Scaling-up Collaborative Learning for Large Introductory Courses Using Active Learning Spaces, TA training, and Computerized Team Management

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1. Introduction

This evidence-based practice paper focuses on techniques for large-scale implementation of collaborative learning. Collaborative learning is a form of pedagogy that emphasizes the co-construction of knowledge, based on socio-cultural theories of learning. [8, 9, 22, 25] While there are many implementations of this underlying concept, one common approach is to have students work together in small teams on learning activities. [8, 16, 35, 38] When implemented correctly, this has been shown to have positive benefits for student motivation, technical learning outcomes, knowledge transfer, and broader objectives such as the ability to work in multidisciplinary teams. [38]

A key challenge for collaborative learning is how to implement it at a large scale, especially in introductory courses with students and instructors who are not familiar with this mode of education. [14] In this paper, we describe results from an iterative design and implementation process of collaborative learning in the introductory mechanics course sequence at the University of Illinois at Urbana-Champaign (UIUC), where over 1000 students per semester now participate in weekly collaborative learning activities during discussion sections.

Successful collaborative learning at scale is a multifactorial problem, requiring consideration of the learners, the instructors, the design of tasks, the tools used to support interaction, and the environment within which the learning takes place. [23] This paper focuses on three factors that were identified as particularly important at UIUC. First, a new active learning classroom was created that aimed to alter the traditional authority structure of the classroom, and foster greater interactions within teams. Second, a new Teaching Assistant (TA) training experience was implemented that focused on collaborative learning, because TAs are the primary student interface and yet have almost always had no prior experience of collaborative learning in their own education. This training aimed to highlight the importance of collaborative problem solving skills and prepare TAs to implement this form of pedagogy. Third, student team creation and management at a large scale necessitated the use of the automated CATME system, allowing teams to be formed and evaluated even with many hundreds of students and tens of discussion sections.

This paper evaluates the collaborative learning implementation at UIUC in the context of research on learning space design, [1, 2, 34] teacher and TA professional development, [27, 37, 40] and team interaction. [3, 28, 36] Longitudinal survey data and two-sample hypothesis testing are used to describe the impact of collaborative learning and particular implementation decisions on students.

2. The introductory mechanics sequence

The introductory mechanics sequence is comprised of three courses: Introductory Statics, Introductory Dynamics, and Introductory Solid Mechanics. Most students encounter these courses during their sophomore year, enrolling first in Introductory Statics, which is a prerequisite for the other two courses. Students studying in ten different engineering majors are required to complete this sequence, and typical enrollment exceeds 1000 students per semester.

Starting in 2012, the introductory mechanics sequence has been the focus of a concerted redesign effort. [43, 46] This redesign was carried out by a group of faculty working together as a mutually supportive Community of Practice [41, 42, 44] with support from both a college-level program [7] and an NSF program. [18, 17] The critical aspect of these two programs is the centrality of using Communities of Practice as the primary mechanism for brokering change rather than incentives. Communities of Practice provide a supportive environment for faculty to learn how to implement better pedagogies and to develop common vision and values that sustain the use of these pedagogies. [18]

Prior to this redesign, students routinely reported that these courses were their least-favorite courses in the curriculum, and the department faced a constant struggle to persuade faculty to teach the courses. The primary reforms included (1) an active learning discussion section format with a focus on "real-world" applications of the course material; (2) a collaborative learning format in discussion sections based on group work, as described in detail in Section 3; (3) active learning in lectures using classroom response systems; (4) online interactive homework with immediate feedback; and (5) online help forums to largely substitute for in-person office hours. Post-reform, both student satisfaction and faculty engagement have increased substantially. [46] Due to the simultaneous implementation of these reforms, a causal link between any single change and improved student learning outcomes cannot be established. For this reason, this paper focuses on the students' affective outcomes that can be directly tied to the discussion sections.

3. Designing an active learning classroom

The influence of classroom design on learning, and collaborative interactions in particular, has recently been documented in the literature. [2, 10, 24] In the initial implementations of collaborative learning activities in discussion sections, all three introductory mechanics courses were assigned to traditional classrooms, typically with slanted, tablet chairs, where students had to move the chairs around to form groups of three or four members.

Student opinions regarding the space and design of these classrooms were evaluated by paper-based surveys in the Introductory Solid Mechanics course during the Spring 2015 semester. Results are shown in Fig. 5. The results confirmed anecdotal feedback from students and teaching assistants: the classroom was too crowded and the chair arrangement did not facilitate

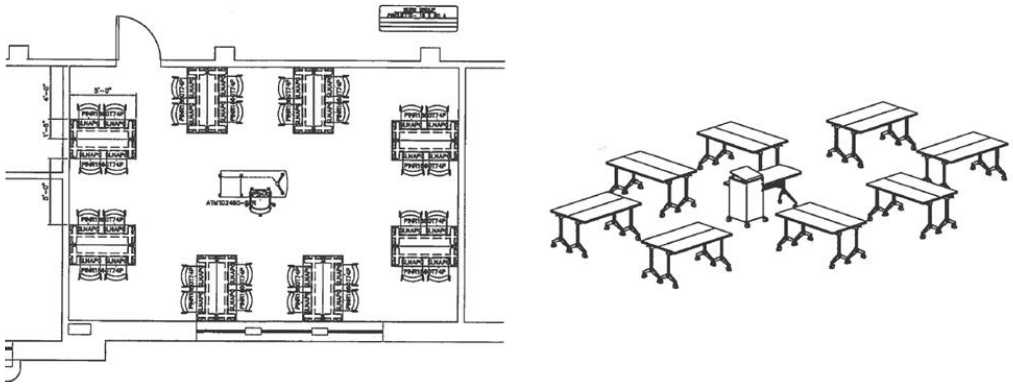

Figure 1: Diagram of classroom layout in active learning configuration.

collaborative learning. [11, 29, 32] To address this issue, a new active/flexible learning classroom was created to host discussion sections for all three introductory mechanics courses.

The initial planning of this active learning classroom began in February 2015. The selection of the furniture was constrained by the available space and the desirable capacity of the classroom (32 students), so that all discussion sections could meet at the same location. Drawing on research that indicates that issues of territoriality limit collaborators' reach when working on groups, [32] and drawing on observations and our own survey data, one large table per group was chosen rather than tablet chairs. In addition, recognizing that the room design can promote traditional classroom authority structures, which need to be altered for successful collaborative learning [6, 24] it was decided that no 'front of room' would exist, and the teacher's podium would be placed in the center of the room. A proposal was submitted to the College of Engineering, and the $20,000 budget was approved in April 2015 for use to re-fit the room in time for the fall semester. The final cost of the room furniture was $16,225.52, including 16 tables, 37 chairs, and one instructor's desk and seat. The furniture allows for two possible layouts for the classroom: collaborative learning (Fig. 1) and traditional lecture style (Fig. 2). The photos in Figs. 3 and 4 show the classroom in use for a discussion section before and after the remodeling.

During the Fall 2015 semester, students in the Introductory Solid Mechanics course responded to

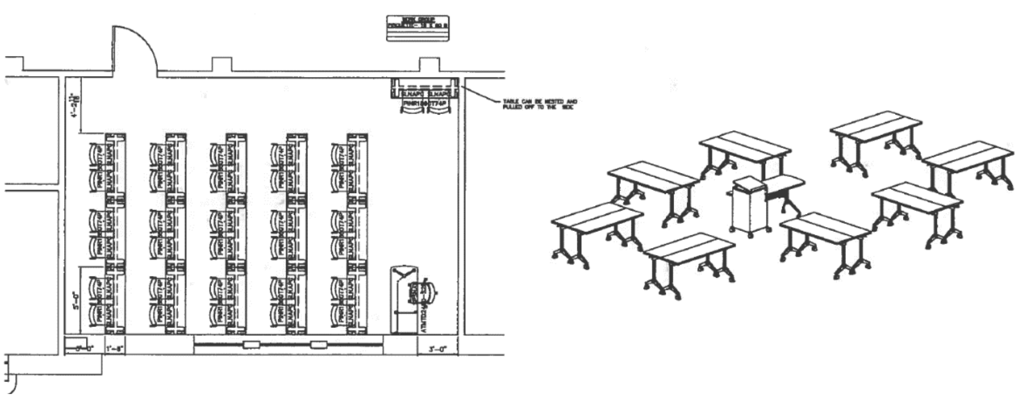

Figure 2: Diagram of classroom layout in traditional lecture-style configuration.

Figure 3: Photo of discussion classroom with older, tablet chairs.

Figure 4: Photo of discussion classroom with new furniture and configuration.

the same paper-based surveys, with the results shown in Fig. 5. By changing the furniture, the classroom became more spacious, allowing teaching assistants to easily move around the tables and hence interact with students more effectively. The change from individual chairs to shared tables created a collaborative environment helping the students to work as a group.

4. Training Teaching Assistants in active learning

Embedding the collaborative problem solving activities within discussion sections provides the opportunities for students to learn in smaller classes; however, it requires a large number of teaching staff to be involved in the courses. In each semester, approximately 40 discussion sections are held each week across the three courses. These courses are predominantly staffed by engineering students. Initially, pairs of graduate students were assigned to each discussion. Currently, discussion sections are staffed by one graduate teaching assistant (TA) paired with one or two undergraduate course assistants (CA). This introduction of undergraduate CAs enables a larger course teaching staff with a perspective that is closer to that of the students taking the class. Across campus, new TAs are required to attend an orientation workshop before the beginning of the year, which addresses a range of topics including legal and privacy issues and the various roles of a TA (office hours, grading, teaching courses). However, TAs receive

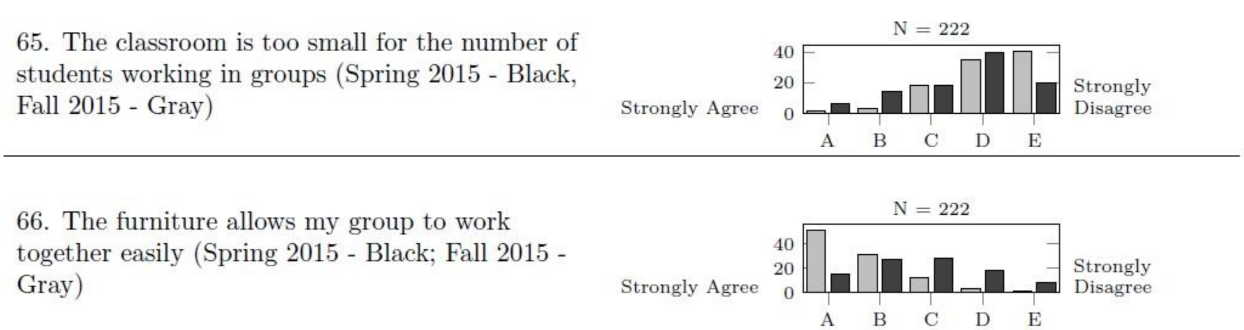

Figure 5: Student survey feedback regarding classroom layout and furniture. Data was collected in Spring 2015 (black), from discussion sections using the tablet desks, and in Fall 2015 (gray), for discussions using the new active learning classroom.

little instruction in the process of teaching and, in particular, how to teach collaborative problem solving activities.

While there is a large amount of research that demonstrates the importance and quality of students' interactions during collaborative problem solving, [4] there is relatively little that describes how a teacher can foster these interactions during collaborative learning activities in their classrooms. [13, 39] Additionally, while trained teachers report concerns and struggles when implementing collaborative learning, [12, 30] there is little evidence to describe the issues encountered by graduate students who are teaching collaborative activities in courses.

For teaching assistants, who are likely developing professional knowledge of teaching while they are engaged in teaching discussion sections, providing on-going learning opportunities throughout the semester of their teaching was proposed as one solution to support their teaching practice. These learning opportunities are needed to provide TAs with opportunities to develop as teachers (pedagogy), and in particular to understand aspects of teaching collaborative problem solving skills. They also needed to ensure TAs were prepared to teach the content, and to help TAs develop pedagogic content knowledge. [33]

For each of the three courses, teaching assistants attend a weekly meeting with the faculty who are teaching the courses. The goals of this meeting are to deal with logistics associated with the course, discuss any issues as they arise, and review the discussion section activity for the coming week.

It was decided try to support TAs in learning pedagogy through an additional weekly graduate-level course that would focus on the pedagogical aspects of their teaching assignments, while they would continue to attend the weekly meeting to address content related issues. This new course focused on topics such as classroom management, and classrooms as learning communities. The course addressed issues related to theories of learning (e.g. constructivism, social constructivism) and concepts such as adaptive expertise, [15, 31] in order to help the TAs understand why collaborative learning activities were being used in these courses, and the different types of learning that they require. Finally, the course focused on issues of how to implement collaborative learning in classrooms [20] and collaborative problem solving skills. [19] In addition to weekly classes, the teaching team conducted observations in many of the discussion sections, using the observations to inform future class topics and provide real examples for the class to discuss. Critically, the additional cost for this course is minimal as the TAs receive course credit rather than pay for this extra time and the course can be taught by a graduate student.

Taking an iterative, design research approach to this course, [5] surveys are collected before and after each semester, and the content is revised as necessary. The TAs response to the course ranges from not seeing the point to becoming deeply engaged and committed to learning more to improve their teaching. There remains a concern about the need to repeat content for new TAs, aligning the pedagogical theory with the current needs of the TAs, and integration with each course specifically, in order to help TAs develop pedagogic content knowledge.

The current iteration of the course is focused more on aligning with the weekly class activities, embedding the pedagogic content within discussion of the TAs plans for the coming week. Future iterations will consider how best to align this with the weekly TA meeting, the development of appropriate content for the discussion activities and the most suitable way to provide TAs with the opportunity to learn content and pedagogic skills, and develop pedagogic content knowledge.

5. Student team creation using CATME

An important aspect of collaborative learning used in the introductory mechanics courses is the formation of groups of three or four students who work together during discussion sections to solve various types of engineering problems. Since the first implementation of collaborative learning activities in discussion sections, groups have been formed week-to-week using a variety of randomization methods, with students working in a new group of students each week. After the Fall 2015 semester, a proposal was made to form permanent groups instead, allowing the same group of students to work together throughout the semester. The instructors in the mechanics sequence had a particular interest in avoiding the isolation of women or racial minorities in engineering classes; anecdotal feedback collected each semester indicated that an isolated student in a group often felt excluded from group activities, or that their contributions were perceived as less valuable. It was also desirable to form groups which combined different levels of performance in past courses, to encourage collaboration between team members.

In order to collect the necessary information from each student in a confidential way, and to properly use that information for group formation, an electronic group-formation software solution was sought out. The CATME Team-Maker software, which was already in use by other groups on campus, was recommended by multiple colleagues at UIUC as a research-based and research-validated system for team formation. [21, 26] CATME is an externally-developed system, initially created for self- and peer-evaluation in a group setting, and has been extended to include tools for student team formation. The Team-Maker system allows for the creation of a survey collecting demographic and personal information about each student in a class, before using this information to form teams with instructor-designed goals such as avoiding the isolation of females or other minorities, to distribute students with similar levels of achievement, or to group students from a common engineering major to provide common interest. Because of its development maturity and research-based approach, the CATME system was selected for permanent group formation.

During the Spring 2015 semester, students in the Introductory Dynamics course were assigned to permanent groups using the CATME system, while students in the Introductory Solid Mechanics course continued in using week-to-week random assignment of groups. It is worth noting that many students take these courses in the same semester, and experienced both types of group assignment simultaneously. At approximately the midpoint of the semester, students responded to paper-based surveys which included three questions about group dynamics. The results of these surveys in each class are show in Fig. 6. Notably, students who were assigned to permanent groups were found that it was easier to communicate with students in their groups, and were more likely to have made friends with students in their discussion section. The comparison of the two systems shows that students felt they liked working with the same group more strongly than they preferred working in random groups. As a result of this data, it was decided that all three courses in the mechanics sequence would move to the assignment of permanent discussion groups, rather than week-to-week randomization of group members, beginning in Fall 2015.

6. Impact and sustainability

As was noted in Section 2, the changes described in this paper have been implemented simultaneously in the mechanics sequence, so no direct causal link between these efforts and improved student learning outcomes can be demonstrated at this time. For this reason, we focus our discussion of the impact of these changes on student and faculty affective outcomes. It is worth noting that these changes are supported by existing education literature, so we expect to see long-term improvements in student learning and assessment results. It is worth noting that the improvements already seen in student satisfaction have come without any loss in assessment success, which is a non-trivial result in its own right.

In addition to the positive student responses demonstrated by our student survey data, these changes have had a positive impact on faculty satisfaction with the mechanics sequence, and interest in teaching one of the mechanics sequence courses has grown. The number of faculty requesting a teaching assignment in the three mechanics courses approximately doubled, from an

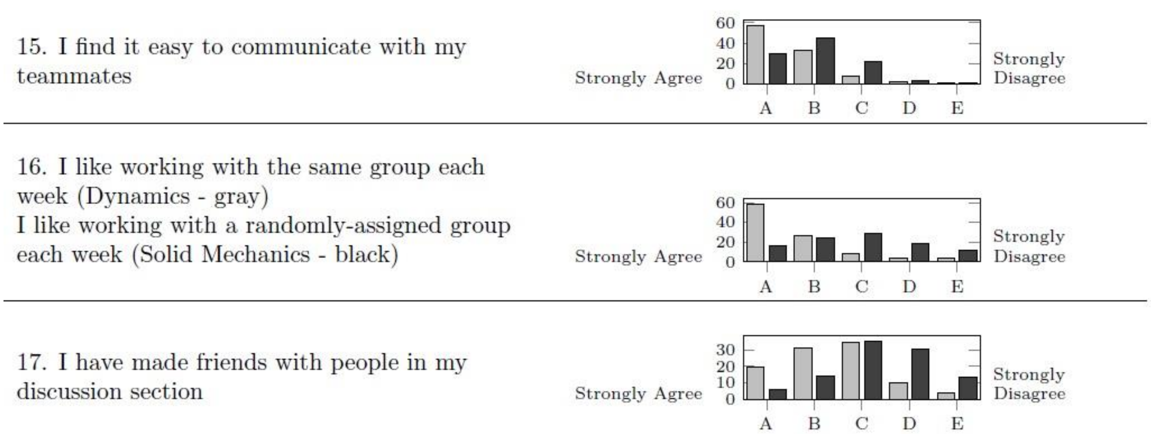

Figure 6: Student survey feedback regarding classroom layout and furniture. Data was collected in Spring 2015 from two different courses using different group assignment strategies. Introductory Solid Mechanics (black) used random group assignments each week, while Introductory Dynamics (gray) used permanent assignments created with the CATME system.

average of 7 requests per semester in 2012 and 2013 to over 16 requests per semester after 2014. This interest extends to active participation in weekly meetings to discuss course pedagogy and continued improvements, as well as participating in teaching observations and feedback sessions. The ongoing work is also supported by faculty from the College of Education, who are active in developing the content presented in the TA training course. These improvements have also attracted the attention of other faculty within the College of Engineering; groups of instructors in three different departments are in preparation to implement the changes described here in their own introductory course sequences, beginning in the Fall 2016 semester.

These improvements to the mechanics sequence have also proven to be sustainable over multiple semesters. The renovations made to the active learning classroom represent a one-time expense and will require little to no additional expenditure to maintain the room. Similarly, the CATME tool for group formation is provided online without charge, so the use of this software in future semesters does not require funding.

The principal recurring expense related to these changes lies in the ongoing TA training course. The costs associated with such training can be divided between 1) the use of TA hours in training and preparation for collaborative learning, and 2) the funding needed to develop and teach this training course. Rather than require increased work hours from the TAs to accommodate this training course, efforts are proceeding instead to reduce TA workload in other areas of the course. Ongoing efforts to this end include the use of undergraduate Course Assistants to support TA work during discussion sections, and expanded use of online homework and testing systems [45] to focus TA time and effort on training for collaborative learning and direct student interaction. Our collaboration with faculty from the College of Education includes a graduate student who leads the TA training as an instructor (with faculty support). This mutually beneficial arrangement allows for the graduate student instructor to develop expertise in teaching instructors to teach collaborative learning and prepare for a future faculty career in education, while the use of a graduate TA to lead this class provides a significant cost reduction compared to a faculty instructor for the College of Engineering.

7. Conclusions and future work

This paper has described the implementation of large-scale collaborative learning across multiple courses at the University of Illinois at Urbana-Champaign. Based on student feedback, we believe that student satisfaction with the discussion sections has improved in these courses. Based on existing education literature, we also believe that the nature of the collaborative learning activities will result in greater long-term learning and the development of problem solving skills, which while highly necessary in the students’ future careers are not easily assessed through current end-of-semester exams.

We continue in our efforts to develop training for course staff, particularly graduate Teaching Assistants, to better facilitate discussion sections. As discussed in Section 4, two challenges remain in developing TA competencies around teaching in a collaborative learning environment. First, TA response to the training course remains mixed, with some TAs responding positively to the new teaching style while others are disinterested. Second, as new TAs are assigned to courses in the mechanics sequence each semester, the variation in experience and exposure of TAs to pedagogic skill, classroom experience, and course content remains high. Continued iteration on the design of this training course is needed to further improve on these courses. We also continue our efforts to reduce the TA workload in other teaching-related tasks through the introduction of undergraduate course assistants and the use of electronic homework and testing systems, in order to focus TA time and effort on direct student interaction and training for these interactions.

8. Acknowledgements

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