FOUNDATIONS – Integrating Evidence-based Teaching and Learning Practices into the Core Engineering Curriculum

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FOUNDATIONS – Integrating Evidence-based Teaching and Learning Practices into the Core Engineering Curriculum: Experience with the First Faculty Cohort

Introduction

Research has convincingly shown that traditional, content-centered, didactic teaching is not effective for developing depth of understanding and knowledge transfer. Nor does it adequately address development of critical problem-solving skills for success in further study or the workforce. Active and collaborative instruction coupled with various means to encourage student engagement invariably lead to better student learning outcomes irrespective of academic discipline [1, 2]. Despite decades of research and calls for change and effort, traditional teaching is still the norm in higher education STEM teaching. The purpose of this project is to translate the results from the significant body of research on teaching and learning into effective, evidence-based teaching practices in all core mathematics, science, and engineering-science courses taken by students in their first two years, with approximately 600 students entering engineering each year. The project provides support to enable the faculty who teach these critical core courses to understand and adopt evidence-based practices, target deep and transferable learning within and across disciplinary domains, iteratively redesign their courses and assess the impact of those changes. Strategies to support faculty change include, ongoing discussions of the principles of teaching & learning, and discipline-based education research; trained peer assistants to facilitate active-learning pedagogies in lectures and recitations; midterm course evaluations as formative feedback; and advocacy with colleagues to catalyze diffusion beyond these early courses.

Approach

Currently, the project has three cohorts of faculty, nine who began in summer 2016, six in 2017, and five in 2018. These are faculty members who teach the core Calculus, Chemistry, Physics and Biology courses, together with the foundational computer programming, and engineering science courses in Thermodynamics, Mechanics of Solids, and Electrical Circuits. All sixteen of the core courses that are targeted in the project have so far been impacted to some degree. The faculty engaged to date have been primarily teaching stream, but our theory of action anticipates these being the champions to effect diffusion through sharing their experiences and successes with the tenure-stream faculty who tend to teach upper-level courses.

Here we focus on Cohort 1, the first cohort of nine faculty members recruited in Spring 2016. This cohort has received support for three summers and is currently involved in their third academic year of implementation. During this time, Cohort 1 faculty were introduced to: (1) the Principles of Teaching and Learning [3] as a framework for thinking about and guiding changes in their practice; (2) Teaching as Research as a strategy to effect changes in their courses and assess the impact [4]; and (3) a Community of Practice to share and reflect on their efforts to change practices. Workshops with experts in the field on active learning, deep and transferable learning, and cross-course connections were supplemented with research on how people learn [5, 6] and discipline-based education research.

The extent of participating faculty and classroom transformation is being examined through the lens of limiting-factor analysis, which identifies and addresses those factors that need to be in place if the project is to be sustainable. Faculty are interviewed before and after implementing changes. Midterm course evaluations provide student input on their perceptions of the changes introduced by faculty and provides an opportunity to examine differences between males and females in a School of Engineering whose student body is approximately 30% female.

Results & Discussion

Limiting Factors Analysis

Faculty wrote reports at the end of the first summer of their Foundations work (i.e., Fall 2016) in which they outlined their plans for adopting evidence-based practices to address issues of student motivation and relevance of course content to students' lives and goals. Planned instructional changes included rewriting course objectives and outcomes to be more specific and streamlining and reorganizing course content. Most wanted to make the courses more engaging, for example, by turning some recitations into problem-solving workshops and by shifting the role of the TAs from lecturers to learning guides. There were plans to focus more on learning key concepts and connecting concepts within and across courses. In several cases this was addressed by using concept maps to help students organize knowledge. Other approaches included relating the foundational courses to each other and to future coursework and adding more real-life problems that would appeal to students from different majors. There was clear recognition of the need to have TAs and peer leaders prepared to support active learning in the lectures and recitations.

With each subsequent year in the project, changes were implemented based on lessons learned in the previous semester. In addition, the focus on cross-course connections has deepened, with faculty not only looking at concepts that apply across courses but trying to understand why certain concepts are not transferring. There has also been an increased use of assessments to identify exactly where the students are having difficulty to address deficiencies in understanding (or, in some cases, gaps in prior knowledge). There are beginning to be more sophisticated attempts to evaluate the success of the changes that had been made. For example, efforts were made to check to see if students recognized a thermodynamics problem on compressing an ideal gas as requiring the same solution as a problem they had seen in their Calculus course; Most students did not. While the Cohort 1 faculty members have not all implemented the same changes or even implemented change to the same degree, it is clear that the support of the Foundations project, including the professional development activities and the opportunity to share ideas and strategies with their peers, has been a major factor in their willingness to risk failure by changing practices that appeared to have worked well enough—if not perfectly—in the past.

Major challenges facing the Cohort 1 faculty at this point include figuring out how to measure the impact of instructional practices on student outcomes and how to overcome the continued resistance of many students to embrace active learning in favor of a preference for a more structured teach-to-the-test pedagogy that many of them experienced in high school. The impact of the latter on lowered student evaluations of the faculty is a risk to the Foundations faculty, especially those in teaching-stream positions whose continued employment relies heavily on strong positive evaluations.

Peer Leaders and Teaching Assistants

The results from the faculty interviews showed that well-prepared peer leaders and teaching assistants (TA's) are an essential component of the ecology of active learning. The TA's are graduate students and the peer leaders are upper-class undergraduates who have successfully completed the course they assist with and have demonstrated an interest in helping teach their fellow undergraduates. Additionally, a pool of undergraduate tutors is provided as an out-of-class resource to students who need extra assistance with coursework. Because of the recognition of their key roles to support active learning, an agreement was made to coordinate and strengthen TA, tutor, and peer leader training. Historically, these efforts were handled by different centers on campus with differing levels of faculty and/or department input. Teaching Assistants are selected and hired by specific departments. Training is provided by the Center for Faculty Engagement and Advancement (CFEA). Although multiple levels of training are available, departments typically require TAs to attend a one-half day orientation session. Tutors are selected and hired by the Academic Support Center (ASC) to tutor one or more courses. ASC provides a general orientation to all tutors that covers logistics and some strategies for supporting students. Peer Leaders are hired by individual faculty with no specific campus-wide training. Rather, each faculty member meets with the peer leaders to discuss their role and expectations. Currently, little attention is paid to the correspondence between peer leader expectations and their performance in the classroom.

Foundations' leadership met with representatives from CFEA, ASC, and the School of Engineering (faculty, Associate Dean for Undergraduate Studies, Chair Department of Mechanical Engineering) to discuss needs of each group, what each group can offer, and how to move forward to coordinate the efforts to support improved teaching and learning in the School of Engineering. Because CFEA offers several relevant programs (e.g., teaching circles, a course on teaching at the college level), it was felt that some existing programs could be refined to suit the needs of TAs, tutors, and peer leaders. A pilot effort is being undertaken.

Student Perceptions of Instructional Changes. At approximately the midpoint of the Fall 2018 semester, students were asked to complete a short five-minute survey about their experiences in each of the core courses. For each question, students were asked to indicate the extent to which they disagreed or agreed with various statements about the teaching and learning environment. Here we include responses to three questions. Response options were the same for each question: Strongly disagree (1); Agree (2), Neither Disagree nor Agree (3), Agree (4) and Strongly Agree (5). Gender by Faculty two-way ANOVA was used to determine the significance of mean rating differences between students taught by Cohort 1 faculty and students taught by all other faculty (cohort main effect), males and females (gender main effect) and gender x faculty interactions. See Tables 1, 2, and 3 for mean differences between Cohort 1 and all other faculty.

As shown in Table 1, mean ratings were higher for students of Cohort 1 faculty than for students in core courses taught by all other faculty. In addition to these cohort effects, significant gender differences were found for Questions 5A (professor is interesting) and 5C (professor makes it easy to get a good grade). Student ratings for "professor interesting" and "makes it easy to get a good grade" were significantly higher for males than for females. There were no significant gender by cohort interactions; the magnitude of the cohort differences were consistent for males and females.

Table 1. Mean ratings cohort 1 faculty compared to all other faculty teaching the same core courses: Question 5.

Question 5: To what extent do you agree or disagree with the following?		N	Mean	Std. Deviation	Sig.
A. The professor is interesting and brings the material to life	Cohort 1	266	4.09	1.02	***
	Other Faculty	658	3.17	1.50	
B. The professor is accessible outside the classroom	Cohort 1	267	4.23	0.83	***
	Other Faculty	660	3.62	1.05	
C. The professor makes it easy to get a good grade in this class	Cohort 1	267	3.52	1.07	***
	Other Faculty	660	3.14	1.28	
D. It is clear to me how this course is related to my other courses	Cohort 1	267	4.00	1.06	***
	Other Faculty	660	3.48	1.29	
E. It is clear to me why I need to take this course	Cohort 1	267	4.12	1.04	***
	Other Faculty	658	3.64	1.29	

*p < 0.05; **p < 0.01; ***p < 0.001; ns = not significant

Students were asked where they go for help when they have trouble understanding the course material. Mean ratings were highest for "look online, talk to my friends or talk to others in the class" and lowest for "meet with tutor from academic support center." Students of Cohort 1 faculty were more likely than their peers in courses taught by other faculty to seek help from the Professor, the TA or student assistant (See Table 2). Mean ratings for questions 10C (talk to my friends) and 10F (talk to the course TA or assistant) were significantly higher for females than for males. That is, female students were more likely than their male peers to seek help from those outside the class. Although mean ratings for questions 10D (talk to others in the class) and 10E (meet with the tutor) did not differ between Cohort 1 and all other faculty, there was a gender by cohort interaction. The magnitude of the male-female differences in mean ratings was larger for students taught by non-cohort 1 faculty. Some research has suggested that a gender difference in seeking academic help is associated with male reluctance but that the link by which masculinity constructs influence this may not be simple [7].

Table 2. Mean rating cohort 1 faculty compared to all other faculty teaching the same core courses: Question 10.

Question 10: When I have trouble understanding the course material, I typically…		N	Mean	Std. Deviation	Sig.
A. Talk to the course instructor	Cohort 1	264	3.16	1.16	***
	Other Faculty	650	2.73	1.29	
B. Look online for similar courses or content	Cohort 1	264	4.14	0.91	ns
	Other Faculty	649	4.23	0.82	
C. Talk to my friends	Cohort 1	264	4.12	0.99	ns
	Other Faculty	648	4.16	0.89	
D. Talk to others in the course	Cohort 1	262	4.02	0.97	ns
	Other Faculty	648	4.07	0.94	
E. Meet with a tutor from the academic support center	Cohort 1	264	2.63	1.19	ns
	Other Faculty	649	2.72	1.26	
F. Talk to the course TA or student assistant	Cohort 1	264	3.25	1.28	*
	Other Faculty	647	3.05	1.32	

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ns=not significant

Students were asked about the aspects of the course they liked. As expected, mean ratings were higher for students of Cohort 1 faculty than students taught by other faculty (see Table 3). Cohort 1 faculty had spent significant time reading and discussing strategies to create a more learner-centered classroom where the faculty facilitate learning opportunities rather than rely solely on lecturing to students. Gender mean differences were found on 2 items. For question 11A, males agreed more strongly than did females that “the instructor explains the course material so I can connect it to other concepts I know.” Further the magnitude of the gender difference was higher for students taught by Cohort 1 faculty. For students of Cohort 1 faculty, mean ratings were 4.19 and 3.58 for males and females, respectively. In contrast mean ratings for students taught by other faculty were 3.22 and 3.19 for males and females, respectively. Mean ratings for question 11F were also higher for males than for females. Males agreed more strongly than their female classmates that “students have opportunities to explain the material to other students during class.” This may be a reflection of the 2:1 ratio of males to females in the school of engineering and provides an opportunity to make faculty aware that they may need to be proactive in ensuring females have sufficient opportunities to explain material to their peers.

Table 3. Mean ratings cohort 1 faculty compared to all other faculty teaching the same core course: Question 11.

Question 11: What I like/appreciate about how this course is taught is that…		N	Mean	Std. Deviation	Sig.
A. The instructor explains the course material so I can connect it to other concepts I know	Cohort 1	257	4.02	1.04	***
	Other Faculty	636	3.22	1.47	
B. The instructor asks for written feedback on what I understood from the lecture at the end of class	Cohort 1	130	2.83	1.23	***
	Other Faculty	402	2.11	1.26	
C. During class, the student assistant helps me think about how to solve problems	Cohort 1	172	3.84	1.13	***
	Other Faculty	480	3.23	1.39	
D. The instructor points out the connections between concepts in this course and other courses in my major	Cohort 1	233	3.73	1.15	***
	Other Faculty	605	2.92	1.44	
E. The instructor provides class notes and worksheets BEFORE class so I know what we are going to learn	Cohort 1	208	3.76	1.10	***
	Other Faculty	561	3.41	1.35	
F. Students have opportunities to explain the material to other students during class	Cohort 1	230	3.56	1.15	***
	Other Faculty	564	3.03	1.35	
G. Students have opportunities to work in pairs or groups to solve problems during class	Cohort 1	224	3.79	1.18	***
	Other Faculty	550	3.31	1.37	

*p < 0.05; **p < 0.01; ***p < 0.001; ns=not significant

Cross-Course Connections

During the 2017-2018 academic year, Foundations faculty began to map cross-course connections in the foundational core courses as a key strategy to support deep learning and the development of usable knowledge that supports transfer (see initial draft in Fig. 1). They asked themselves: What are the key concepts and skills that students need to be successful in upper level engineering courses? In what ways are these concepts and skills introduced and how are they developed across courses? The project will build on this faculty-initiated approach both to address improved pedagogy but also to provide input to curriculum evolution that can work synergistically to advance learning.

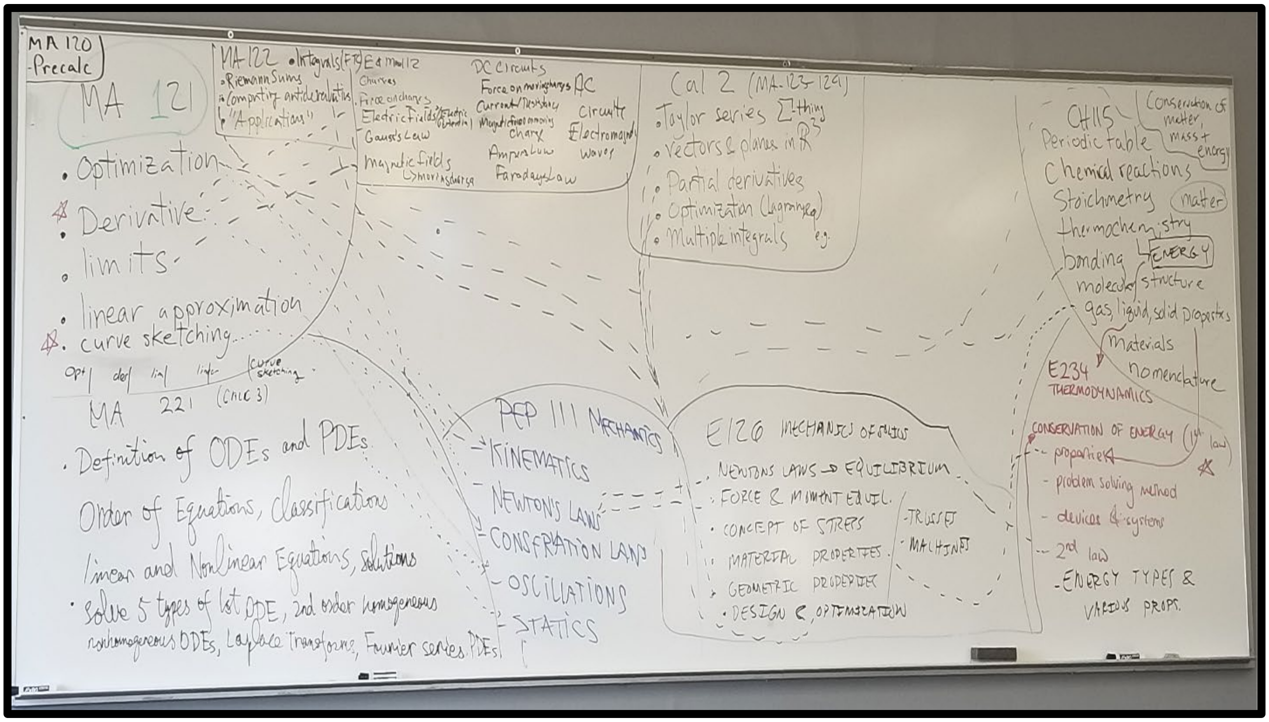

Fig. 1. Initial mapping of cross-course connections created at a Foundations faculty workshop

One of the major challenges is finding software to display the map in a way that is useful not only to the faculty but also to the students. Level of detail is critical so as to be maximally useful to the user. However, such maps become complex as courses and the key topics are added. Figure 2 is one example of a map. It was created with Mathematica and derived from the initial topical connections that the Foundations faculty made across the early core courses in calculus, physics, chemistry, mechanics of solids and thermodynamics. This work will continue over the next year. To date, discussions of the cross-course connections have been beneficial to the Foundations faculty, allowing them to emphasize various topics that students will revisit in subsequent courses. Moreover, these discussions have resulted in faculty beginning to rethink the content of their courses and others rethinking the sequence of courses. Once completed, the cross-course connections will directly benefit the students as they will be able to “see” why they need to take certain courses (e.g., calculus) in their freshmen year.

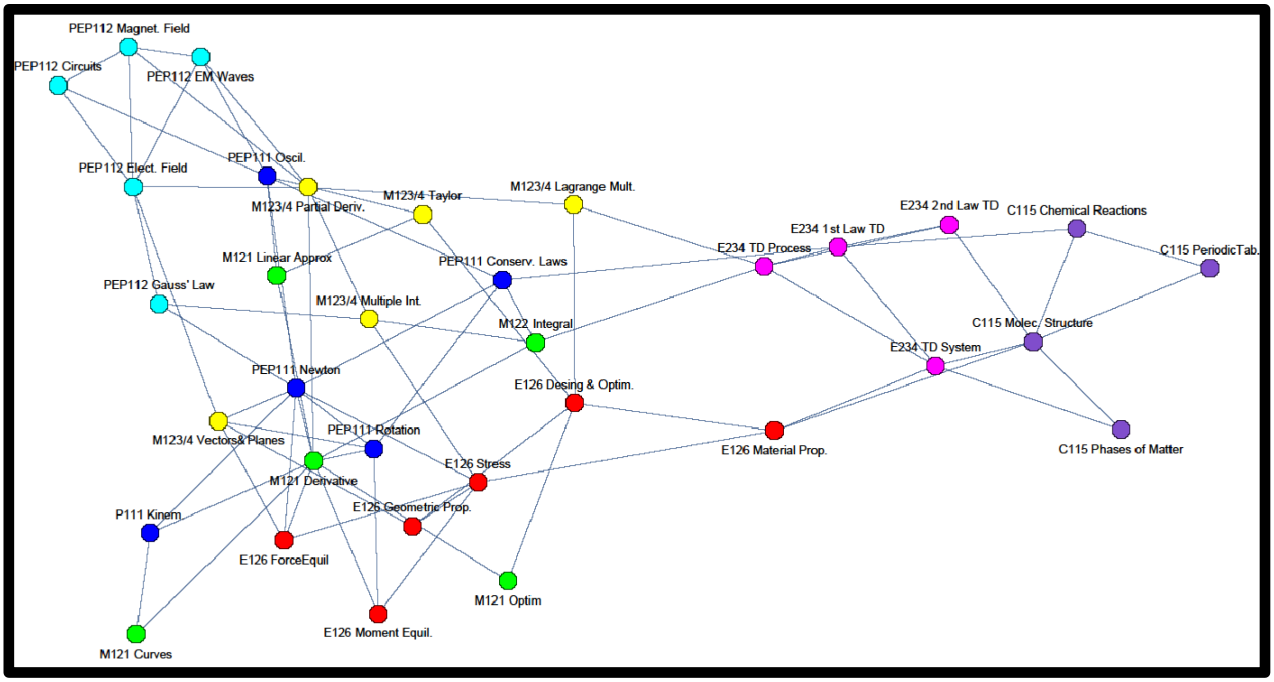

Fig. 2. Initial cross-course mapping captured in software. Colors differentiate different core courses, dots identify topics within those courses.

Summary & Conclusions

A group of 9 faculty became the first Foundations project cohort and over the past three years they have continued to meet regularly to discuss how to change their practice, reflect on the impact of those changes on student engagement, and work together to understand and articulate how their course is related to other core courses. Despite significant progress, a substantial number of students continue to resist efforts to become self-directed learners, opting instead for faculty to deliver content in a traditional lecture-based fashion. The addition of peer leaders is viewed as a positive change and in the coming year the process of selection and preparation will become more formalized and consistent across courses. Gender differences in student perceptions of the teaching and learning environment merit further attention.

Acknowledgements

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