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Collaborative Problem Solving at Chalkboard vs. On Paper For First-Year Calculus

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ABSTRACT

Collaborative learning is well-established as a method to improve student learning and retention in engineering classrooms. One problem with collaborative learning is difficulty maximizing engagement of all students during group activities. We tested a change in implementation of collaborative problem solving sessions (Workshops) in a first-year Calculus for Engineers course. Previously, students sat at tables and worked together in small groups to solve provided problems, with each student ending the class period with her or his own written solution. The innovation in this study had students solving the same problems in the same small groups, but working together on the chalkboards, with each group ending the class period with a mutually agreed upon solution. Data collection to assess the innovation included student surveys, TA feedback, and observation and video recording of Workshop sections. The data support this innovation as a way to increase student collaboration and engagement during collaborative problem solving.

Key words: Collaborative learning, increasing small-group interaction, work at board

INTRODUCTION

In 2006, Engineering College faculty at Cornell University collaborated with Mathematics faculty to develop an enhancement to the first required calculus course for first-year engineering students (Schneider, Kelley, and Baker, 2007). Noting dual goals of integrating science and engineering with the first-year calculus content and of providing a collaborative problem-solving component within the course, the Engineering Math Workshops effort began. Faculty developed Workshop problems in which students must use mathematical concepts from the single-variable calculus course to solve problems with stimulating and thought-provoking real-world physics and engineering applications.

One of the two existing Teaching Assistant (TA)-led recitation/discussion sections for the course was replaced with an interactive, problem-solving session in which students would work in small groups on solving those Workshop problems. An example Workshop problem is found here.

The Engineering Math Workshops effort was partially motivated by the wealth of studies demonstrating the benefits of active learning (Felder, Felder, and Dietz, 1998; Prince, 2004; Hake, 1998) and collaborative learning (Colbeck, Campbell, and Bjorklund, 2000; Johnson, Johnson, and Smith, 1998a,b; Springer, Stanne, and Donovan, 1999; Terenzini, et al., 2001) in improving learning outcomes for students in a variety of fields. The Workshops were further informed by curricular innovations toward greater integration of math, science, and engineering content in undergraduate engineering programs at other institutions (Carr, 2003; Froyd and Ohland, 2005; Olds and Miller, 2004). These documented experiences with integrated curricula suggested that the skill of applying mathematics to engineering problems can and should be explicitly taught to engineering students early in their undergraduate careers. Expected outcomes of this type of integration for students include a more thorough understanding of the mathematical concepts, a stronger sense of engagement with the first-year curriculum through an exposure to engineering applications, and an enhanced ability to recognize and apply the mathematical concepts when called upon to do so in subsequent engineering courses.

With almost a decade of experience with these Workshops in this calculus course, in addition to realizing the many benefits, some recurring problems have come to light. Some repeated complaints in student feedback about the Workshops over the years have to do with how the small groups work together. Examples of this feedback include:

- *“I wish the teamwork aspect was more present because most of the students don’t actually work in groups. They all just do the problem sets by themselves and maybe will compare the answers with someone else in the group;”*
- *“In the groups for the workshops, usually there are one or two people that complete the workshop quite easily while others are struggling. This imbalance makes the group members somewhat demotivated;”*
- *“I think we should promote more collaboration in workshop because some people just work on their own and ignore everybody else.”*

These types of challenges are consistent with those experienced and documented by other educators striving to successfully include active group problem-solving in the college classroom (Colbeck, Campbell, and Bjorklund, 2000; Felder and Brent, 1996; Hansen and Stephens, 2000; Shimazoe and Aldrich, 2010). Student resistance to working in groups, and the resulting difficulties instructors face when requiring or encouraging group work, are substantial impediments that must be addressed. In this study, we are assessing the effectiveness of an attempt to mitigate some of these difficulties.

ENGINEERING MATH WORKSHOPS IMPLEMENTATION AND CURRENT INNOVATION

The Engineering Math Workshops are implemented as one portion of the first required calculus course in the core engineering math sequence at Cornell. The overall structure of the calculus course includes three weekly 50-minute lectures taught by Math department or Engineering College faculty and two weekly 50-minute discussions led by graduate student TAs. There are typically twelve to fourteen discussion sections for the Calculus for Engineers course, enrolling 25-30 students per section. Six to seven TAs staff the course and teach two sections each. The second discussion section each week is generally used for an Engineering Math Workshop, in which students work collaboratively in small groups on solving the applied Workshop problems. The Workshops are facilitated by the TA along with an upper-level engineering undergraduate course assistant (CA).

The course TAs and CAs attend a 90-minute training session at the outset of each semester designed to prepare them to facilitate the Workshops. The training includes an explanation of the motivation for the Workshop program and the expected learning gains for students, a description of the optimal Workshop environment they are called on to create and tips on how to foster that optimal environment, important information on administrative procedures and record-keeping for program evaluation, and practice guiding group work on the actual Workshop problems. In the Workshops students are instructed to work in groups on the applied problems. Teaching assistants and course assistants facilitate the group work and provide guidance where necessary. Students are encouraged to discuss and grapple with the problems together with their group members and to help each other to reach a joint solution (Schneider and Terrell, 2010).

Engineering Math Workshops have been proceeding in the first engineering calculus course with this general structure since 2007, with regular collection of student feedback surveys, and a focused effort to document and characterize student learning gains (Schneider and Terrell, 2010; Terrell, Terrell, and Schneider, 2010). However, since the lead instructor and the lead TA for the course change from year-to-year, as do the group of TAs hired to staff the sections, continuity and integrity of workshop implementation can be a challenge.

In 2015, the authors began an intensive effort to thoroughly review the workshop problems, student feedback, and workshop implementation practices to identify areas needing revision, enhancement, or reinforcement. As part of this overall effort to rejuvenate the Engineering Math Workshops, we experimented with a change in Workshop implementation, which is the focus of the current study. To encourage more interaction amongst group members, we experimented with having each group work on the chalkboard and come up with a unified solution that each person can see and contribute to, rather than having each student in the group complete their own version of the solution on paper. Historically, in the Workshops, students work together at classroom tables, solving problems in small groups, but with each student writing the solution on their own worksheet. They are encouraged to discuss each aspect of the problems as they progress through the worksheets, yet each ultimately creates their own written solution. In the new method, students work together in the same small groups and solve the same engineering-inspired problems, but each group stands at their own section of the chalkboard and must generate a single solution to the problem on the board.

The idea for this innovation came from conversations with colleagues, however having students work on the chalkboard is a common educational tool (Arney et al., 1995; Graham et al., 1999; Khalid et al., 2011; Subramanian, Cates, and Gutarts, 2009). Some of the known benefits of students' in-class use of chalkboards or white boards include facilitating student collaboration on problems and allowing instructors to follow student work more easily. For this study, we assigned some of the course's discussion sections as experimental sections where they implemented the chalkboard version of the workshops, while the rest of the sections worked on paper as before. Since the chalkboard format requires a classroom with ample board space to accommodate five to seven groups of approximately four students each, working together on board space, the number of experimental sections during Fall 2015 was constrained by the classroom assignments for the sections. Two of the TAs had appropriate rooms assigned and each ran one of their sections in the usual way (paper) and the other section as an experimental section (chalkboard). This strategy was utilized to help control the effects of implementation bias across different TAs; we recognized that some TAs may be more effective at motivating and guiding the group problem-solving in their Workshops. This design allowed us to compare the outcomes for experimental versus traditional sections being led by the same TA. To study whether the experimental sections saw any benefits over the traditional paper-based sections we utilized: student surveys after every Workshop and at the end of the semester; observation and limited video recording of both experimental and paper-based sections; and interviews with the TAs who led experimental sections. Details of the methods used and the results obtained follow.

Hypotheses

We hypothesized that the format of the chalkboard sections, in which students work together with their group members to produce a single written solution, should result in a higher level of group engagement and interaction among group members. In turn, we expect this higher level of engagement and interaction, in the process of attempting to reach consensus for a common solution, should lead to a higher incidence of students helping each other and learning from each other. Finally, we expect that as students talk about their approaches to problem solving, and listen to others' approaches, they will ultimately attain a fuller understanding of the Workshop problems. The diagram in Figure 1 illustrates our central hypotheses, with the expectation of positive relationships between each aspect.

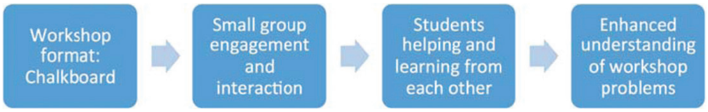


Figure 1. Diagram illustrating expectations for the Workshops completed at the chalkboard.

Data Collection

The data collected for this study include: student surveys after each workshop; an end-of-term student survey; observation, including limited video recording, of both traditional and experimental Workshop sections; and an exit survey with the experimental section TAs. Each of these data sets is described in more detail below. Note that the data collection does not include direct measurement of student learning outcomes. This study relies on the already established link between active or collaborative learning and student learning outcomes, as seen in the literature. Here we are specifically measuring whether this innovation can enhance the intended collaborative aspect of the Workshops.

During the semester there were 8 Workshops. The first Workshop involved filling out missing entries in a table, and as such was poorly suited to work on the board; all groups worked on paper. For Workshops 2-6, there were two sections working on the chalkboard. Due to a miscommunication, one of the experimental section TAs had their traditional "paper" section switch to working on the chalkboard for Workshops 7 and 8, the last two of the semester. The data analysis takes into account this change.

Table 1. Student response rates for each Workshop survey. The experimental sections include both the two sections with work completed at the chalkboard and the two paper sections led by the same experimental TAs.

WS #	Total # of responses	Response rate [%]	# of responses in experimental section	Response rate in experimental sections [%]
2	177	60	68	65
3	69	23	29	28
4	82	28	36	34
5	228	77	78	74
6	198	67	68	65
7	201	68	77	73
8	176	59	63	60

After every Workshop students were asked to complete a survey on the course website. The questions after each Workshop were identical and are listed in Appendix A. Participation was encouraged by allotting a small portion of their grade to submitting a survey response. Even so, participation varied widely by Workshop and by discussion section, from a low of 23% to a high of 77%, as shown in Table 1. In the data analysis, responses from Workshops 2, 5, 6, 7, and 8 are combined into a single data set, omitting Workshops 3 and 4 which had very low response rates.

In addition to the surveys after every Workshop, students were asked to complete an end-of-term (EOT) survey. The response rate for this EOT survey was 54%. Questions on the EOT survey are shown in Appendix B.

For both survey types, in addition to the multiple choice or rating-on-a-scale questions, there were multiple prompts for written feedback. After presenting statistical analyses of the former, we will give selections of notable feedback from the latter.

Both authors observed Workshop sections in person. Clips of video taken during experimental and traditional sections support the observations made there, which are included in the Findings section, below.

After the semester concluded, we conducted an exit interview with the two TAs who ran experimental sections. They described their experiences and observations in both the paper and chalkboard sections, shared their preferences, and offered ideas for improvements going forward.

FINDINGS

Observational

From observation, the chalkboard sections seem much more interactive, as evident in the video clips of sections. The noise level in the room, from students in every group talking, is noticeably higher than when students sit and work on paper. When a student writes an answer that others in their group disagree with, the group has no choice but to resolve it before moving on. When sitting at tables together, the students took longer to start interacting, and spoke less frequently, as everyone was writing their own solutions. Interaction is observable in both types of Workshop sections, but the free exchange of ideas seems to happen more quickly and consistently in the chalkboard sections.

In the exit interview with the experimental section TAs after the semester's end, they noted the following benefits to the chalkboard implementation:

- Groups were more interactive with each other
- Easier for TA to see the progress each group is making and keep everyone on track and on task

- Easier for TA to see common problems among several groups
- When a group gets stuck, it can sometimes get ideas from what other groups have written on the board
- Groups were able to complete the Workshops more quickly

Suggestions from the TAs for maximizing the benefit of the Workshops include:

- TAs should choose students who seem less involved to explain everything their group has written on the board
- Students should be forced to rotate who is writing for different parts of the problem to prevent one or two students from dominating the Workshop

Both expressed a clear preference for the chalkboard format.

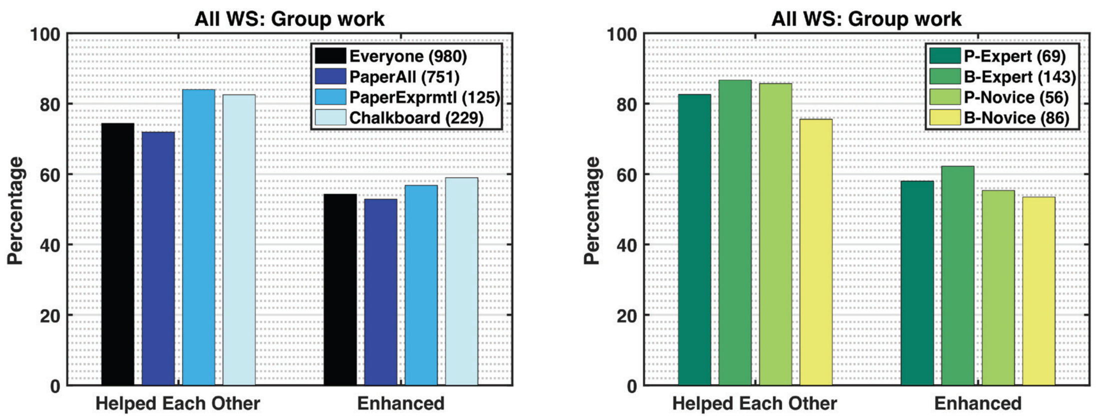
Student surveys

Through analyses of students' survey responses, we identified several trends that support our hypotheses, as well as some unanticipated but noteworthy results, all of which are presented below.

The following series of figures show selected survey results from the combined individual Workshop surveys. A total of 980 responses are included from Workshops 2, 5, 6, 7, and 8. The legend entries have the following meanings: "Everyone" is students from all sections; "Chalkboard" is students who completed the Workshop on the chalkboards; "PaperExprmtl" is students from the two sections taught by the experimental TAs who completed the work on paper; "PaperAll" is all students who worked on paper (experimental and traditional sections). "P-Expert" and "B-Expert" are the paper and chalkboard sections of one of the experimental TAs, respectively, and "P-Novice" and "B-Novice" are from the other experimental TA. One of the experimental section TAs was a more experienced TA with high ratings for teaching in past semesters. We will sometimes refer to this one as the expert TA. The other was a first semester graduate student with no prior teaching experience. We will sometimes refer to this one as the novice TA.

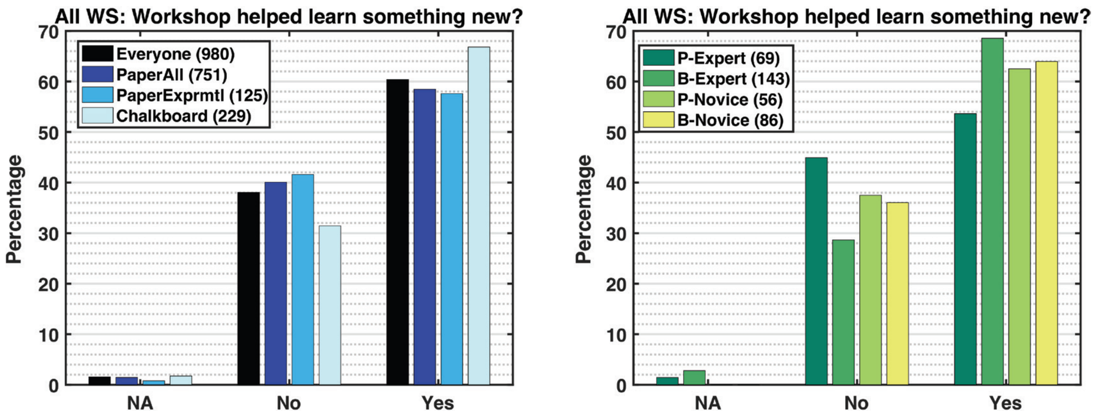
As seen in Figure 2, when asked to select the statements they agree with, students in the expert TA's chalkboard section were more likely than those in the expert TA's paper section to choose: "In my group, students were helping each other understand the problem and solution," and, "Working in my group enhanced my understanding of the problem and solution." However, in the novice TA's sections that trend is reversed. Overall, the students in the two chalkboard sections were more likely than the students in the class as a whole to select those options.

Students in the chalkboard sections were significantly more likely to say that the Workshop helped them learn something new, as shown in Figure 3. That trend holds between the chalkboard students and the class as a whole, and also between each experimental TA's two sections. However, analysis of this finding also shows the difficulty in teasing out the effect of working on the chalkboard



(a) All students *(b) Experimental sections*

Figure 2. Consolidated results for individual Workshop surveys. This shows the proportion of respondents in each subset of students who selected the options, "In my group, students were helping each other understand the problem and solution," and, "Working in my group enhanced my understanding of the problem and solution." The numbers in the legend are the counts of student responses within each category.



(a) All students *(b) Experimental sections*

Figure 3. Consolidated results for individual Workshop surveys. This shows the answers to the question, "Did this workshop help you learn something you had not learned before? (e.g. mathematical concepts, applications, different ways of looking at things, etc.)" The numbers in the legend are the counts of student responses within each category.

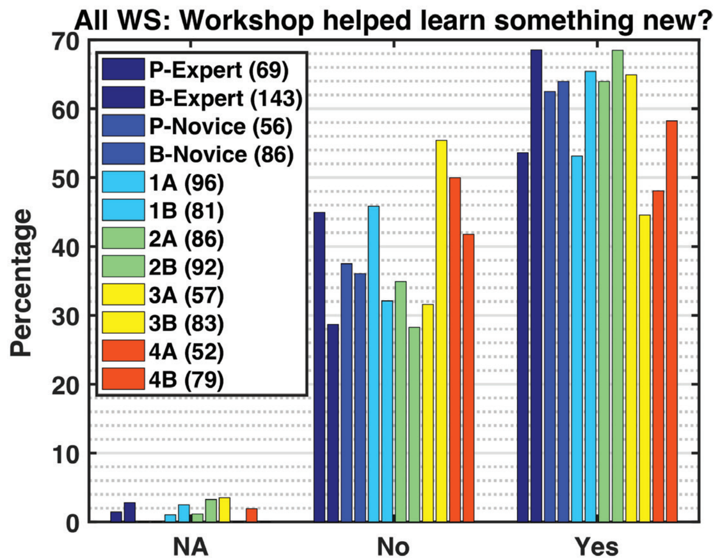
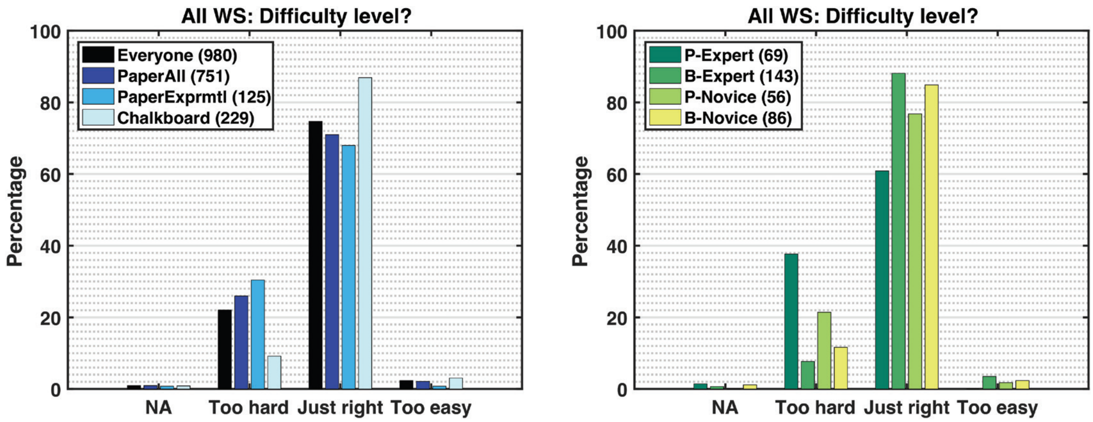


Figure 4. Answers to the question, "Did this workshop help you learn something you had not learned before? (e.g. mathematical concepts, applications, different ways of looking at things, etc.)" Results are shown for all sections and grouped by TA. 1A and 1B refer to a single TA's two sections, for example. The numbers in the legend are the counts of student responses within each category. This emphasizes the variation between a single TA's two sections, regardless of whether any implementation differences existed.

versus working on paper, since there is broad variation between TAs and also between a single TA's two sections, as shown more clearly in Figure 4. Even considering these difficulties, several other answers are worth exploring.

Both Figure 2 and Figure 3 address the changes we anticipated from our central hypothesis, but Figure 5 and Figure 6 show two unanticipated but noteworthy findings. Students in the chalkboard sections were significantly more likely than students completing the Workshops on paper to find both the difficulty and the length of the Workshops to be optimum. They were also significantly less likely to find them too hard or too long for the time allotted.

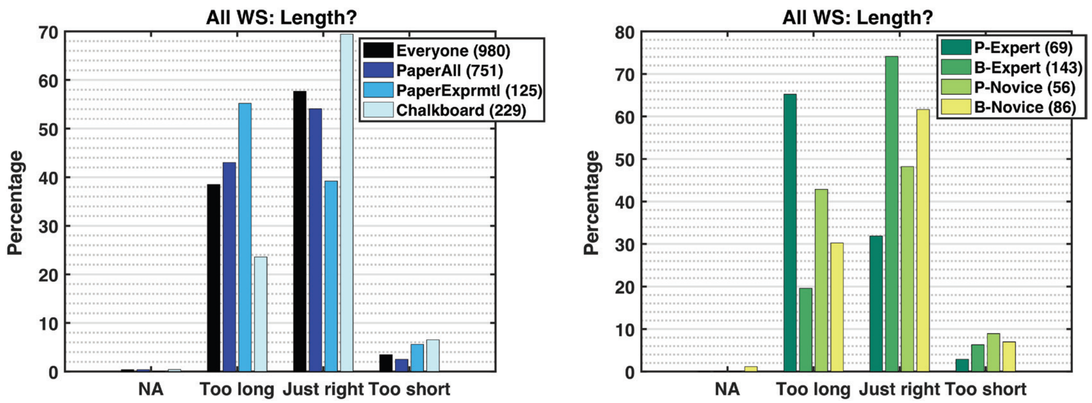
In addition to charting the results of individual questions, we also ran analyses looking for statistically significant differences between the responses of students working on chalkboards versus students working on paper. The results of those analyses are shown in Table 2. The data behind that table are the same as the data behind the bar charts already presented: a consolidation of the answers to the individual Workshop surveys taken from Workshops 2 and 5-8. All students working on the chalkboard are compared to all students working on paper. Because we are testing five



(a) All students *(b) Experimental sections*

Figure 5. Consolidated results for individual Workshop surveys. This shows the answers to the question, "What did you think of the difficulty of this workshop?" The numbers in the legend are the counts of student responses within each category.

hypotheses with this one data set, we use the Bonferroni correction to adjust our typical standard for statistical significance ($p < 0.05$) to the more conservative standard of $p < 0.01$. Results from these analyses show that the largest and most statistically significant effects relate to the perceived length and difficulty of the Workshop problems. When students work together in groups



(a) All students *(b) Experimental sections*

Figure 6. Consolidated results for individual Workshop surveys. This shows the answers to the question, "What did you think of the length of this workshop?" The numbers in the legend are the counts of student responses within each category.

Table 2. Statistical analysis of student responses to questions on the surveys following individual Workshops. Data from Workshops 2, 5, 6, 7, and 8 are included. This table is a summary of the central comparisons and significance test results for five cross-tabulations. The full cross-tabulations are included in Appendix C. The asterisks denote items with statistical significance at the 0.01 level (adjusted from p < 0.05 with the Bonferroni correction to compensate for multiple (five) comparisons on the data).

	Chalkboard "yes" or "just right"		Paper "yes" or "just right"		Pearson chi-square	p-value
QUESTION	***COUNT***	*PERCENT*	*COUNT*	*PERCENT*		
Helping each other?	189	82.5%*	540	72.1%*	10.066	0.002
Enhanced understanding?	135	59.0%	397	53.0%	2.501	0.114
Learn something new?	153	68.0%	439	59.3%	5.477	0.019
Difficulty?	199	87.7%*	532	71.6%*	29.138	0.000
Length?	159	69.7%*	405	54.2%*	32.707	0.000

at the chalkboard, they are significantly more likely to perceive the problem difficulty and length as "just right," rather than "too difficult" or "too long." With a smaller magnitude of effect, yet still significant, students are more likely to say that they helped each other when working together at the chalkboard. Meanwhile, the apparent positive effect of the chalkboard innovation on students' perceptions of learning something new would be significant with a $p < 0.05$ standard. However, with the corrected $p < 0.01$ standard, the statistical significance of this difference is not retained. Finally, the effect of the innovation on enhancing students' understanding, while positive, is not statistically significant.

Looking further, at the end-of-term survey, we consider students' retrospective perceptions of the benefits of the Workshops at the end of the semester. In this survey, many questions asked for a rating on a scale of 1–10. That allows us to find the average and standard deviation of the responses for different subsets of students. The results for five key questions are shown in Figure 7. While the trends for all of these questions do show the results we expected between the chalkboard and paper sections, the effects appear small. The variation in each answer overwhelms the difference between averages.

Examples of student comments

Both the end-of-term survey and the individual Workshop surveys gave several opportunities for students to elaborate on their experiences in the Workshops with written comments. Focusing only on the expert TA's sections, there are some comments that come up more often from students

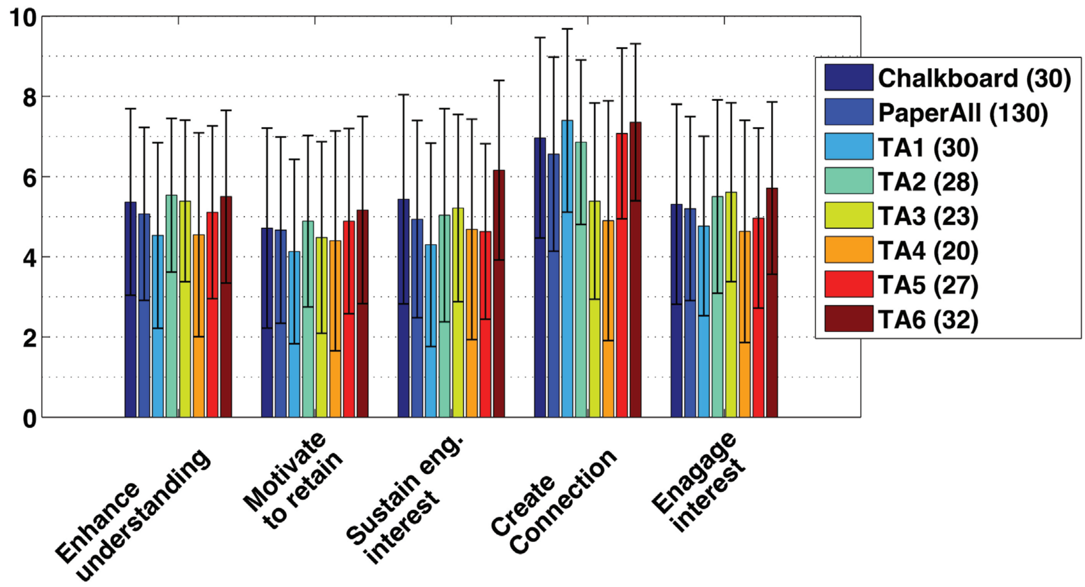


Figure 7. Average numerical response to the end-of-term survey questions. The error bars indicate the standard deviation of the responses for each subset of people. "TA5" is the novice TA and "TA6" is the expert TA. The numbers in the legend are the counts of student responses within each category. Refer to Appendix B for the full version of each question.

working on paper versus students working on the board. For example, from the paper section some more common sentiments include:

- *"Nobody in my group participated. I did most of the problems."*
- *"The group dynamics are turning out to be the same every week, regardless of who I am with. The people who know what's going on speed through it, catching each other's stupid mistakes but leaving the people who have no idea what's going on behind. I have been on both sides of this, depending on the week. I can say it is incredibly frustrating to be left out."*
- *"Sometimes group members were quiet and did not say anything when they were having difficulty."*

and from the chalkboard section:

- *"I liked the fact that we didn't have to write on our papers but instead on the blackboard... It made people more engaged to the group work than trying to finish their own individual work."*
- *"We all worked together to arrive at our answers and used each others' ideas in the process."*

One notable aspect of the open-ended feedback was how often students mentioned a lack of time devoted to the Workshops, regardless of the survey prompt. For example, responding to whether the Workshops engaged their interest, one student wrote, "We never finished any of them, so it's hard to be really interested," and another commented, "Workshops were interesting, but many were a struggle that could not be finished in the time given." For the prompt as to whether the Workshops enhanced understanding of course content, one student responded, "Not enough time most classes to work and thoroughly understand concepts, but had potential to help understand deeper," and another said, "I think they were helpful in learning real life application of the math, but sometimes they were too complicated for the given time and could not be finished." For practically every free response question on the end-of-term survey, at least one student mentioned a lack of time for completion. Under the prompt for suggested improvements dozens of students said the problems should be shorter or more time should be devoted to them.

DISCUSSION

The central hypothesis of this study is that having students work in groups while standing at the chalkboard will increase the interaction within each group and force each student to be more engaged than when groups sit together at tables and solve the same problems on paper. We hypothesized that the increased interaction would lead to more instances of students in the groups helping each other and learning from each other, which in turn should enhance students' understanding of the problems, the mathematics behind them, and the engineering topics.

The first part of the hypothesis was positively borne out as confirmed from observation. In the recorded videos much more interaction is visible (and audible). The TAs who worked both with groups at the chalkboard and with groups working on paper indicated several clear benefits to board work. Some of these benefits are strictly from the point of view of course staff: it's easier for them to keep track of student progress, it's easier for them to see which groups are having trouble, they can keep students on task. But they also noted benefits for the students: the collaboration seemed better, groups could get ideas from other groups' work instead of having to wait for a TA or CA to circulate and help. In their exit interview, the experimental TAs offered several suggestions for improving the Workshops in the future. For example, they recommended forcing students to take turns writing on the board and not allowing a single student to serve as de facto leader of a group. Also, TAs should periodically ask a quiet student to explain everything their group has written on the board, to make sure all students are equally engaged.

The following steps in the hypothesis are supported to some extent by the student surveys. Statistically significant correlation exists between working on the chalkboard and students helping each other, and learning something new. However, the survey data suffers from inconsistent response rates and wide variation within each subset of students. As demonstrated in Figure 4, the differences seen between the expert TA's chalkboard section and paper section are sometimes similar in magnitude to the difference between a non-experimental TA's two paper-based sections. There may be many other factors influencing the student perceptions from section to section – such as time of day, individual personalities, group dynamics, among others – making strong conclusions based only on student responses difficult to reach.

An unanticipated result that is clearly borne out by the survey data is that students find working on the board makes the Workshops seem much more manageable, both in terms of time and difficulty. Apparently working together on the board increases the speed of idea exchange. It's impossible for each person to be sitting quietly, unsure whether everyone else is progressing or stuck. On the board, it's immediately clear whether progress is being made and that helps break down the barriers to asking questions of group members, trying solution methodologies, or seeking outside help if everyone in the group is stuck. The work can proceed much more efficiently when in full view of all participants.

Comparing the effects of the chalkboard innovation between the expert TA and novice TA, another trend emerges. TA experience and skill has an impact not just on the overall value of the Workshops, but on the efficacy of the innovation itself. The TA has many critical roles during these Workshops, including motivating the students to focus on the problems, encouraging and facilitating group interaction, monitoring progress, and in general ensuring successful completion and understanding of the problems. The expert TA reported taking a very active role in classroom management, singling out individual students to report on their group's progress, for example. The novice TA had a more hands-off approach, circulating but not intervening unless called upon. The board work increases the ability of the TA to enact the former methods, but has little influence on the latter.

A final finding of note relates to general implementation of the Workshops. Survey comments revealed cases of TAs, either through lack of skill or lack of interest, failing to provide sufficient time for the Workshops, failing to require group work and interaction, and failing to provide sufficient guidance. For example, whether the TA uses 30 minutes to discuss homework problems (indicating a lack of interest in the Workshop) or takes 10 minutes to get the students organized into groups (indicating a lack of organization and skill in classroom management), the end result is a lack of time for the students to devote to a successful Workshop experience. The integrity of the implementation (requiring students to work in groups, making full and efficient use of the allotted class period, circulating to keep groups on task and making progress) is crucial to the value of the Workshops. Without these basic necessities in place, no innovation can be effective.

CONCLUSIONS

Switching in-class collaborative problem solving activities from group work on paper worksheets to group work on sections of the chalkboard is a simple way to immediately improve the efficiency of the sessions and the student experience. The only requirement is a classroom with sufficient chalkboard (or whiteboard) space to allow the entire class, in groups of four to five, to work at the board simultaneously. If such a room is not available, this may be implemented in a modified way. For example, some students could work on the board while others work at tables, and the groups could be rotated from problem to problem. Another option is mentioned in Howard and Stimpson (2017), where students work on small whiteboards distributed to each table. Collaboration is enforced by only distributing a single marker with each board. If the utility of adequate board space is proven and recognized, then as classroom facilities are updated some weight can be given to prioritizing the inclusion of such space.

Making the switch to groups working on board space can improve the course staff's ability to run the sessions efficiently, keeping everyone on task and progressing through the problems. It increases the ease of collaboration within each group. It makes it easier to keep all students engaged with the problems. Interaction with group members is impossible to avoid, unlike when working on paper. Students experience even difficult problems as more manageable when working at the board.

Undertaking this study also allowed us to see very clearly the importance of maintaining the integrity of the Workshop implementation. Sufficient time must be devoted to problem solving, organizing the class into groups must proceed efficiently, students must be required to collaborate, and course staff must convey the importance and value of these collaborative experiences to ensure that students get maximum benefit. This work is continued in Ritz and Schneider-Bentley (2017), based on the Fall 2016 implementation.

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REFERENCES

Arney, D. C., W. P. Fox, K. B. Mohrmann, J. D. Myers, and R. A. West (1995). Core mathematics at the united states military academy: Leading into the 21st century. *Problems, Resources, and Issues in Mathematics Undergraduate Studies 5*(4), 343–367. http://dx.doi.org/10.1080/10511979508965799

Carr, S. H. 2003. Engineering First at Northwestern University: Where are we in 2003? *Proceedings of the American Society for Engineering Education Annual Conference & Exposition*, June 2003. https://peer.asee.org/12395

Colbeck, C. L., Campbell, S. E. and Bjorklund, S. A. 2000. Grouping in the dark: What college students learn from group projects. *The Journal of Higher Education. 71* (1): 60-83. http://dx.doi.org/10.1080/00221546.2000.11780816

Felder, R. M. and Brent, R. 1996. Navigating the bumpy road to student-centered instruction. *College Teaching. 44* (2): 43-47. http://www4.ncsu.edu/unity/lockers/users/f/felder/public/Papers/Resist.html

Felder, R. M., G. N. Felder and E. J. Dietz. 1998. A Longitudinal Study of Engineering Student Performance and Retention. V. Comparisons with Traditionally-Taught Students. *Journal of Engineering Education*, 87 (4): 469–480. http://www4.ncsu.edu/unity/lockers/users/f/felder/public/Papers/long5.html

Froyd, J. E. and M. W. Ohland. 2005. Integrated Engineering Curricula. *Journal of Engineering Education, 94* (1): 147–164. http://dx.doi.org/10.1002/j.2168-9830.2005.tb00835.x

Graham, T., S. Rowlands, S. Jennings, and J. English (1999). Towards whole-class interactive teaching. *Teaching Mathematics and its applications 18*(2), 50–60. https://doi.org/10.1093/teamat/18.2.50

Hake, R. R. 1998. Interactive Engagement Versus Traditional Methods: A Six–thousand Student Survey of Mechanics Test Data for Physics Courses. *American Journal of Physics, 66*, 64. http://dx.doi.org/10.1119/1.18809

Hansen, E. J. and Stephens, J. A. 2000. The ethics of learner-centered education. *Change, 32* (5): 41–47. http://dx.doi.org/10.1080/00091380009605739

Howard, A. K. T. and M. T. Stimpson (2017). Online-only statics compared to a flipped classroom. In *Paper presented at 2017 ASEE Annual Conference & Exposition*, Columbus, Ohio. ASEE Conferences. https://peer.asee.org/28724

Johnson, D., R. Johnson and K. Smith. 1998a. *Active Learning: Cooperation in the College Classroom,* 2nd ed. Edina, MN: Interaction Book Co.

Johnson, D., R. Johnson and K. Smith. 1998b. Cooperative Learning Returns to College: What Evidence is There That it Works? *Change, 30* (4): 26–35. http://dx.doi.org/10.1080/00091389809602629

Khalid, A., B. Nuhfer-Halten, J. Vandenbussche, D. Colebeck, M. Atiqullah, S. Toson, C. A. Chin, and B. Stutzmann (2011). Effective multidisciplinary active learning techniques for freshmen polytechnic students. *Review of Higher Education & Self-Learning 4*(13).

Olds, B. M. and R. Miller. 2004. The effect of a First-Year Integrated Engineering Curriculum on Graduation Rates and Student Satisfaction: A Longitudinal Study. *Journal of Engineering Education 93* (1): 23-35. http://dx.doi.org/10.1002/j.2168-9830.2004.tb00785.x

Prince, M. 2004. Does Active Learning Work? A Review of the Research. *Journal of Engineering Education, 93* (3). http://dx.doi.org/10.1002/j.2168-9830.2004.tb00809.x

Ritz, H. and L. Schneider-Bentley (2017). Chalkboard vs. paper: Technique for improving collaboration in active learning activities. In *Paper presented at 2017 ASEE Annual Conference & Exposition, Columbus, Ohio*. ASEE Conferences. https://peer.asee.org/28020

Schneider, L., M. Kelley, and S. Baker. Integrating Engineering Applications into First-Year Calculus. *Proceedings of the American Society for Engineering Education, St. Lawrence Section Conference*. University of Toronto. October 2007. https://www.asee.org/documents/sections/st-lawrence/2007/Schneider-2007-Engineering-Applications-in-Calc.pdf

Schneider, L. and M. Terrell. 2010. Applications and Confidence Inventories for Assessing Curricular Change in Introductory Engineering Mathematics Instruction. *Proceedings of the American Society for Engineering Education Annual Conference & Exposition*, June 2010. https://peer.asee.org/16113

Shimazoe, J. and Aldrich, H. 2010. Group work can be gratifying: Understanding and overcoming resistance to cooperative learning. *College Teaching.* 58: 52-57. http://dx.doi.org/10.1080/87567550903418594

Springer, L., M. Stanne and S. Donovan. 1999. Effects of Small-Group Learning on Undergraduates in Science, Mathematics, Engineering and Technology: A Meta-Analysis. *Review of Educational Research, 69* (1): 21-52. http://journals.sagepub.com/doi/abs/10.3102/00346543069001021

Subramanian, P., M. Cates, and B. Gutarts (2009). Improving calculus success rates at California State University Los Angeles. *Mathematics and Computer Education 43* (3), 259.

Terenzini, P., A. Cabrera, C. Colbeck, J. Parente and S. Bjorklund. 2001. Collaborative Learning vs. Lecture/Discussion: Students' Reported Learning Gains. *Journal of Engineering Education, 90*(1): 123–130. http://dx.doi.org/10.1002/j.2168-9830.2001.tb00579.x

Terrell, M., R. Terrell, and L. Schneider. 2010. Assessing Engineering Students' Ability to Use the Mathematics They Have Learned. *Proceedings of the American Society for Engineering Education Annual Conference & Exposition*, June 2010. https://peer.asee.org/16109

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APPENDIX A: INDIVIDUAL WORKSHOP SURVEY QUESTIONS

Questions in the survey students were asked to take online immediately following each Workshop.

- Overall, did you like this workshop?
  - Like
  - Neutral
  - Dislike
- Overall, did this workshop help you better understand how the materials learned in this class can be applied in engineering and the real world?
  - Yes, a lot.
  - Yes, a little.
  - Maybe, but I don't really see it yet.
  - No.
- What did you think of the difficulty of this workshop?
  - Too difficult.
  - Just about right.
  - Too easy.
- What did you think of the length of this workshop?
  - Too long.
  - Just about right.
  - Too short.
- Did you find working in groups on this workshop to be helpful?
  - Yes.
  - Neutral.
  - No.
- Select all that apply.
  - In my group, students were helping each other understand the problem and solution.
  - I learned from students in my group.
  - I helped students in my group learn.
  - Working in my group enhanced my understanding of the problem and solution.
  - I felt left out of my group.
  - The group dynamics were an impediment to learning.
- Please provide any additional comments you have about the group-work aspects of this workshop.

- Did this workshop help you learn something you had not learned before? (e.g. mathematical concepts, applications, different ways of looking at things, etc.)
  - Yes.
  - No.
- Workshops are designed to introduce new concepts that are related to the materials you learn in this class. The problem statements should be self-contained and include all essential information you need to solve the problem. Do you think this workshop assumed unfamiliar knowledge that was not explained nor hinted in the problem statement?
  - Yes.
  - Maybe a little, but I figured it out.
  - No.
- Did your TA seem prepared to facilitate this workshop?
  - Yes.
  - No.
- Did your undergraduate course assistant (CA) seem prepared to facilitate this workshop?
  - Yes.
  - No.
- Did you read the workshop before class?
  - Yes, I read it carefully.
  - Yes, I skimmed through it.
  - No.
- Have you read the solutions for this workshop?
  - Yes, I read the solutions thoroughly.
  - Yes, I checked the solutions of a few problems.
  - No, but I'm planning on reading the solution eventually.
  - No, and I have no plans to read the solutions.
- Please provide any additional comments or suggestions you have about this workshop.

APPENDIX B: END OF TERM SURVEY QUESTIONS

Questions in the survey students were asked to take online at the end of the semester. Almost every one of these questions was followed by a free response field with a prompt such as, "Please explain." Optional demographic questions were also included.

- There were 8 problem-solving workshop sections for MATH 1910 over the course of the semester. How many of these sections did you attend?
- On a scale from 1 to 10, how much did participation in workshop sections enhance your understanding of MATH 1910 content?
- On a scale from 1 to 10, how much did the workshop sections motivate you to learn the math well and retain it?
- On a scale from 1 to 10, how much did the workshop sections help to sustain your interest in engineering?
- On a scale from 1 to 10, how much did the collaborative aspect of the workshop sections help to create a positive sense of teamwork, connection, and cooperation among MATH 1910 students?
- On a scale from 1 to 10, how much did the workshop problems engage your interest?
- Please rate the general level of difficulty of the workshop problems.
    - In general, the workshop problems were too easy. They were not challenging enough to require a group effort to complete.
    - In general, the workshop problems were at an optimum level of difficulty that was challenging for the group without being exceedingly difficult.
    - In general, the workshop problems were too difficult. Groups often became frustrated and were unable to complete the problems through group effort.
    - Unable to generalize across all workshop problems.
- For how many of the workshops did you read the solutions that were posted on Blackboard?
    - None of them.
    - A few of them.
    - Some of them.
    - Most of them.
    - All of them.
- On a scale from 1 to 10, to what extent was the teaching assistant an effective facilitator, i.e., knowledgeable, prepared, and able to provide helpful guidance for the workshops?

- On a scale from 1 to 10, to what extent was the undergraduate course assistant an effective facilitator, i.e., knowledgeable, prepared, and able to provide helpful guidance for the workshops?
- What did you like the most about the problem-solving workshop sections for MATH 1910?
- In what ways could the problem-solving workshop sections for MATH 1910 be improved?

APPENDIX C: CROSS-TABULATIONS

This appendix includes statistical analysis of student responses to questions on the surveys following individual Workshops. Data from Workshops 2, 5, 6, 7, and 8 are included. In all of the following tables, an asterisk (*) indicates a statistically significant difference at $p < 0.01$ (applying the Bonferroni correction to compensate for multiple (five) comparisons on the data set, we are using a statistical significance standard of $p < (0.05/5) = 0.01$).

Table 3. Responses to the prompt, "In my group, students were helping each other understand the problem and solution."

Helping Each Other?	Chalkboard	Paper	Total
No	40	209	249
	17.5%*	**27.9%***	**25.5%**
Yes	189	540	729
	82.5%*	**72.1%***	**74.5%**
Total	229	749	978
	100%	100%	100%

Pearson chi-square: value=10.066; df=1; asymp. sig (2-sided)=0.002

Table 4. Responses to the prompt, "Working in my group enhanced my understanding of the problem and solution."

Enhanced Understanding?	Chalkboard	Paper	Total
No	94	352	446
	41.0%	**47.0%**	**45.6%**
Yes	135	397	532
	59.0%	**53.0%**	**54.4%**
Total	229	749	978
	100%	100%	100%

Pearson chi-square: value=2.501; df=1; asymp. sig (2-sided)=0.114

Table 5. Responses to the question, "Did this workshop help you learn something you had not learned before (e.g. mathematical concepts, applications, different ways of looking at things, etc.?"

Learn Something New?	Chalkboard	Paper	Total
No	72	301	373
	32.0%	**40.7%**	**38.7%**
Yes	153	439	592
	68.0%	**59.3%**	**61.3%**
Total	225	740	965
	100%	100%	100%

Pearson chi-square: value=5.477; df=1; asymp. sig (2-sided)=0.019

Table 6. Responses to the question, "What did you think of the difficulty level of this workshop?"

Difficulty Level?	Chalkboard	Paper	Total
Too Easy	7	16	23
	3.1%	**2.2%**	**2.4%**
Just About Right	199	532	731
	87.7%*	**71.6%***	**75.4%**
Too Difficult	21	195	216
	9.3%*	**26.2%***	**22.3%***
Total	227	743	970
	100%	100%	100%

Pearson chi-square: value=29.138; df=2; asymp. sig (2-sided)=0.000

Table 7. Responses to the question, "What did you think of the length of this workshop?"

Length?	Chalkboard	Paper	Total
Too Short	15	19	34
	6.6%	**2.5%**	**3.5%**
Just About Right	159	405	564
	69.7%*	**54.2%***	**57.8%**
Too Long	54	323	377
	23.7%*	**43.2%***	**38.7%***
Total	228	747	975
	100%	100%	100%

Pearson chi-square: value=32.707; df=2; asymp. sig (2-sided)=0.000