A Tiered Mentoring Model for Deepening Student Learning Across Undergraduate and Graduate Design Courses

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Abstract

The authors are experimenting with implementation of a tiered mentoring model across undergraduate and graduate-level concurrently-taught design courses.

The undergraduate course is a senior-level design course in which students learn the fundamentals of designing steel structures. It is structured around an authentic semester-long team-based design project in which student design teams develop the structural plans for a real building based on an architectural concept. A series of intermediate project deliverables are sequenced throughout the semester to ensure that the undergraduate students receive ample feedback and scaffolding to develop meaningful design solutions. Upon project completion, student teams present final designs to a panel of practicing engineers who provide feedback and evaluation on their designs.

The graduate course parallels much of the undergraduate course, but delves more in the realms of theory and advanced applications. While it is a design course, the class has historically relied on discrete assigned problems to provide students the occasion to gain design experiences, rather than engaging with a project.

The instructors of both courses share a goal of desiring to deepen student learning, which would be evidenced by improved sophistication in the course deliverables. To accomplish this shared goal, the authors hypothesized that by developing a tiered mentoring model that engages both the undergraduate and graduate students, student learning outcomes in both courses could be better achieved.

To test their hypothesis, the authors began by mapping student learning outcomes to the respective course deliverables (i.e., final project submissions in the undergraduate course) which would later be assessed and compared against student performance from a prior semester. Next, the authors devised a plan in which students in the graduate-level course would be embedded into the undergraduate course as graduate mentors. The class sizes were such that this resulted in approximately one graduate student being embedded into each design team of five undergraduate students each week. The graduate students were responsible for serving as an external review checkpoint for the undergraduate students before the latter submitted each of the intermediate project deliverables, and were graded in part on the quality of their feedback to the undergraduate students.

Measured differences in student learning outcomes are presented and discussed. Methods and recommendations for generalizing the approach taken by the authors to other course pairs and sequences are presented.

Introduction

This paper describes a tiered peer mentoring model implemented at the University of Kansas in Fall 2016 that relied on participation of all students in two civil engineering courses: a graduate course in steel design, and an undergraduate course in steel design. The graduate course was CE

765 *Advanced Steel Design: Buildings* (3 cr), and the undergraduate course was CE 562 *Design of Steel Structures* (3 cr). Both the instructor of the graduate course and the undergraduate steel course approached the semester with a goal of deepening student learning. To accomplish this shared goal, the authors hypothesized that by developing a tiered mentoring model that engages both the undergraduate and graduate students, student learning outcomes in both courses could be better achieved.

The undergraduate course is a senior-level design course in which students learn the fundamentals of designing steel structures. It is structured around an authentic semester-long team-based design project in which student teams develop the structural plans for a real building based on an architectural concept. A series of intermediate project deliverables are sequenced throughout the semester to ensure that the undergraduate students receive ample feedback and scaffolding to develop meaningful design solutions. Upon project completion, student teams present their final designs to a panel of practicing engineers who provide feedback and evaluation on their designs.

In Fall 2016, 47 students, divided into ten design teams, were enrolled in CE 562. Structurally, the undergraduate steel design course consists of a 'lecture' period (3 hrs/week) and a 'lab' component (2.5 hrs/week). The 'lecture' component of the course is primarily focused on developing student understanding of steel member resistances, while the 'lab' component focuses primarily on building student understanding of loads (i.e., gravity, wind, snow, etc.) and building system behavior. In Fall 2016, the course was taught using a mixture of lecture, led example problems, and in-class problem-solving performed within student teams; a similar structure was reflected in both the 'lecture' and 'lab' components of the course.

CE 562 has been the focus of careful course redesign in recent years. Learning objectives have been mapped to assignments, exams, and the design project. In particular, the CE 562 instructors have shared a desire to coach students to produce project deliverables that better mimic actual engineering design artifacts, including:

- Structural drawings that incorporate detail, clarity, and sophistication, and
- Design reports with increased focus on "big-picture" structural performance, and improved understanding of how various design pieces synthesize together

The content of the graduate course (CE 765) parallels much of the undergraduate course content, but has greater focus on theory and advanced applications. While it is a design course, the class has historically relied on discrete assigned problems to provide students with the occasion to gain design experiences, rather than engaging with a design project. Nine graduate students were enrolled in CE 765 in Fall 2016. The CE 765 instructors have desired to provide the graduate students with more authentic design experiences to provide greater context for their learning and theoretical understanding of steel building behavior, and considered engagement with the CE 562 students as an opportunity to achieve this goal.

Background

Peer Mentoring, in a variety of forms, has been shown to improve learning, retention, and identity development for students (Collings, et al. 2014; McCavit and Zellner 2016; Gafney and Varma-

Nelson 2008; Talbot, et al. 2015; Van Dusen, et al. 2015; Otero, et al. 2010). Three primary models of peer mentoring in higher education are prevalent in the literature: first-year mentoring projects, Peer-led Team Learning (PLTL), and the Learning Assistant (LA) model. First-year mentoring projects refer to academic and social mentoring for first-year university students by older students. A significant part of the mentoring is non-academic and focuses on assisting students in making their transition to the university and establish their identity. PLTL refers to an NSF-funded, national initiative where peer leaders work with small groups (6-8) of students outside of class using instructor-provided materials in weekly meetings (Gafney and Varma-Nelson 2008). The LA Model refers to peer mentoring primarily used during active learning in the classroom, and includes instruction on pedagogy for the mentors (Otero, et al. 2010).

Peer mentoring has been shown to improve learning outcomes and retention for mentees. Many studies have documented quantitative evidence of improvement in student learning after the implementation of a peer mentoring program (Pascarella and Terenzini, 2005). A large study investigating the effects of a PLTL program across 16 universities found that the percentage of students scoring an A, B, or C in a course increased by up to 20% compared to a non-PLTL implementation of the same course (Gafney and Varma-Nelson, 2008). In one of the 16 universities studied, standardized test scores (American Chemical Society Organic Chemistry standardized exams) improved from the 36-43 percentile nationally prior to the use of PLTL to the 83 percentile nationally after the introduction of PLTL (Gafney and Varma-Nelson 2008). In the LA model context, significant improvements in learning gains have been documented across science disciplines. Significantly larger learning gains for students in courses with LA support compared to without have been observed in biology, physics, and chemistry (Van Dusen, et al. 2015; Talbot, et al. 2015; Otero, et al. 2010). For example, normalized learning gains of 0.44 based on a pre-post physics concept inventory in physics courses taught with LA support were realized at the University of Colorado-Boulder, compared to the national average of learning gains in traditionally taught courses of the same topic of 0.15-0.3 (Otero, et al. 2010). These learning gains persisted into the downstream course, where students who were in the sections of Physics I with LA support scored higher in Physics II.

In addition to outcomes evidence, student surveys have revealed the significant impact of peer mentoring programs on students (Gafney and Varma-Nelson 2008; Talbot, et al. 2015). In a large study of PLTL, 70% of students agreed that "workshops are improving my grade," and students indicated workshops were beneficial to their understanding of the content, their confidence, their ability to work in groups, their problem-solving ability, and leadership capability (Gafney and Varma-Nelson, 2008). Surveys revealed that the majority of students working with LAs agreed that LAs helped them learn and increased their satisfaction with the course (Talbot, et al. 2015).

However, learning and attitudinal gains are even greater for those serving as mentors, and these gains persist beyond the time served as a mentor (Otero, et al. 2010; Amaral and Vala 2009). Some of the same studies mentioned above that identified significant learning gains for mentees also found even greater learning gains for mentors. For instance, the study in Physics at Colorado (Otero, et al. 2010) demonstrated that LAs showed higher normalized learning gains than the mentees. In the downstream course (Physics II), those who had served as LAs scored even higher than those who had been students in a course with LAs (Otero, et al. 2010). In a compelling study on the use of PLTL in Chemistry, Amaral and Vala investigated the achievement gains of mentors by looking at grades in downstream courses and retention of mentors in these courses, compared

to students who did not serve as mentors (Amaral and Vala 2009). They studied three groups: 1) students deemed prepared for the first semester general chemistry course and not required to take a remedial course, 2) students who were deemed unprepared and who took the remedial course but did not serve as mentors, and 3) students who were deemed unprepared, took the remedial course, and then served as mentors. The results are striking. Students who came into the program less prepared but then served as mentors went on to have higher grades in the general chemistry course *and* the subsequent chemistry course than *either* of the groups- even the students who were deemed more prepared at the onset. In addition, these students went on to take more chemistry courses than either group.

In the Amaral and Vala study (2009) it is important to note that mentors had to have earned a C or better in the *remedial* chemistry course- so the mentors were not only the highest achieving students, and that these students went on to outperform the students who were higher-achieving at admission. In addition, 75% of the mentors were minorities or female, showing strong support for the implementation of these types of programs for the retention of minority and female students in STEM.

In addition to learning gains, the experience of mentoring has many benefits in the development of professional soft skills and interpersonal growth (Miller, 2004; Terrion and Leonard, 2007; Seymour and Hewitt 1997). In a study of long-term effects of mentoring in a PLTL setting in Chemistry (Gafney and Varma-Nelson), more than 90% indicated that acting as a peer leader resulted in confidence in presenting and working in teams that was useful later on. Additionally, in response to open-ended questions (not prompted), more than 40% said that their experience provided a more thorough knowledge of the discipline, made them better problem solvers, and enhanced their skills in working with others. In a PLTL study in computer science (Hug et al. 2014), more than 80% of respondents indicated that their experience improved oral communication, leadership, interpersonal, and decision-making skills. Research also reveals that students who participate in peer mentoring, particularly as mentors, experience interpersonal growth as peer mentoring is positively linked to higher levels of self-satisfaction, communication and social skills (Seymour & Hewitt, 1997).

Based on the literature surrounding peer mentoring, there is a strong case to be made that additional learning gains can be achieved by developing a peer-mentoring structure between a graduate and an undergraduate course in a similar content area. The instructors hypothesized that by developing a tiered mentoring model that engages both the undergraduate and graduate students, student learning outcomes in both CE 562 and CE 765 could be better achieved. The tiered mentoring plan and implementation is described in the following section.

Tiered Mentoring Implementation

To test their hypothesis that implementation of a tiered peer mentoring program across two steel design classes would improve learning outcome achievement, the authors devised a plan in which students in the graduate-level course would be embedded into the undergraduate course as graduate mentors, represented by the sketch in Figure 1. The graduate students were assigned a consulting rotation, such that they would each meet with the CE 562 design teams 10 times across the second

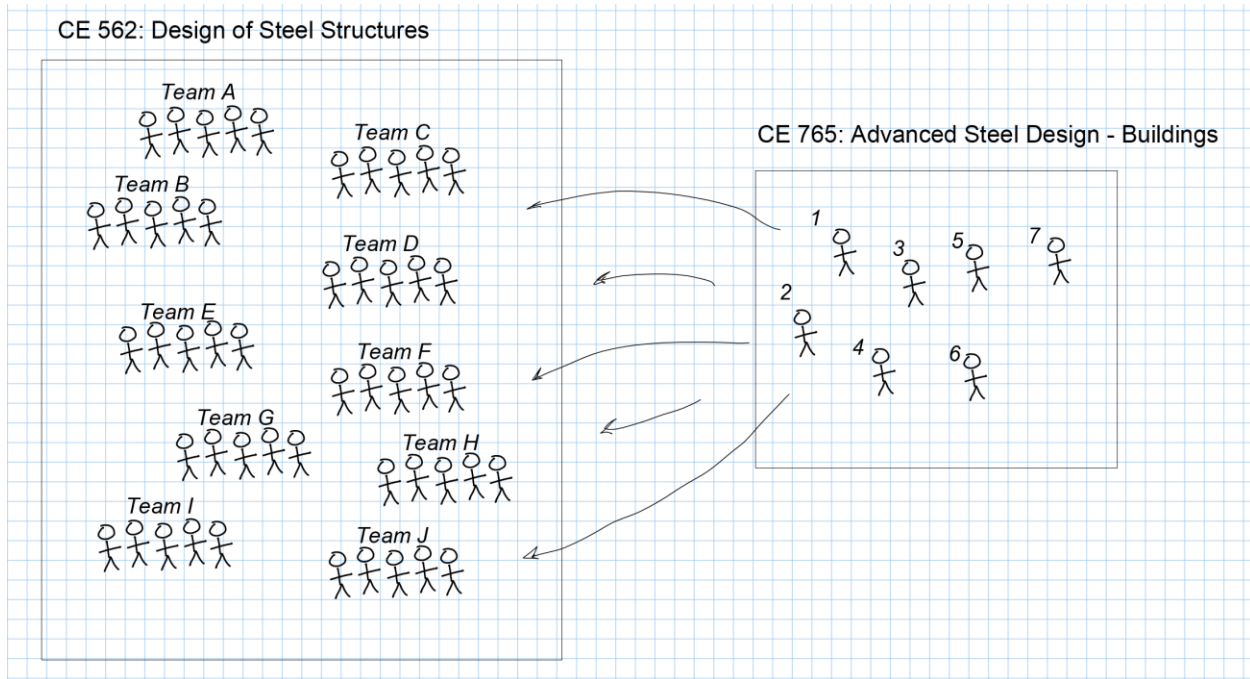half of the semester. Each consulting occasion was intended to be approximately a one-hour duration.

Figure 1. Schematic Showing Tiered Mentoring Assignments

The CE 765 consultants were provided with the following guidance in written documentation: *"The CE 765 consultants are not intended to fulfil the role of GTAs for CE 562. Therefore, logistical project-related questions should still be directed to the CE 562 GTA. The CE 765 consultants are expected to provide regular external reviews, and can help provide project development guidance. Additionally, the consultants are not to perform design calculations or create drawings for the CE 562 students, but to provide review and feedback on those types of materials produced by the CE 562 students."*

The two class sizes were such that this resulted in approximately one graduate student being embedded into each design team of five undergraduate students per week of class, although in each week three consultants met with two CE 562 project teams. The graduate students consulting assignments were made as shown in Table 1.

Table 1. Tiered Mentoring Graduate Student Consulting Assignments

CE 562 DESIGN TEAM	CE 765 Graduate Student (GS) Consultant						
	Week of 10/24	Week of 10/31	Week of 11/7	Week of 11/14	Week of 11/21	Week of 11/28	Week of 12/5
Team A	GS 1	GS 4	GS 7	GS 3	GS 6	GS 2	GS 5
Team B	GS 2	GS 5	GS 1	GS 4	GS 7	GS 3	GS 6
Team C	GS 3	GS 6	GS 2	GS 5	GS 1	GS 4	GS 7
Team D	GS 4	GS 7	GS 3	GS 6	GS 2	GS 5	GS 1
Team E	GS 5	GS 1	GS 4	GS 7	GS 3	GS 6	GS 2
Team F	GS 6	GS 2	GS 5	GS 1	GS 4	GS 7	GS 3
Team G	GS 7	GS 3	GS 6	GS 2	GS 5	GS 1	GS 4
Team H	GS 1	GS 4	GS 7	GS 3	GS 6	GS 2	GS 5
Team I	GS 2	GS 5	GS 1	GS 4	GS 7	GS 3	GS 6
Team J	GS 3	GS 6	GS 2	GS 5	GS 1	GS 4	GS 7

The graduate students were responsible for serving as an external review checkpoint for the undergraduate students before the latter submitted each of the intermediate project deliverables, and were graded in part on the quality of their feedback to the undergraduate students, as judged by the undergraduate students. Therefore, for each consulting occasion, two deliverables were required, one from the graduate student and one from the undergraduate design team:

- The consultant was required to submit a timecard signed by the undergraduate student team, including a description of the consulting feedback / input provided (Figure 2a), and
- The Project Manager of the undergraduate design team was required to submit an evaluation of the consulting experience (Figure 2b).

Figure 2. a) Graduate Consultant Timecard and b) Design Team Mentor Evaluation

Documentation from the CE 562 and CE 765 students was collected throughout the semester, and was used during end-of-semester grade determination for CE 765 students.

In addition to the graduate-undergraduate tiered mentoring, an additional level of mentoring was added to the undergraduate project. Practicing engineers serving as project panel members met with design teams for a mid-project meeting. Design teams presented to the panel completed load calculations, conceptual framing layout and rationale, and plans for project completion. Panel members were able to provide feedback and offer suggestions to design teams. This additional mentoring from practicing engineers represented a change from previous iterations of CE 562, where the panel only interacted with students during final presentations.

Results and Discussion

The student reporting forms (from both CE 562 and CE 765 students) were examined when gauging the effectiveness of the tiered peer mentoring program, and CE 562 project deliverables were also closely examined to compare student performance on the project to performance from previous semesters.

Findings from Student Reporting Forms

The student reporting forms (both those submitted by CE 765 mentors and those submitted by CE 562 students) provided insight into both the content of the mentoring discussions, as well as the quality of the mentoring interactions. The CE 562 reporting forms, which were used in grade determinations for the CE 765 students, were overwhelmingly positive. It was apparent from the

CE 562 evaluations of the CE 765 mentors that the undergraduate students highly valued the contributions that the mentors were making in their meetings. A frequent comment made by the CE 562 students was how the CE 765 graduate students had gone above and beyond to find external resources to aid their work and understanding. This turned out to be a very interesting component of this inquiry, and was further explained by a review of the CE 765 mentor-reported summary of consulting activities.

Mentors consistently reported helping with such topics as:

- Assisting undergraduate students with structural analysis software, such as RISA or SAP;
- Aiding in design of bracing systems for the building;
- Roof truss systems;
- Layout of a floor system;
- Modeling steel connections using structural analysis software; helping students make appropriate modeling assumptions and approaches;
- Determination of building loads using the ASCE 7 Specifications;
- Providing advice on making a professional presentation;
- Constructability; and
- Column and beam design

This list of topics that the CE 765 students were highly engaged in was surprising. Many of the activities in the reporting forms showed content coverage that often was outside the scope of content in CE 765. The authors had expected more of the consulting occasions to be centered around topics for which the graduate students which were already well-situated to serve as coaches, such as designing structural member and connections, or helping coach the undergraduate students through the "why" or theoretical questions behind their design challenges. Instead, the graduate students were often pushed outside their comfort zones to help the CE 562 students with topics that often fell outside of the direct CE 765 course content. Many of the graduate students made significant efforts outside of their consulting occasions in gathering information and generating resources to assist the undergraduate students. This outcome turned out to be one of the most important benefits to the graduate student mentors -- that their content mastery was "pushed" outside the confines of classroom topics.

Design Project Evaluation

To evaluate learning outcomes of CE 562 students, project results were compared with those from the previous year. The CE 562 course in Fall 2015 (comparison group) was nearly identical to the class of Fall 2016. There were 53 students enrolled in the course in Spring 2015, and both groups were divided into ten design teams. The instructor for the course was the same, as were the course materials and teaching practices. Although the building chosen for the projects were different, they were similar in both scale and complexity, and project deliverables were the same. Due to the mid-project panel meeting introduced in 2016, the Fall 2016 project schedule was slightly more structured than the comparison group from Fall 2015.

The projects were graded based on the same extensive rubric in 2015 and in 2016. The rubric was divided into eight different categories as shown in Table 2. Each major category was sub-divided

into various subcategories, with designated points for each subcategory. In total, the rubric contained 66 individual subcategories, each representing a certain aspect of the design project. Points possible for each of the eight major categories is presented in Table 2, with the entire project worth 327 points. Student learning outcomes were assessed based on the final three categories, as they represented almost 90 percent of the project as well as the majority of the technical content.

Statistical analysis was performed to compare overall project score and scores in the 8 major subcategories across semesters. The Shapiro-Wilk test was used to determine normality of distribution. The overall project scores were normally distributed, so an independent samples t-test was used to compare across semesters. Since the scores in the 8 subcategories were not normally distributed a non-parametric test (Mann-Whitney U test) was used to compare each category across semesters. Due to the preliminary nature of this work, a correction for multiple comparisons was not used.

Table 2. Design Project Rubric Categories and Possible Points

Category	Topic	Points Possible
i.	Submittal 1	10
ii.	Submittal 2	5
iii.	Submittal 3	5
1	Cover Letter	9
2	Billing Letter (Invoice)	9
3	Design Report	191
4	Drawings	48
5	Presentation	50

It was found that the average overall project score improved 5.4 percent, increasing from 85.4 (279 points) in the Fall 2015 control group to 90.8 (297 points) in Fall 2016, and this difference was statistically significant (p = .001). Unsurprisingly, the majority of this increase came from the Design Report category, which accounted for 4.6 percentage points of the total 5.4 percent increase. However, Fall 2016 scores for the Drawings and Presentation categories did not change significantly from those of the comparison group, with average point totals within a single point for each of the two student groups. Average design group point totals for the Design Report, Drawings, and Presentation categories of the project are presented in Table 3.

Table 3. Average Design Team Point Totals for Controlling Categories

Category	Topic	Fall 2015 Average	Fall 2016 Average
3	Design Report	161.8	177.0

4	Drawings	40.7	41.0
5	Presentation	41.6	41.7

To identify specific tasks where design teams were able to improve performance, scores for each subcategory within the Design Report were examined. Between the two groups, the difference in point total for a given subcategory was calculated as a percentage of the points available in that subcategory. This allowed for a comparison between subcategories of varying possible point totals. When examined in this way, eight subcategories indicated improved student learning with a ten percent or more score increase over the comparison group. In three out of eight subcategories, the difference in scores was statistically significant ($p < .05$). A negative trend of more than ten percent was observed in one subcategory. These subcategories and their corresponding performance changes are presented in Table 4 (* indicates $p < .05$).

Table 4. Sub-Category Change in Performance

Category	Topic	% Change in Performance between Fa 2015 and Fa 2016
3.4.7*	Brace Loading and Distribution	26.0
3.4.8	Lateral Deflection	15.0
3.4.9	Floor and Deck Selection/Design	10.0
3.4.10	Joist Selection/Design	17.0
3.4.12*	Fill Beam Design	31.0
3.4.13*	Girder Design	15.0
3.4.17	Beam/Girder to Column Web Shear Connections	15.0
3.4.18	Column Base Plates	-13.3
3.5.1.8	Discussion of Connection Design and Economy	26.7

Examining the topics listed in Table 4, it is apparent design teams displayed improved performance in a few broad topic areas: lateral force resisting system design and analysis (3.4.7 and 3.4.8), floor system layout and design (3.4.9, 3.4.10, 3.4.12, and 3.4.13), and connection design (3.4.18 and 3.5.1.8). Each of these improved topic areas correlated directly with student feedback regarding topics consistently discussed during mentoring meetings, indicating a positive impact of the applied tiered mentoring model. Interestingly, the topic area for which a negative change in performance was observed, column base plates, was not mentioned in any of the mentor reports.

Conclusions and Future Work

A tiered mentoring program was developed which connected graduate students with undergraduate students with the goal of providing guidance and feedback on a semester-long design project. Success of the program was evaluated based on changes in undergraduate student learning outcomes and self-reported feedback from the graduate students. Undergraduate student learning outcomes were measured through analysis of an extensive grading rubric evaluating the design project in eight categories. Project scores were compared with those from a control group that did not use a tiered mentoring model.

Graduate mentors self-reported the tiered mentoring program to have a positive impact on their learning, particularly with respect to topics not focused on in class. To effectively mentor the undergraduate design teams, mentors were required to learn new topics and prepare additional material to present in meetings. This pushed the graduate student mentors to learn more than what was specifically required for the course, expanding their content mastery beyond the level they would have experienced had they not been involved in the tiered mentoring program.

Comparing design team scores with those of the control group, it was shown that average performance improved by over five percent. The majority of the improvement came from the Design Report section of the project, with eight specific sub-category topics accounting for a large portion of the improved scoring. There was a direct correlation between the categories where improvement was measured and topics specifically covered in mentoring meetings. This indicates that the tiered mentoring model had a direct and positive impact on undergraduate student learning outcomes.

As the tiered mentoring program appears to have been successful in improving learning outcomes for the undergraduate students and expanding content mastery for the graduate students, the authors anticipate the program will be continued in future semesters. In future iterations of the model, changes will be made to allow for more quantitative evaluation of mentor outcomes. As there was no equivalent CE 765 comparison group as existed for the CE 562 course, evaluation of graduate student learning outcomes relied on the anecdotal evidence of student reporting forms. A more developed evaluation plan will allow for the quantification of tiered mentoring impact for both mentors and mentees participating in the program. More broadly, such future work will help establish to what extent the peer mentoring benefits also extend to the mentors.

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