from the assignment (see Figure 6b). Students were more varied in how they felt the whiteboard activities impacted their learning. Some physics students felt that whiteboard meetings were beneficial to those who spoke, 46% Strongly Agreed/Agreed (see Figure 6c), but there were responses for all other choices to this statement, from Neutral to Strong Disagreement.

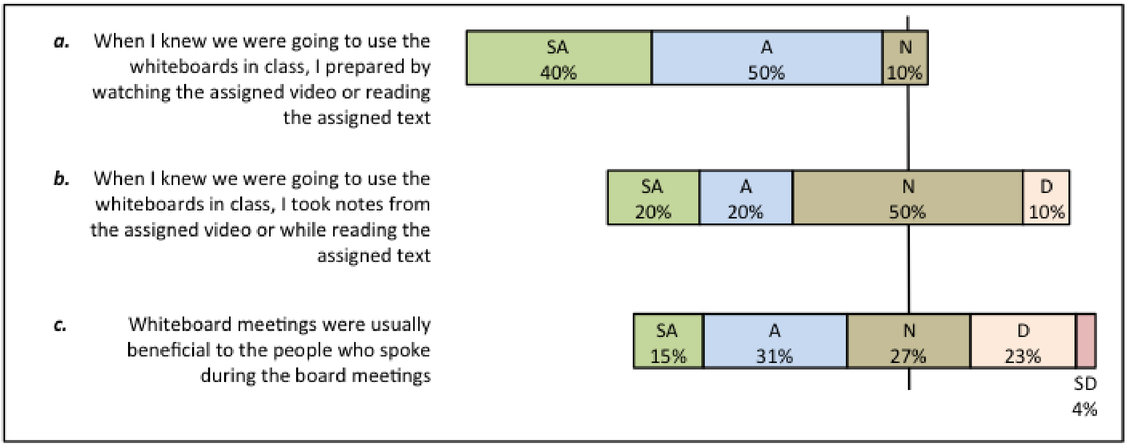

Figure 6. Class preparation when using small group whiteboards

Discussion

Introductory STEM courses are typically challenging for first or second year college students – the terminology is unfamiliar, a substantial amount of content must be learned, and the concepts sometimes seem counter-intuitive. Physics students often come to the class with pre-conceived ideas of "how the world works" that are at odds with the accepted scientific models used in the discipline. In Anatomy & Physiology, students have a tendency to view the body as a series of discrete systems without considering how these individual parts interact in the whole person.

Overcoming the three challenges of terminology, content, and concepts requires techniques that can enhance problem solving and critical thinking skills while students actually work with the terms and models of the discipline. The pedagogical technique described here, small-group whiteboarding, was developed in physics (Desbien, 2002; Jackson, Dukerich, & Hestenes, 2008; Megowan-Romanowicz, 2016) out of work in social learning (Bandura, 1971) and distributed cognition (Dillenbourg & Traum, 1997). The concept of social learning extends the acquisition and integration of knowledge beyond the learner-material interchange and into the social and physical environment (Dillenbourg & Traum, 1997).

Various forms of group work have been developed to enhance social learning, including think-pair-share questions, problem-based learning, jigsaw techniques, team-based quizzes, and other types of interactive problem solving. Effective group work requires multiple skills (Blumenfeld, Marx, Soloway, & Krajcik, 1996), some of which are counter to the traditional solo-skills students are used to using. As a result, students are sometimes resistant to group work. Some students strongly preferred to work on their own and disliked writing on whiteboards (anecdotal observation). In addition, students may prefer to have their notes written on paper they can take with them after class. For this reason, we encouraged students to take photos of their whiteboards for reference later. While this works for many, there were still some students who resisted whiteboard activities. It takes extra effort and encouragement on the part of the instructor to draw resistant students into the group activities. The group activity described here – using small whiteboards to facilitate group discussion and problem solving – shows promise for many students for learning concepts and terminology in STEM classrooms. Nonetheless, a few students preferred the traditional lecture with note-taking. As with any pedagogical technique, what students prefer may not necessarily correspond to how students learn effectively.

In the sciences, experimental design can be challenging for students to learn. Fundamental to good experimental design is the ability to identify the dependent and independent variables and how to set up appropriate controls. We have found that having students explain their problems and thought-processes in groups, with the addition of a small whiteboard to easily facilitate diagraming and simple graphing, enhanced student understanding of experimental controls and variables. When students use whiteboards as the centerpiece of their group discussions, it has the added benefit of allowing the instructor easier access to the group's cognitive processes so that the instructor can spot, and correct, missteps or push high performing groups to extend their work.

A challenge that is not unique to STEM classes is setting expectations to encourage good student preparation. One currently popular pedagogical strategy is the flipped classroom. In this approach, students are expected to access content outside of class and come to the classroom ready to engage in active learning utilizing that content. For the A&P classes surveyed here, the whiteboard activities were structured to encourage pre-work; in particular students were expected to take notes while reading or watching the resource where content was delivered. Once in the classroom these notes became the resource that students would use in their whiteboard discussions. Structuring the whiteboard activities this way did encourage some students to prepare for class. That is, for some students the whiteboard activities reinforced what they had already studied on their own, although for a number of students the whiteboards represented the first time they were learning the material. Being more explicit in the expectations of the whiteboarding process may increase that type of participation.

Student group work will likely always come with some drawbacks, and hence some resistance. Students have valid concerns that others in their group may be "loafing" and not contributing – however we have found that with whiteboarding it is harder for these students to hide behind the group. A more difficult challenge to overcome may be the forceful students who take over the group. Some students have expressed concern that only those who participated gained from the whiteboarding experience (data not shown). Because the group work occurs during the class time, and because the whiteboards help the instructor monitor what is happening in the group, it may be possible to minimize the adverse effects of a dominant student.

Implementing Whiteboards in Other Settings

An important benefit of using whiteboards with small groups during class is that student thinking is visible and collaborative learning becomes possible. While we implemented whiteboarding in STEM classes, this pedagogical strategy could be used in other disciplines, as well. We have found whiteboard activities to be particularly effective for conceptually challenging topics or multi-step problems in which students would benefit from peer-to-peer discussions and collaboration. With simple concepts or problems students do not engage in deep discussions and are more likely to be off task and not benefit from the group interactions.

Another benefit to using whiteboarding is that more students tend to prepare prior to class so they can contribute during the whiteboard activities. Using whiteboard activities, an instructor can make a quick assessment of student learning by a glance around the whiteboards. Most students do not want to be noticeably unprepared and tend to complete the pre-class assignment in preparation for the in-class whiteboard activity. Consistent use of whiteboard activities seems to encourage a greater level of student preparation for class. For many instructors, this may be a sufficiently good reason to implement whiteboard activities.

The challenges of implementing whiteboard activities is that the instructor needs to (1) identify complex topics or problems worthy of the time invested in class, and (2) develop a different set of instructor skills to effectively implement whiteboarding. An instructor should consider what concepts are typically difficult for students and what type of whiteboard activity would help students overcome these difficulties. While the literature may have identified common student difficulties, the best method of determining challenging topics is by learning from your students. In what areas do they consistently struggle? Instructor skills necessary for implementing whiteboard activities include developing a collaborative classroom atmosphere, learning to ask effective questions, and developing a habit of reflection after each class to determine what students learned, where they are still struggling, and how to adapt the next class to help them overcome their difficulties.

An important instructor skill is developing a repertoire of clarification and extension questions. Clarifying questions direct students to find their own answers or to think deeper. Examples include:

- How do you know…?
- Where did you get...?
- What does….mean?

Extending questions push students beyond their current thinking and help make connections to other concepts. Examples include:

- What is the key to solving this problem?
- How is this different from/similar to…?
- Is there another way to do this?
- What if (something) changed?

Although STEM students often have challenges and resistance to developing critical thinking skills, these skills can be taught by having small groups work problems on whiteboards to elucidate their thinking, practice terminology, strengthen individual learning, and achieve higher level problem solving through group work. Overall, we have found substantial benefits from using small group whiteboards in STEM classes. Students are more likely to prepare for class and are visibly more engaged. Sharing their work on whiteboards allows everyone, instructors included, to follow their problem solving progress. In addition, the "Board Meetings" provide an important forum for students to learn by teaching and to review by seeing the results other groups' discussions. Future work will focus on assessment of learning outcomes. The nature of classroom research can make quantifying differences between pedagogical techniques challenging, but the rich body of work in both physics and A&P instruction can help to identify specific, testable outcomes to pursue.

Acknowledgements

We are deeply grateful to the students in Physics for giving us permission to use their photos to illustrate whiteboard activities.

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