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Implementing Collaborative Learning across the Engineering Curriculum

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Abstract: Active and collaborative teaching methods increase student learning, and it is broadly accepted that almost any active or collaborative approach will improve learning outcomes as compared to lecture. Yet, large numbers of faculty have not embraced these methods. Thus, the challenge to encourage evidence-based change in teaching is not only how to educate faculty about collaborative learning techniques, but how to support them as they attempt to implement paradigmatic changes in how they deliver their courses. This paper presents a multiple case study detailing the approach the University of Louisville's J. B. Speed School of Engineering used to encourage faculty in all departments to embrace the use of collaborative learning techniques, and then analyzes the impact of the approach on faculty participants. Support structures to enable faculty to implement collaborative teaching techniques, as well as the benefits participants experienced from pedagogical shifts, are discussed.

Keywords: collaborative learning, faculty development, case study, barriers to pedagogical change

Substantive and widespread research over the past 20 years has shown active and collaborative teaching methods increase student learning, and it is broadly accepted that almost any active or collaborative approach will improve learning outcomes as compared to lecture, the dominant pedagogical approach in Science, Technology, Engineering, and Mathematics (STEM) courses. Yet, large numbers of faculty have not embraced these methods perhaps because of lack of pedagogical support from administrators and colleagues when faculty attempt to implement these teaching techniques. Thus, the challenge to encourage evidence-based change in teaching is not only *how to educate* faculty about collaborative learning techniques, but *how to support* them as they attempt to implement paradigmatic changes in course delivery. This paper presents a multiple case study detailing the approach the University of Louisville's J. B. Speed School of Engineering used to encourage faculty in all departments to embrace the use of collaborative learning techniques, and then analyzes the impact of the approach on faculty participants.

The Speed School of Engineering has a Center for Teaching and Learning Engineering (CTLE) that works in partnership with the university's center for teaching and learning. Through this partnership, which is supported by the dean and the center director, a faculty learning community (FLC) on collaborative teaching was designed to educate one faculty member from each engineering department (a total of six participants) about collaborative teaching techniques and to provide support and guidance during an initial implementation. FLC facilitators collected data throughout the process in order to answer the following research questions:

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1.) How can engineering faculty overcome challenges and barriers to implementing collaborative learning approaches in their teaching?

2.) What benefits do engineering faculty members perceive from the implementation of collaborative learning techniques?

The emergent structure and themes that arose from the analysis will serve to guide others interested in effecting evidence-based change in engineering faculty pedagogical practice.

Theoretical Framework

Collaborative Learning in Engineering

The benefits of collaborative teaching techniques on student learning have been well documented over the last 20 years (Johnson, Johnson, & Smith, 1998 a, b; Prince, 2004; Springer, Stanne, & Donovan, 1999). Specific benefits include improvements in student achievement, quality of interpersonal interactions, self-esteem, student attitudes, and retention. Collaborative learning falls under an umbrella term that includes or overlaps with many terms associated with active learning in the literature, but in this paper, we use the term as defined in Barkley, Cross, and Major (2005); they describe collaborative learning as any structured form of small group interaction. In addition to content learning and understanding gains, collaborative activities improve students' communication and social skills necessary for the global workplace.

In addition to the challenge by Prince (2004) for engineering faculty to promote collaboration in their classes, the accrediting agency for engineering programs (ABET, 2014) specifically links collaboration to the engineering curriculum via two of the 11 required student outcomes (ABET, 2014). The two outcomes directly related to a student's ability to collaborate are "an ability to function on multidisciplinary teams" and "an ability to communicate effectively." Additionally, employers desire graduates who are able to collaborate on teams, but have reported that students are not well prepared to do so (Jaschik, 2015).

An extensive series of surveys of engineering graduates from a large public university showed that graduates rated teamwork and communication along with data analysis and problem solving as the most important ABET competencies for their professional practice (Passow, 2012), and a recent review of the international literature to identify the skills needed by graduate and future engineers found teamwork and communication skills to be among the five most emphasized skills (Abdulwahed et al., 2013). Despite this body of evidence that should inspire engineering and other STEM faculty to strive to incorporate collaborative activities in their courses, changes in teaching practice have been slow to take place (Borrego & Henderson, 2014; Fairweather, 2010). Fairweather (2010) noted that one reason is that faculty perceive that curricular change will take valuable time away from research activities critical to promotion and tenure. This is not necessarily the case as barriers to change for STEM faculty have been researched and discussed broadly and include situational constraints – most notably fear that time taken would prevent necessary content coverage, student attitudes (including laziness and resistance), lack of ongoing professional development, unsupportive institutional or departmental culture, and personal beliefs and expectations about teaching and learning (Henderson & Dancy, 2007; Michael, 2007; Sunal et al., 2001; Walczyk et al., 2007).

Until recently, efforts to effect change in undergraduate STEM education focused on individual faculty innovators to test, create, and disseminate reform approaches (Kezar et al., 2015). This method of change has been challenged as unsuccessful (Fairweather, 2010; Kezar, 2011). The research results of Kezar and colleagues highlight the need for change agents to develop explicit change theories rather than work from implicit theories that do not engage in an examination and evaluation process. They describe the need to create professional dialogues and supporting networks to implement and spread reform. Borrego and Henderson (2014) identify and categorize eight change strategies supported in STEM literature, one of which is faculty learning communities. We selected the faculty learning community (FLC) approach as the strategy for effecting change.

Faculty Learning Communities

An FLC is a group of interdisciplinary faculty members (6-15) engaging in an active, collaborative program of significant duration designed to foster scholarly teaching and enhance student learning (Cox, 2003). FLCs are structured, intensive professional development opportunities designed to provide encouragement, support, reflection, and community building, and participants typically produce deliverables to share their knowledge and accomplishments with the wider university community (Cox, 2004). Research suggests that FLCs increase faculty interest and confidence in teaching; foster growth and innovation in scholarly teaching; encourage active, learner-centered, multidisciplinary approaches to teaching; and lead to increased student learning and retention, and higher rates of tenure. Faculty learning communities have also been demonstrated to generate a knowledge base accessible to the broader university community, thus improving teaching more broadly (Cox, 2001; 2003; 2004).

Methods

Methodological considerations include research design, participants, intervention support structures, data sources, and analysis. This study employs a cross-case methodology to allow the use of multiple data sources to illuminate converging and diverging patterns across cases. Case studies are suitable for exploratory, descriptive and explanatory research (Yin, 2003), and cross-case methodology has been specifically highlighted as appropriate and rigorous for community and systems change research (Lee & Chavis, 2012), which is consistent with the research goals of this study. Methodological and data source triangulation affords construct validity and reliability which increases confidence in interpretation and facilitates uncovering the story of whether, how, and why change transpired.

Cross-Case Research Design

The current study is a multiple replication study of a common pedagogical problem of practice: that of implementing collaborative learning approaches in college-level engineering courses. This research design is appropriate from a systems change research perspective because of the complex and varied contexts in which pedagogical experiences in engineering occur (Lee & Davis, 2012). Understanding system change is often facilitated by cross-case synthesis which can illustrate both common themes and unique experiences (Yin, 2003; 2012). Accordingly, we wanted to study cases that vary on a number of parameters (e.g., disciplinary perspective, course level, level of prior experience with collaborative teaching, tenure status) in order to get a snapshot across the engineering curriculum.

FLC Participants and Facilitators

The dean of the Speed School of Engineering charged the CTLE with encouraging faculty to embrace collaborative learning strategies, in large part because the administration had redesigned some classrooms to facilitate collaborative learning, and these new learning spaces were not appropriate for a lecture-only approach. The CTLE director collaborated with the university's teaching and learning center to lay the groundwork and begin preparations for a new topically-based faculty learning community to accomplish this goal. The CTLE director contacted the chairs of each of the school's seven engineering departments to identify faculty participants. This process ensured cross-departmental participation that aligned with department goals and individual faculty work plans. The chairs responded positively by forwarding one or more faculty names. Final selection of participants was made by the CTLE director after conversations with the faculty members. In the end, the FLC proceeded with six participants from six departments who included one junior faculty member near mid-tenure, three faculty members in their tenure year or just tenured, one tenured associate professor, and one tenured full professor. There were five males and one female. Table 1 describes the faculty members' disciplinary affiliation, implementation course and student composition, and type of collaborative technique implemented.

Table 1. Participants and Context for Implementing Collaborative Learning

Faculty and Department	Course and Students	Collaborative Learning Technique(s)[a]
FM1[b] Civil and Environmental Engineering	CEE graduate course Taught 3 times prior (*n*=9)	Case Study Collaborative Writing
FM2 Chemical Engineering	CHE senior required course First time with this course (n=36)	Structured Problem Solving Test Taking Teams
FM3 Mechanical Engineering	ME graduate elective course (*n*=27) Taught course approx. 15 times	Send A Problem Group Investigation Jigsaw
FM4 Engineering Fundamentals	Introductory Calculus (remedial course) Freshmen (*n*=35)	Think Aloud Problem Solving
FM5 Electrical Engineering	Sophomore course for most majors (*n*=41) Taught approximately 5 times prior	Jigsaw Team Matrix Structured Problem Solving
FM6 Computer Engineering and Computer Science	Graduate course in CECS Grad students & Seniors (*n*=29)	Critical Debate

[a] Adapted from Barkley, E.F., Cross, K.P., & Major, C.G. (2005). *Collaborative learning techniques: A handbook for college faculty*. San Francisco: Jossey-Bass.
[b] FM 1-6 indicates FLC faculty member one through six.

The facilitators for the learning community were paper co-authors Pat, Marie, and Tom. Pat is the director of the CTLE, an experienced engineering educator and department chair, and she actively leads engineering faculty development efforts for the engineering school. Among those efforts, she has been immersed in the literature for course redesign and collaborative learning in engineering. Marie is associate director for teaching, learning, and innovation at the university's teaching center and a faculty development expert at the university. She has initiated and supported numerous faculty learning communities, and one strand of her work has been focused on teaching and retention in STEM. Tom is an experienced science education researcher, including qualitative, quantitative, and mixed research design methodologies. He holds both a bachelor's and master's degree in engineering, contributing to his unique perspective on education initiatives within engineering contexts.

FLC implementation

The faculty learning community kick-off took place in January 2014 and four one-hour meetings of the group occurred through spring semester. Participants received a copy of the FLC focus book, *Collaborative Learning Techniques: A Handbook for College Faculty* (Barkley, Major, & Cross, 2005) to create a shared understanding of collaborative learning as a pedagogical technique. Participants implemented some collaborative activities in their spring courses. At the beginning of the summer, a half-day workshop was held to share the research design and implementation plan. The group reconvened for a follow-up half-day workshop at the end of the summer to share their planned redesign and to obtain feedback from the session facilitators and their fellow FLC members. Facilitators designed the FLC so that participants experienced opportunities to:

- Enhance their knowledge of the research base for collaborative learning as a pedagogical approach and its implications for teaching in engineering;
- Identify and explore practical classroom applications for collaborative learning that will maximize the capabilities of the Speed School of Engineering's redesigned collaborative learning spaces;
- Implement a range of collaborative learning techniques and evaluate the effectiveness of these approaches relative to "traditional" teaching methods;
- Receive pedagogical and technological support for integrating digital collaborative techniques into a selected course in a meaningful way;
- Engage with colleagues and share ideas for enhancing student learning;
- Reflect on one's personal philosophy and approach to teaching; and
- Become part of a cohort of the Speed School of Engineering FLC graduates who can provide collegial support and advocacy for collaborative teaching approaches at the school.

In order to successfully complete the learning community, participants were expected to attend FLC meetings and workshops and identify, develop, and assess the implementation of a collaborative activity in a selected course. Participants submitted reflective memos, project proposals, took part in collaborative learning activities themselves, conducted peer classroom observations during the implementation period, and met in the Speed School of Engineering's new collaborative learning space. After all participants completed their implementation, the facilitators and participants organized and led an all-school presentation to engineering faculty in which they each described their FLC collaborative activities and shared their findings and reflections. Upon completion of the program, participants received a $2000 grant for professional development activities.

Sources of data

Consistent with recommendations by Lee and Chavis (2012) for triangulating both methods of data collection as well as data sources, we collected data on each case as outlined in Table 2. Data were collected by facilitators at three points during the semester-long implementation cycle. Among the data collection triangulation approaches, we employed both emic (insider) and etic (outsider) perspectives (Fetterman, 1998).

Table 2. Sources of Data

	Pre-semester	During semester	Post-semester
Emic (insider) perspective			
	Intent and plan (written summary to articulate outcome goals and implementation plan)	Written reflections and observations (to capture impressions and thoughts in the moment)	
	Written course documents (e.g., syllabus, handouts, directions for students)		Semi-structured post-interview (see Appendix 2)
	Semi-structured individual pre-interview (to focus on particulars of upcoming effort)		
Etic (outsider) perspective			
	FLC Facilitators: Semi-structured pre-interview (see Appendix 1) with interpretation and follow-up questions	FLC Facilitator observation (at least one)	FLC Facilitators: Semi-structured post- interview (see Appendix 2) with interpretation and follow-up questions
	FLC Facilitators: Interpretations of course documents and collaboration intent and plan	Peer Faculty observation (at least one)	

The emic perspective from the faculty teaching the course and implementing the collaborative learning strategies offers strength because this perspective appreciates the rich, detailed context of the work, and brings value to exploring the implementation of collaborative learning techniques from those closest to the work. By contrast, the FLC facilitator team is outside of the classroom teaching-learning experience, and this etic perspective from the FLC facilitator team permits comparisons across the multiple teaching contexts and contributes to generalization of overall conclusions. The etic perspective also complements the embedded insider perspective to mitigate potential blind spots from being too close to the implementation.

Analytic approach

The three facilitators collected all data for each case in common online folders accessible to all facilitators plus the faculty implementer. For each case, Pat and Tom read through the corpus of data, in time sequence from pre-semester, during-semester, post-semester in order to capture the time-dependent development of implementation challenges and faculty approaches to ameliorating those challenges as they emerged. Using a grounded theory approach (Corbin & Strauss, 2015), these two facilitators independently, inductively developed themes emergent from the data that were relevant to responding to the research questions targeting challenges and benefits to implementation. Pat and Tom applied the emergent themes to the data iteratively, moving back and forth among the different sources of data within each case, and wrote research memos capturing how the implementation of the particular collaborative learning strategy unfolded. Specific pieces of data were attached to salient elements of the emergent themes in order to document the evidentiary chain. Finally, Pat and Tom triangulated core elements of the emergent themes with multiple sources of evidence (Yin, 2003).

Pat and Tom then shared their emergent themes with each other for each case for critical and reflexive feedback. Evidence taken directly from the raw data was used to confirm or disconfirm any substantial discrepancies between the two facilitators in order to ensure validity and reliability in this analytic approach. Once the individual case reports for each faculty implementer had been developed via this process and consensus was reached, the six cases each became a unit of analysis for the cross-case analysis. Collaboratively identified patterns emerged across cases. In addition to commonalities, unique aspects of cases were identified. These aspects generated interpretations about which features of a given case might be most salient. In this manner, the cross-case analysis was able to identify both commonalities as well as unique aspects across the six faculty implementation cases. After Pat and Tom completed the individual case summaries and cross-case analysis, Marie independently read and offered input into a final draft of each. This independent third perspective was used to strengthen and validate the case development.

Results – Individual Cases

Results are presented for each of the six faculty cases. After each individual case summary for the six faculty implementers is presented, the discussion is organized around the research questions and informed by a cross-case synthesis across all six cases. *AUTHORS' NOTE: The masculine pronoun is used throughout the paper to anonymize participants, but one of the faculty members was female.*

Case of FM1—Civil and Environmental Engineering

FM1's graduate level course in civil engineering was redesigned to implement collaborative learning activities in and outside of class in order to improve student motivation and learning of course content. FM1 had taught the course three times before with lecture as the primary class activity. However, as a result of the FLC study, FM1 felt teamwork and collaboration could be used to develop students' (independent) thinking ability about real-world issues in course content area as well as to improve their understanding of fundamental course concepts. FM1 decided to assign semester-long group projects that applied course concepts to real world problems.

Implementation required a literature review, intermediate and final writing steps, presentations, and a feedback system that evaluated both the project and the collaboration. FM1 also decided to integrate collaborative activities associated with the group project and group problem solving into regular class meetings.

FM1 stated that the biggest challenge in this re-design was deciding how to condense content to make time for collaborative activities. He ultimately replaced approximately one-fourth of his lectures with collaborative activities. Tegrity videos, PowerPoint presentations, and assigned readings replaced the previous lectures. He also used class time to have students work together on one problem, rather than simply working two or more examples for them. FM1 explicitly communicated to students the value of collaboration via the way he integrated and implemented activities into class (e.g., explicit schedule, rubrics, and evaluation plans for the group project), and his syllabus noted that these activities were worth 35% of the final grade. FM1 used careful pre-planning to design and implement well-structured activities. He noted that making use of a structured format (such as requiring students to use Google Drive and a Blackboard link) forced individual and group accountability and resulted in a portfolio that chronicled the collaboration.

During class observations, several students stated that the structured group project helped them learn the content better as they worked to understand their real-world problem. They also noted that they gained a better understanding of the benefits of collaboration both for individual learning and for tackling a large project. Some students related equations and material from class to various articles they read, linking material to real-world issues (a goal of FM1), and others noted that they were able to transfer and apply the knowledge they gained to another class in civil engineering. One student commented in response to a question after a presentation about the collaborative experience, “I definitely learned more with this group process than I could have learned alone.”

FM1’s implementation was a major pedagogical change from his previous practice of lecture only. During the semester, as he reflected on his own progress and on feedback from observers, he judiciously made changes by adding more structure to some activities, but wisely waited for the next implementation to make more involved changes. FM1 was comfortable that he had delivered all of the course’s primary objectives. He also described his experience this way, “I learned a different way of teaching. At first I viewed traditional and collaborative learning as separate entities, but gradually learned to be comfortable integrating the two.” He further noted that he thought students’ thinking improved as he was able to interact with them during in-class problem-solving activities.

Case of FM2—Chemical Engineering

FM2 taught a new senior-level transport phenomena course in chemical engineering that was added to the curriculum to develop students’ appreciation of fundamental phenomena behind chemical engineering processes. FM2 incorporated small group homework sessions into the course to allow students to work through problems by pooling their individual knowledge. Since FM2 was present, he could guide and redirect students’ thinking in real-time. Students completed group homework instead of individual homework. FM2 communicated to students the value of the collaborative activities by assigning one-third of the course grade for group homework. Individual accountability for course objectives was maintained through conventional assessments for the other two-thirds of the grade. FM2 had experience with utilizing undergraduate teaching assistants

(UTAs) in another educational research project and thus recognized the value of peer learning. He had tried a few collaborative techniques in previous classes, although non-systematically.

FM2's main goal with collaborative learning techniques was to help students develop careful and critical thinking about fundamental concepts so that they could better understand problems. FM2 wanted them to generate the correct differential or partial differential equation to solve, rather than attempting a solution by simply mimicking an example, which is what FM2 had observed that many students do when faced with transport problems. FM2 had two goals for this approach, one was to give "real-time" feedback that would correct and adjust student thinking as they were challenged with problems, and the second was to empower students to connect with each other as learning sources. He also hoped that the stronger students would emerge as peer mentors for the class in the future. FM2 noted the importance of planning ahead of time with focus on how to rearrange course content. He decided to use PowerPoint presentations and Tegrity videos to "flip some pieces" in order to make time for the in-class group homework activity.

FM2 did not explicitly tell students *how* to be effective collaborators in the group activities, and he noted that some students were not properly prepared for daily activities. This caused time-management issues: some groups finished way ahead of others, some groups were off-task, and others were unsure of what to do. Observers similarly noted that although most students were on task and focused, there were varying degrees of student-student and student-teacher interaction. FLC members suggested that additional structures such as including a "close-the-loop" activity or an individual daily deliverable, coupled with explicit instruction on student roles and responsibilities for group activities, might improve the experience for everyone.

FM2 recognized the need for alterations in his next iteration of the course to better manage time and further structure activities to stimulate deeper thinking which was his overall goal. He found that incorporating collaborative activities didn't take as much time as he originally thought, although doing so was "a different way of teaching." He was pleased that stronger students emerged as peer mentors for their classmates and he valued the ability to give real-time feedback to students to help them shape their thinking dynamically rather than waiting for exam feedback.

Case of FM3—Mechanical Engineering

FM3 is a traditional lecturer who had taught a graduate-level course in mechanical engineering 15 times. He re-designed the course to incorporate in-class exercises that focused on a single problem that students worked in randomly selected 3-person teams to solve. FM3 then reviewed the problem and answered questions for the class before he continued with lecture. In other, more-structured activities, different teams applied a particular theory to a problem, then combined their results with other teams to compare theories. FM3's overall goal in implementing collaborative techniques was to give students more opportunities to "think through" concepts with "real-time" teacher input and feedback to improve students' learning.

FM3 initially thought that he would need to free up 4-5 full class sessions in order to incorporate the planned collaborative activities, and he wanted to be intentional about the change both for himself and students. He explicitly communicated the value of collaboration via the integrated activities that changed the class time from purely lecture-driven to some collaboration most days. While preparing for the revision, FM3 noticed that many things he covered were "booky and dry" and topics for which he could find alternate means of delivery, such as Tegrity or PowerPoint presentations. A goal for FM3 was to make his course "more interesting for me as well as for the students" by incorporating structured collaborative activities. Making these changes opened time for more interaction, both student-student and faculty-student. He also thought class would be more interesting if he answered student questions, rather than just “talked.” He shared that he had “never done a wholesale edit” of the course and the “idea of change [in reference to how he taught] was a challenge in and of itself.” Prior to implementing the course, FM3 indicated “doing this at all will be an area of growth. I’ve never done anything like this before” which highlights his initial feelings of “stress and anxiety” as he prepared for this shift. FM3 ultimately discovered he could make the edits necessary to incorporate collaborative learning without sacrificing content.

During class observations, the 25-30 students participated and interacted well with each other and FM3, although observers noted that many students didn’t follow instructions of assigning one recorder per group which meant that multiple students were writing at the same time. However, observers and FM3 noted this didn’t seem to keep students from interacting with each other. Observers specifically mentioned that the instructor did an outstanding job interacting with students and “closing the loop” at the conclusion of the structured team activity which seemed to bring everyone’s understanding to same point. In response to an observer question about the collaborative activities, one student said, “Doing this helps me break things up one step at a time instead of cramming things together like I would do if I just listened to lecture and then did homework by myself.”

FM3 is convinced of the value of collaborative activities for students and plans to use them again in his courses. He found that he really “liked being able to direct students’ thinking by interacting as they solved a problem, correcting faulty thinking as it arose (‘real-time’), rather than correcting a flawed final solution” on a test. He found the “overall stress of change was manageable” and learned that “planning ahead is essential.” He also “learned some things related to managing time that should change in the next implementation, but overall, the activities didn’t take as much time as originally thought.” Having been a traditional lecturer for a long time, FM3 mentioned that “this isn’t the thing I would have done [on my own]. This process and experience has been very good.”

Case of FM4—Engineering Fundamentals

FM4 teaches an introductory engineering calculus class to engineering freshmen majors who are not calculus-ready. The course includes a content delivery component through an online interactive and education system that accompanies the textbook, and a twice weekly face-to-face component, which is where the collaborative learning strategies were implemented. FM4 is deeply interested in exploring pedagogical approaches to best teach his students, and for a number of years prior to this project had been engaged in experimentation with pedagogical approaches including “flipped” teaching where students view recorded lectures prior to class so that class time can be used on problem-solving, question/answer, and otherwise addressing student needs. FM4 approached this collaborative experiment with enthusiasm and some familiarity with relevant literature in engineering education. He decided to restructure the face-to-face component of the course around small-group student collaboration. Every day, his 27 students worked on a series of problems in small groups. They had well-defined roles that had been explicitly taught and modeled by FM4 at the beginning of the course. FM4 also provided handouts and other written guidance on how to effectively collaborate with this small-group activity. Observers noted that while students were collaboratively solving problems, FM4 was actively engaging various students and groups of students throughout the room, primarily asking them to articulate their thinking.

Given FM4's expressed conviction that the entire purpose of the course was to support the development of student thinking about the course's underlying logic, he did not find any conflict with time. He reported that the "last time [I taught this course, it was] was me meeting with students one-on-one to talk about how to think [which] was NOT effective. With this collaboration approach I'm trying this time, students have to share ideas with each other." External observers noted that students seemed to appreciate the central focus on their thinking—rather than their problem-solving skills—as the reason for the course.

FM4 was overall pleased with student cognitive engagement in the course compared to prior years. He was surprised at how well students reflected on their own thinking and potential gaps in understanding, and he was pleased with their willingness to engage in this new learning experience. In particular, he noted that he was able to help students improve their abilities to think about calculus concepts by addressing their explicit, articulated thinking and by giving feedback to them in the moment, rather than at a later time. He learned that for the desired impact to be realized, the collaborative tasks had to be well-structured and well-designed. He noted that preparing for the course required a different instructor skill set as compared to preparation for a typical lecture-based course. He recognized that collaborative learning approaches can be effective ways of teaching, but noted that "reading about it and doing it" are two very different things so he hypothesized that most faculty will need practice and support in order to fully realize the benefits.

Case of FM5 – Electrical Engineering

FM5 taught the first sophomore-level electrical circuits and network analysis course. He had been exploring and implementing a variety of pedagogical strategies over the last few years and was genuinely interested in exploring additional pedagogical approaches. He chose to use a structured problem-solving team approach as the core of his collaborative pedagogy, wherein students in class (e.g., quick sample problems, sometimes longer problem sets) and out of class (e.g., homework problem sets) were assigned to groups of approximately four and asked to turn in one solution set for the entire group. His approach to the collaborative pedagogy was thorough and intentional. He generated a number of documents and a scaffolded sequence of mini-tasks in the first weeks to introduce and reinforce for students both how to function as a team as well as why. During the planning and implementation stages, he sought advice and suggestions from the faculty learning community members regularly, in part to anticipate potential issues and design approaches to avoid or minimize them.

In addition to setting learning goals for his students (e.g., increased grades, learning to work successfully in teams), this faculty member also had a clear goal for himself: "I hope to gain experience on effective strategies for forming and managing collaborative teams." Of potential concern were how much additional time and effort this would require on his part for structuring teamwork, but he was able to recapture some time by using the first class session to discuss teamwork instead of routine review of syllabus and class policies. It became clear late in the semester that FM5 was struggling with the scope of implementation and myriad details in an effort to maintain fidelity with the literature on structuring teams, but in his implementation targeting frequent short homework assignments, such extensive structure proved problematic. Additionally, as was the case for other participating faculty, he wanted to "ensure that collaboration activities would not negatively impact content coverage in terms of taking away time from a content focus." He expressed some initial anxiety about intentionally implementing team collaboration strategies, which he characterized as very different from the abstract, theoretical concept he had previously read about.

Case of FM6—Computer Engineering

FM6 taught a senior/graduate-level course in computer science and incorporated two new collaborative learning approaches in the course. A motivating factor in his participation in this FLC was his belief that, "if I'm better at teaching, it will have a better outcome for students." However, in the pre-interview he also indicated, "I prefer to work alone" and "I don't want to emphasize teamwork [as part of my teaching activities]." He further articulated this stance by saying, "I definitely will not explicitly teach teams; I don't feel like I should force it on them. They are senior students so I am assuming they will have experience in teams." Therefore, he provided no formal structure for group exercises. The first collaborative activity he suggested using was to have students share lecture notes with each other for the purpose of collaboratively working on select class exercises. For the second collaborative approach, FM6 decided to hold an in-class debate on a related computer science topic near the end of the semester.

A primary concern for FM6—as was an issue for other study participants—was "making time" in the course structure for collaborative activities. He believed that his students were taking the course to benefit from his expertise on the subject, and he was hesitant to release class time to other student-focused activities because it would negatively impact how much content he could deliver. The group exercises replaced his prior approach for individual exercises, resulting in a one-to-one trade-off in terms of time. He was able to make time for the in-class debate by omitting his standard lecture on ethics, and instead shared the slides from that lecture to help students prepare for the debate. FM6 reported that he shared a teamwork paper with his students as an option for them to read, but he did not otherwise explicitly teach or monitor any team skills. He reported being satisfied with the student debate experience, based in large part on his observation of students engaged during the process. While independent observers noted the active attention and involvement of students, they also noted that only some students spoke throughout the debate, perhaps because of the large group sizes (two groups of about 15 students in each group) or because English was not the first language of all students. FM6 did not note any appreciable cognitive benefits for students.

Overall, FM6's implementation of collaborative techniques was minimal and did not represent a significant change in course structure. His domain expertise in the content of the course shaped his decision to retain a lecture format so that his students would be able to take advantage of that expertise. FM6 commented that he was satisfied that these collaborative activities, but the limited and disconnected nature of the implementation likely had little to no impact on student learning. In such cases, it may be preferable to retain a traditional course structure rather than to implement a collaborative activity without appropriate support, conviction, and follow-through.

Discussion

This discussion section is organized to address the two research questions related to engineering faculty incorporating more student-centered collaborative techniques in their classes: (1) challenges and barriers to overcome, and (2) benefits of this implementation. The discussion draws on the 6 individual case results above and synthesizes across those cases.

Overcoming Challenges and Barriers

There were two primary challenges that the faculty identified for implementing student collaborative teaching approaches. The first, and most dominant, was how to create time in the class schedule for student collaboration without sacrificing content coverage. As is true for all engineering courses, the content covered in a course was substantial and completely filled the semester schedule in prior implementation. A second challenge was recognizing the need to plan for this different way of teaching. For some, this included not just time or need to learn new teaching strategies, but also some anxiety about changing a long-standing approach to teaching.

Time and Content Coverage. A challenge considered to be a dominant potential barrier for implementing student-centered collaboration was the concern about carving out class time for collaborative activities and the potential for reduced content coverage in the course. This challenge was articulated by all faculty in our study, and was a major topic of feedback and discussion with faculty both during and after teaching their classes. This concern could also be framed from an efficiency perspective, a framework very familiar to an engineering mind, because delivering content via instructor lecture is much more time efficient for content coverage than student collaborative sense-making tasks during class. However, as was noted in the individual cases above, these faculty were interested in exploring collaborative student learning approaches so that they could have stronger, more timely opportunities to uncover student thinking and respond to that thinking in the moment. Essentially, there was a willingness to (potentially) sacrifice some content in exchange for strengthening depth of student learning. Several faculty commented that it was because of the FLC structure that they were willing to experiment with implementing collaborative techniques, and FM3 said that he never would have tried this without the support of the FLC.

Revisiting this theme of the challenge of time and content coverage at the end of the semester, every faculty member confidently expressed that they had found a way to not substantially sacrifice content coverage. Faculty indicated that they were able to modify their pedagogical approaches to still achieve the primary course content objectives while making time for student-centered collaboration during class time. One theme that emerged is that some faculty noted that the collaborative activities did not take as much time as they originally thought, especially when the instructor explicitly taught students the parameters around how to collaborate effectively. Most were able to gain some class time for these collaborative tasks by assigning students independent viewing/reading (Tegrity videos, powerpoint, assigned readings) of material that in the past he would have spent time lecturing in class.

All faculty indicated that they were very satisfied with the content coverage of the revised course, and in many cases, there was either explicit or implicit (via tone of voice or facial expression) surprise exhibited when they noted that content coverage was not negatively impacted. Across the six cases there were varying degrees of modification to existing courses as described in the individual cases, and positive outcomes were achievable across this spectrum. Generally, faculty noted that the changes – especially frontloading reading/powerpoint/videos prior to class – were relatively small, but took some time to plan for and implement.

Planning. Faculty consistently emphasized the necessity of planning ahead for implementing collaborative learning techniques. Several participants observed that they needed to prepare differently for this type of teaching because it requires different teaching skills than traditional lecture or problem-solving courses. They also noted a gap between reading about collaborative teaching and actually implementing meaningful activities. Most faculty also expressed that they approached this experience with clear intentions about seeking change for themselves in terms of how they teach *as well as* change for what students would do to learn in their course. In short, the extent to which each participant engaged with the experience was self-determined, but clearly required some investment of time and energy for planning this new way of teaching.

Because this approach to teaching is innovative for most faculty, participants regularly expressed appreciation for the support provided by faculty learning community. FM3 went so far as to say he never would have tried these collaborative techniques without the support of the FLC, and even with that support he was a bit anxious about changing things in a course he had taught 15 times previously. This was expressed in a positive sense, in that this same faculty member indicated post-semester that he would now teach this course differently in the future—even without the FLC support—since the supportive experience helped him move past his initial nervousness.

Benefits of Collaborative Learning Techniques

In all cases, faculty expressed overall satisfaction with the course enhanced with the student collaborative learning techniques. The faculty reported benefits they noted for the students as well as for themselves, and student comments were consistent with the faculty perspectives on student benefits. Most (FM1, FM2, FM3, FM4) highlighted that their approaches really helped them uncover student thinking in the moment, and gave them opportunities to directly address misconceptions or other confusions before those became deeply entrenched in student thinking. Faculty also highlighted that independent student thinking was a strong element of benefit for the students through these approaches. Student thinking about problem-solving or connecting course content to real-world situations were explicit goals of the courses that faculty and students themselves reported were stronger outcomes as a result of the collaborative techniques.

The ability to interact more directly and frequently with students was another theme that emerged from many of the faculty. Students themselves expressed appreciation for the opportunities to try out their thinking, and get immediate feedback from peers and the faculty, underscoring that the faculty perception of benefits to the students paralleled what students themselves thought. Faculty also indicated that these approaches made teaching the course more interesting to them because they could more regularly hear and interact with students about their questions and thinking process, which was more interesting to explore together rather than the instructor doing all of the talking at the front of the room.

Conclusions

Overcoming Challenges and Barriers

Two main barriers or challenges that have been documented in the literature concerning pedagogical change in general were also mentioned in one form or another by most participants in this study: i) the concern that collaborative activities would reduce time for content coverage and ii) the fact that faculty need support in course re-design and a community of peers to share concerns and frustrations with as they make course changes. Results showed that these faculty were able to overcome both of these challenges in this study. Most faculty found that by restructuring the course to deliver some content outside of class (e.g., video, assigned readings, posted PowerPoints), they could gain some class time for collaborative activities. They reported strong satisfaction with this approach for retaining appropriate coverage of content while making class time for student collaborative activities.

This study confirmed the faculty learning community model was a positive vehicle for helping faculty implement collaborative learning techniques for 5 of the 6 participants. One participant (FM6) realized that he was more focused on relating his expertise to students and did not value time students spent together. A faculty member must be authentically committed to trying collaborative techniques to be successful, and should consider his/her stance on the value of student-centered collaboration before deciding to implement collaborative approaches.

The FLC allowed barriers to be overcome by providing the time and structure to introduce collaborative techniques, and to encourage faculty to "make a whole-sale edit" of their course, examining why and how they covered material and how could it be re-designed in ways that would allow time for collaboration without sacrificing needed content. The FLC provided a safe environment of peer scholars and facilitators whose only purpose was to help and encourage the faculty member. FLCs are not evaluative or punitive, but participants are held to providing deliverables. Being able to share successes and challenges in a safe community of faculty is critical to success of such an implementation.

Further, the FLC facilitators and participants engaged in discussions and peer observations that helped participants recognize the need for alignment of collaborative techniques with course activities, the need for well-structured collaborative activities that clearly relate to course objectives, and the need for the faculty member to "close-the-loop" for students after activities – clearly relating it back to course objectives. Participants also learned that it is OK to move slowly, make small changes, evaluate, revise and try again. Participants also recognized that even small changes are very different from traditional lecture methods and preparation is entirely different. The reason the faculty learning community model was successful is it provided a structured environment where faculty recognize these challenges and learn ways to overcome them together.

Benefits of Collaborative Teaching

Benefits faculty perceived from the collaborative learning implementation related primarily to students, but also to faculty themselves. The most often mentioned benefit was the opportunity to give "real-time" feedback to correct a student's thinking interactively in class instead of days or weeks later on an exam. Participants noted with satisfaction the demonstrated improvement in their students' thinking and understanding based on conversations they had with students. Some participants noticed an improvement in knowledge transfer from content in one course to another due to the collaborative activities used. Faculty participants were pleased with the largely positive attitudes students had about the activities as many students expressed an increase in understanding because of the real-time feedback. Another benefit was the understanding of collaboration and teamwork and the many ways faculty can support students' acquiring skills in becoming good team members. One faculty participant specifically noted that this FLC experience inspired him to approach his research activities with a different attitude, actively seeking more collaborators to expand his work.

Summary

Three elements necessary for success clearly emerged from our study. The first element concerns the faculty member's philosophical position with respect to the value of collaborative learning for a particular course. The second element concerns aligning appropriate collaborative techniques with course activities. The third element concerns a fully developed pedagogy, i.e. structured follow through and integration within the course.

When a faculty member's philosophical position is centered on the importance of the expertise the faculty member brings, then the faculty member may view students spending time collaborating with each other as a less valuable use of time. FM6 represents this situation in our data set. Authentic commitment by the faculty member is a must for a meaningful collaborative experience for students.

The alignment of collaborative techniques with course activities is critical for success. Drawing from our results from FM5, we see FM5's well-intentioned commitment to student collaboration being implemented sub-optimally. FM5's implementation began with several readings and course discussions about the importance of collaboration and how to be an effective team contributor. However, in this case, trying to force each homework activity to be a team evaluated effort led to student resistance as well as an overwhelming management burden for FM5. Whereas this teamwork accountability approach, including the intentional instruction on how to collaborate, would be very appropriate in larger, longer-term projects, students perceived it as artificial for frequent, relatively short homework assignments.

Well-structured collaborative activities need to include both a clear explanation of process and desired outcome as well as a closure element that integrates the collaborative activity with the course goals. Considering the case of FM2, both facilitators and peer observers noted that not all students were equally engaged in collaboration during the activity. This was likely because FM2 did not explicitly impose structure on the collaboration. A piece of the structure that was missing was explicit teaching or discussion during class about how to be an effective collaborator; note the contrast with FM5. One effective way to emphasize the intended learning outcome of a collaborative task is to bring the class's attention back and make explicit the connection of the activity to the overall course goals.

Our results provide evidence that it is possible for engineering faculty to overcome barriers for implementing student collaborative teaching pedagogies, including widespread concern that these approaches will interfere with course content coverage. However, as noted above, there are several elements to consider in order for implementation to be successful. Of note is the importance faculty expressed for careful planning of these teaching approaches, and of supportive structures such as those offered by a faculty learning community. It is encouraging that these positive shifts in instructional pedagogy toward student-centered collaboration are possible in a wide variety of engineering courses (from freshmen level to graduate level, across many different engineering domains) and by a wide spectrum of faculty. Faculty long-experienced in exploring implementation of collaborative techniques (e.g., FM4) as well as faculty who were interested but who—even with many years of teaching experience—had yet to systematically undertake a shift in instruction (e.g., FM3) were able to meaningfully reconsider and modify their instructional approaches.

Appendix 1. Pre-Semester Semi-Structured Interview Protocol

1. How do you anticipate that collaborative teaching will impact your teaching effectiveness?

2. What are your goals for student benefits from your collaboration strategies?

Follow-up: How will you know it when you see it *(e.g. what would be the evidence – student engagement, peer-peer conversation, academic outcomes, classroom dynamics, …*)

3. What components, if any, of your collaborative learning strategies are you most looking forward to/ curious about/ interested in/ have high expectations? Why? (*if all the same without highlighting and particular component, ask what (s)he expects will be the most atypical for students*.)

4. What parts of your collaborative strategy effort do you expect will be the most significant growth area for yourself as a faculty?

Appendix 2. Post-Semester Semi-Structured Interview Protocol

1. What are your thoughts now about collaborative learning and your ability to implement collaborative learning techniques in your teaching?

2. Has your thinking about collaborative learning changed since the beginning of the semester? If so, how?

3. Did you learn anything from this experience that you hadn't thought you would learn?

4. Would you do anything differently if you were to try this again?

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