Shared Capstone Project Mentoring for Improved Learning

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Kevin Sutterer is Professor and Department Head of Civil Engineering at Rose-Hulman Institute of Technology in Terre Haute, Indiana. He received BS and MS degrees in Civil Engineering at University of Missouri-Rolla, a second MS in Civil Engineering at Purdue University, and a Ph.D. from Georgia Institute of Technology. Although his specialization is geotechnical engineering, he has consulted in environmental and structural engineering as well and currently teaches courses in geotechnical and structural engineering. Kevin was a geotechnical consultant with Soil Consultants, Inc. of St. Peters, Missouri from 1984-1988. He also served as Director of Engineering Services for SCI Environmental of Chesterfield, Missouri from 1988-89 before leaving practice to pursue his Ph.D. Kevin was an Assistant Professor at University of Kentucky from 1993-1998, and has been a faculty at Rose-Hulman since then. Kevin has served the Civil Engineering Division of ASEE for over 10 years and was Division Chair in 2010-11. He has also served on numerous ASCE committees. In addition to receiving numerous teaching awards over the years, he was selected by Kentucky Society of Professional Engineering and National Society of Professional Engineers as their 1996 Young Engineer of the Year.

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Dr. Aidoo is currently an Associate Professor of Civil Engineering Department at Rose-Hulman Institute Technology. Prior to this appointment, he worked as the Bridge Design Engineer at South Carolina Department of Transportation. He received a B.Sc. from the University of Science & Technology in Ghana in 1997 and a M.Sc. and Ph.D. from the University of South Carolina. His research activities include repair and strengthening of buildings and bridges using Advanced Composite Materials, laboratory and field testing of structures and the fatigue behavior of concrete bridges.

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Dr. Chapman has a PhD in transportation systems engineering with a focus on traffic safety and human factors from the University of Wisconsin - Madison, where he also earned his JD. Dr. Chapman earned his bachelors degree in civil engineering from Marquette University and his master of science in civil engineering degree from the University of Illinois at Urbana-Champaign. He then worked in industry as a transportation engineer and intelligent transportation systems analyst for several years before returning to school for his joint doctoral studies.

Prof. James H. Hanson P.E., Rose-Hulman Institute of Technology

Dr. James Hanson is a Professor of Civil Engineering at the Rose-Hulman Institute of Technology and the Roland E. Hutchins Endowed Chair. His teaching emphasis is structural analysis and design. Over the last twelve years he has conducted research on teaching students how to evaluate the reasonableness of their results. He is the recipient of several best paper awards and teaching awards including the American Concrete Institute's Young Member Award for Professional Achievement in 2006 and the Walter P. Moore Jr. Faculty Award in 2007. He also received the Ferdinand P. Beer & E. Russell Johnston, Jr., Outstanding New Mechanics Educator Award from the Mechanics Division of ASEE in 2006.

Professor Hanson brings four years of military and industry experience to the classroom. Upon completing his Ph.D. in structural engineering at Cornell University, he taught for two years at Bucknell University. He is a registered Professional Engineer.

Dr. Kyle Kershaw P.E., Rose-Hulman Institute of Technology

Dr. Kyle Kershaw is an Assistant Professor in the Department of Civil Engineering at Rose-Hulman Institute of Technology. Kyle's primary teaching duties include courses in geotechnical engineering and construction materials. His research interests include behavior and monitoring of in-place foundations and retaining structures. In addition to his teaching and research duties, Kyle is involved in geotechnical consulting and Engineers Without Borders.

Dr. Matthew D. Lovell, Rose-Hulman Institute of Technology

Dr. Matthew Lovell obtained his Masters and Ph.D. in Civil Engineering from Purdue University. During his time at Purdue, Matt worked at Bowen Lab gaining experience in large scale experimentation and field instrumentation of structures. He also has experience working as a consultant for a bridge design firm and as the Site Operations Engineer for the Network for Earthquake Engineering Simulation (NEES). Since 2011, Matt has served as an Assistant Professor of Civil Engineering at Rose-Hulman. Dr. Lovell engages his students in undergraduate research experiences and focuses on infusing creative design and structured problem solving in undergraduate engineering courses. He is also an active member of the American Society for Engineering Educators, American Concrete Institute, and American Society of Civil Engineers.

Prof. Michelle Marincel Payne, Rose-Hulman Institute of Technology

Michelle Marincel Payne is an assistant professor in the Civil Engineering Department at Rose-Hulman Institute of Technology. She will earn her Ph.D. this year in environmental engineering from the University of Illinois at Urbana-Champaign. She completed her M.S. in environmental engineering from Missouri University of Science and Technology, and her B.S. in nuclear engineering from the University of Missouri-Rolla. Michelle is interested in developing opportunities for undergraduate students to learn through research, and in developing active and place-based teaching methods for environmental engineering courses.

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Abstract

The Rose-Hulman Institute of Technology (RHIT) Department of Civil Engineering has featured year-long capstone projects for outside clients since 1988. The program had remained essentially the same over that time until 2011. A course instructor was responsible for all of the groups' work and each team was assigned a faculty member as coach. The projects have always been real projects for clients with real needs.

Early in capstone projects, the groups' work often required the expertise of a faculty member to mentor field and lab work even though that faculty member was not the team coach or course instructor. The field and lab work can be of lesser quality because the teams failed to adequately use the faculty expert to plan their work. Later, during project design, the sub-discipline design required on each project was not always mentored by a faculty expert, especially if the faculty expert was not the instructor or team coach. Because group members were not directly accountable in grading to the faculty expert, student design submissions were sometimes of lower quality, submitted late, and/or required substantial revision at the end of the year. These circumstances demanded last-minute effort from both students and faculty experts that resulted in a delayed or incomplete submission of the final project.

In industry, civil engineering consultants form design teams comprised of engineer experts from multiple sub-disciplines. Each expert works in an administrative structure that allows them to work with other experts in their own sub-discipline and with a senior mentor throughout the project. To emulate this, the civil engineering program at RHIT reorganized its capstone design for the 2012-13 academic year to ensure shared learning and collaboration within technical sub-disciplines under a faculty expert. This model is now in its fourth year with the 2015-16 academic year. Assessment of the new model by faculty members indicates significantly improved student learning, earlier completion of design work, and better emphasis on the balance between expectations of each sub-discipline expert and their role in meeting the needs of the project. The new senior design process, which consists of department-wide responsibility for student learning and course facilitation, is a great improvement over existing traditional approaches.

Introduction

Since 1988, the Rose-Hulman Institute of Technology (RHIT) Department of Civil Engineering (CE) has featured year-long capstone projects for outside clients (Jones and Houghtalen, 2000; Aidoo et al. 2008). The projects have always been real projects for clients with real needs. Like most typical senior design programs, one or two instructors directed all of the students' project work while other faculty members in the department volunteered to coach individual teams. All of the faculty members also provided technical advice to all of the teams on an as-requested basis. The program's hallmark was the mentoring of different individual service projects for each project team. The program was highly successful, but presented some major management challenges that are probably typical of many senior design programs. These included

- A process that allowed some students to assume a large portion of the project system design while others minimized their contributions, resulting in variable learning,
- A system that made it difficult to evaluate individual students' work as a team member,
- Inconsistent and sometimes untimely mentoring of technical design work because this occurred only as-requested by groups or after identification by another faculty member, also resulting in widely variable learning experiences,
- A very heavy mentoring load for the year-long course instructor(s) that gave the course a reputation of being a highly undesirable assignment despite the fulfillment often experienced upon completion of successful mentoring of capstone work, and
- Critical dependence of the program on only one or two course instructors.

For these and other reasons, the department undertook a year-long review of the senior design process in 2012 and dramatically revised its organization to feature stronger individual and team mentoring, greater accountability for individual students' learning and project work, and organization of department-wide participation in all aspects of the senior design program. The development of the revised program included significant consultation with industry experts and our department Board of Advisors. Early aspects of the program revision are summarized in Sutterer et al. (2014). Since the time of this earlier paper, the department has further evolved the organization of the process and made other departmental changes to reach what is believed to be a desirable steady state for senior design in which continued evolution will be minor. The outcome is summarized herein.

Mentoring Structure

The key to the reorganization was planning the mentoring needs first and then organizing the courses to support those needs. In industry, project engineers often have three types of mentors. One consists of the upper administration and training staff. A second is the senior project engineer who reviews work, and the third mentor is the engineer who mentors technical work. The department concluded three mentors in similar roles was practical for senior design as well. Figure 1 shows a typical team of four students surrounded by the three types of mentors, the Course Instructor (in the industry role of administrator), the Team Coach (in the role of senior project engineer) and the Technical Design Mentor (obviously in the role of technical mentor).

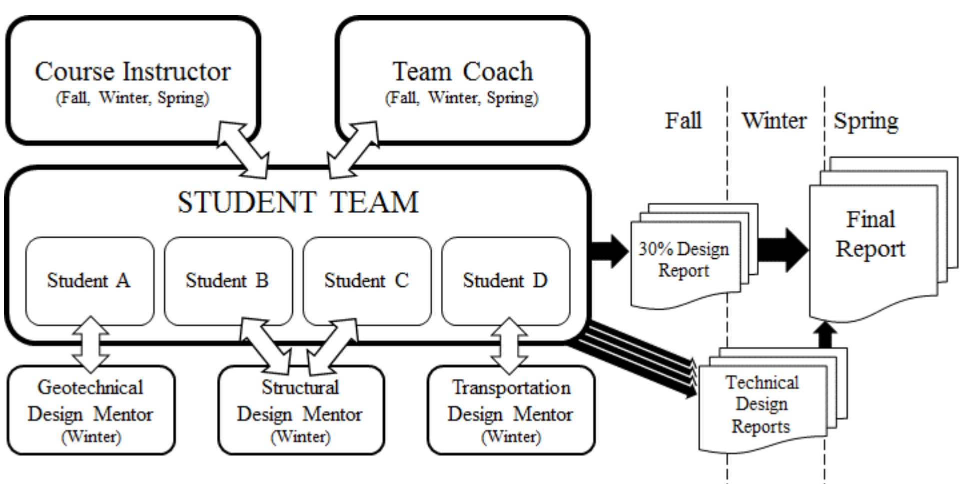

Figure 1. Team mentoring structure, report products, and timing

The Course Instructor on the top left, leads multiple teams during all three terms, teaching content and helping the teams and coaches stay organized. The Course Instructor is also a secondary reviewer of the teams' work products and determines final grades for CE486, CE488 and CE489. The Team Coach on the top right typically only coaches one team through all three terms, meeting weekly to advise, stay informed about design progress and to serve as the primary reviewer of their team's work. The Design Mentors shown at the bottom of the figure, are sub-discipline-specific. These mentors receive course load credit for mentoring the design work. Each student on a team works with a Design Mentor during the winter to complete a design and prepare a design report/appendix for their part of their project. Each student is thus accountable for detailed design work within the system solution for their project as well as for technical report writing about their own work.

Course Structure for Technical Quality and Accountability

The course structure that supports the mentoring over the approximately 27 week project duration is shown in Table 1. Note that the capstone experience is a total of 8 credits, with 2 credits in the fall, 4 in the winter and 2 more in the spring. Note also that CE487x and CE488 are under way simultaneously during the winter quarter to facilitate individual design work while continuing to foster group collaboration towards project completion.

Table 1. Summary of Senior Design Courses Required of All Students

Course	Term	Credits	Weeks	Content/Topics
CE486 – CE Design and Synthesis I	Fall	2	1-6	Desk/Field/Lab Studies
			7-8	Creative Solutions and Decision-Making
			9-10	30% Design Report
CE488 - CE Design and Synthesis II	Winter	2	11-14	Applied Sustainability
			15-16	Reader-Focused Communication
			17-18*	Construction Considerations
CE487x – Technical Design and Synthesis		2	11-20	Sub-Discipline Designs, Bi-Weekly Progress Submissions, Final Technical Reports
CE489 – CE Design and Synthesis III	Spring	2	21-22	Construction Design and Cost Analysis
			23-24	Final Report including all prior work
			25-27*	Client and Public Presentations

*Course includes 2-3 weeks at the end of the term for other course business and project delays.

With approximately 10 teams of four students, the three "CE Design and Synthesis" courses, CE486-488-489, are shared by two Course Instructors (five teams per instructor). These courses focus on management topics, common whole-system design considerations, and team organization. Coaches are kept informed through regular communications and department meeting updates throughout the year.

The "Technical Design and Synthesis" courses in the winter term, designated CE487x, are mentored by sub-discipline faculty experts in 4 different sub-discipline areas. Each individual student is mentored in a part of the system design. The four sub-discipline courses are

- CE487E – Environmental and Water Resources Design
- CE487G – Geotechnical Design
- CE487S – Structural Design
- CE487T – Transportation and Land Development Design

Keeping in mind the mentoring structure in Figure 1 and course structure in Table 1, Figure 2 depicts an example of how students from some of the ten teams might be organized in their teams and courses.

		Fall	Winter					Spring
		CE486 CE Design and Synthesis I (2 cr)	CE487x Technical Design & Synthesis (2 cr)				CE488 CE Design and Synthesis II (2 cr)	CE489 CE Design and Synthesis III (2 cr)
			ENV/WR	GEOTECH	STRUC	TRANS/LD		
Team A	SMITH	Senior Design Instructor Section 1	✓				Senior Design Instructor Section 1	Senior Design Instructor Section 1
	JOHNSON			✓				
	WILLIAMS		✓					
	JONES					✓		
Team B	BROWN			✓				
	DAVIS				✓			
	MILLER				✓			
	WILSON					✓		
Team C	MOORE					✓		
	TAYLOR		✓					
	ANDERSON		✓					
	THOMAS				✓			
Team D	JACKSON		✓					
	WHITE					✓		
	HARRIS				✓			
	MARTIN				✓			
Team E	THOMPSON			✓				
	GARCIA		✓					
	MARTINEZ			✓				
	ROBINSON					✓		

Figure 2. Organization of student teams in courses

Team B in the figure corresponds to the sub-discipline assignments in Figure 1. That team's project required two structural engineers, a geotechnical engineer and a transportation engineer. Note that Davis and Miller from Team B are thus joining Thomas from Team C as well as Harris and Martin from Team D in working with a structural design faculty mentor in CE487S. Similarly, Brown and Wilson from Team B join students from other teams to be mentored together with other faculty experts in CE487G and CE487T, respectively. This organization of students by sub-discipline not only improves technical mentoring by faculty, but also encourages students from different projects to work together on similar technical design work. This collaboration is beneficial for student learning in terms of technical content and professional skills such as teaming. Student collaboration in the CE487x courses also reduces the burden on the technical mentors since students are asking questions of and learning from each other. These improvements specifically address the first three of the five challenges identified in the Introduction to this paper.

Improving Course Instructor Teaching Loads

Before the department revised senior design, review of project reports was clearly the most challenging part of being a course instructor for senior design. It was not uncommon for the instructor(s) to receive a 300-500 page report from each team for review and grading in the spring. It was not uncommon for department faculty to observe the course instructor spend an entire spring break reviewing reports. Some faculty feared the prospect of being asked to be a course instructor for senior design, and the department head feared what would happen if the course instructor became unexpectedly indisposed.

Because each Team Coach is now the primary reviewer of their team's 30% Design Report (in the fall term) and Final Report (in the spring term), the Course Instructor can focus on management of the course and assuring uniformity of feedback and grading. As secondary reviewer, the Course Instructor is only responsible for assuring continuity and fairness of the review across all of the teams, and to be a timely backup for the team coach in the event of an absence or illness. In addition, now that the CE487x instructors are each responsible for assuring the final quality of each student's technical design report at the end of the winter term, the review of those appendices by the Team Coach has become much easier than it was previously. Due to this simple sharing of report review responsibilities, faculty members no longer dread being asked to serve as one of the senior design course instructors. This specifically addresses the last two of the five challenges identified in the Introduction to this paper.

Other Improvements

Empowering Mentors. Now that the technical design work is conducted in the sub-discipline-focused sections of CE487x, subject matter experts in the sub-disciplines assign grades for technical design work. In the prior system, students could be asked to consult with the experts, but the experts had little control on how effectively the students took their advice. This also allows the technical mentors to lead appropriate reporting for their sub-discipline. For example, the geotechnical design work is reported in the form of a traditional geotechnical report while the structural design work is reported as a combination of documented calculations and structural drawings.

The coaches as mentors have also been empowered. The Team Coach is now the primary reviewer of the teams' reports in the fall and spring, and they assign the grade. Teams are told in their writing to "make their coach happy." The Course Instructor provides a secondary review, but only to provide consistence and quality control across mentoring of all of the teams' work. The final report in the fall and spring is valued at 50% of the class grade, so the students know their work must be found satisfactory by the Team Coach.

Grading Uniformity. Consistent grading of senior reports is crucial when mentoring is shared across a department. Course instructors give final grades, yet technical design mentors and coaches are reviewing much of the students' work. Detailed rubrics work for some faculty members, but not all. In our case, the department adopted letter grades for student work based on the institute grading policy. The assignment of letter grades using the descriptors in the institute policy is followed by all of the mentors.

Scheduling Inter-disciplinary Efficiency. The faculty had observed during winter technical mentoring that conversations with students often included advice to consult with a colleague in a different sub-discipline on their project. For example, a student conducting geotechnical design could be encouraged to meet with a student on their project doing water resources work to address a slope stability boundary condition. This desirable cross-disciplinary experience is an obvious important element in design of a system by a team and an important learning objective in the program. To make it easier to put this advice into action, all sections of CE487x now have a common 2 hour meeting block during the day. Thus, the geotechnical design student from the above example is now able, during that common 2 hour block, to immediately walk down the hall to meet with the water resources design student and their faculty mentor.

Facilities. Shared mentoring requires other elements to be effective. For example, the department reorganized work spaces to simplify mentoring opportunities. The senior projects studio lab was reorganized into 4-person work pods and meeting time for classes in that work space was minimized to give more students time during the day to work together as a team. Large screen monitors were placed around the room to allow teams to more easily work on common project work on their computers with each other and with faculty mentors. The larger monitors also facilitated more convenient preparation of engineering drawings. Evening and weekend hours for access to the project space were arranged with the help of campus Public Safety. A nearby conference room was opened up to student use and outfitted with equipment necessary for virtual meetings with remote clients and experts, and students were encouraged to make use of the conference room for such meetings or any others requiring more confidentiality.

Many other improvements in the mentoring of senior design by the entire department are too numerous to include herein. The current system is the outcome of much planning, many meetings, patience with the process, and a persistence to adjust the original plan based on observations and outcomes. This paper provides insight to some of the major elements of the revision.

Faculty Reflection

When the department began working on the overhaul of senior design, we also considered how we would assess the effectiveness of our changes. All of our work is approached so that we "do no harm" to the students while we learn new ways to foster better learning. We concluded the outcome of our work would be better student learning, better work products for clients, and an administrative structure for senior design that was sustainable. We also understood the process would require at least three iterations (three academic years) and many inefficiencies and mistakes that we would address during those iterations. We concluded this could be a case in which a well-designed assessment plan could discourage revisions "as-needed" and decided to trust ourselves as the instruments to monitor effectiveness. We would be delighted to open a dialogue as a group with any other department interested in trying this model, and for this paper offer simply the following benefits on which we all agree.

- The quality, breadth, and depth of the teams' technical designs have improved significantly.
- The students learn more quickly because they are more closely connected to their mentors and thus encouraged to work with their mentors.

- We ensure that all students produce acceptable design work by making each team member responsible for his or her own technical design appendix that is essential to the overall design.
- Although students are still stressed in senior design, we have observed a leveling of the stress as their learning and design work become more efficient, though still heavy.
- Faculty are still spending on average the same amount of time of projects as they had in the past, but now the time commitment is more formally recognized in course assignments and workloads.
- The quality of the final reports produced by the teams has increased, and the length of the reports has decreased (slightly) because they are better written.
- More faculty members are gaining experience as course instructors. One faculty member who recently finished their first term as a Course Instructor told a colleague "This was easy." The fear is gone.
- With all faculty involved in the teaching of parts of senior design, the process is more transparent and there is much more discussion between faculty members about improving the learning.
- The department gains solace from knowing this crucial part of the curriculum is no longer dependent on one or two key faculty members.

There have been a few costs associated with the revision described herein:

- Faculty now can have multiple roles in the process (Course Instructor, Team Coach, Technical Mentor) passing some increased workload onto more of the faculty while reducing workload on the Course Instructor.
- The Team Coach has more responsibility for the grading of final report. In the past, a coach could neglect this responsibility and rely on the Course Instructor to provide a thorough review.
- There have been growing pains over the past three years as the faculty worked to figure out how it all fit together or should fit together. This means that the faculty spent substantial time discussing how to handle different situations, which has taken time and effort. For example, we originally planned as much autonomy as possible for each 487x sub-discipline. So the mentors in each 487x section could choose when assignments would be due and how they would be graded. We discovered this was too much autonomy and agreed to have all 487x sections on a bi-weekly schedule for progressive reporting and work submission. We also adopted a consistent grading scheme for 487x.
- The CE487x technical appendices are not necessarily consistent as the type and format of reporting designs varies between different sub-disciplines. Efforts to make a consistent template and specific grading rubric proved impractical due to these sub-discipline differences.

We also have identified some areas for future improvements. These include

- We have noted that many of the students sort into two groups with respect to completing their work as team members. One group seems to embrace the open-ended nature of the project and is highly committed to top quality work. This group is highly proactive about seeking mentoring and assuring the best final product. This group is not necessarily directly correlated with the highest grade point average (GPA) students. The other group seems to experience great difficulty with the open-ended learning and the independent problem solving that is needed for successful project completion. Sometimes they struggle greatly to carry their part of the work for the team to completion. This group does not necessarily correspond to the lower GPA students. The department hopes to explore further how to facilitate better open-ended problem solving earlier in the students' careers. Perhaps this reflects the need for a combination of the triplet of Knowledge, Skills and Attitudes necessary for successful civil engineering practice.

- There continues to be some confusion with the multiple mentors among the students, as they feel they have several people to which they are reporting. They are unsure of the extent to which various assignments need to be completed, as this is often dictated by the coach or technical mentor and expectations inevitably differ or are at least described differently among faculty members. The faculty are uncertain whether this is an unavoidable outcome of a very different learning structure for the students, or whether some revision could simplify this for the students. We will continue to explore this to reduce the confusion.

In summary, we believe we have developed an effective program for our entire department to team teach or "team mentor" our capstone design program. The program more evenly distributes the mentoring responsibilities across the department faculty, reduces the teaching burden for the course instructor, improves individual student learning towards being accountable to a successful team effort, and results in more complete and "real world" final products for the clients. We believe our program is both more sustainable and practical for fostering the high quality learning in capstone design.

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