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# FOUNDATIONS – Integrating Evidence-based Teaching and Learning Practices into the Core Engineering Curriculum: Retrospective on the Progress of Teaching-Track Faculty Participants

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## Introduction

Improving the quality of teaching and learning in higher education is an ongoing challenge particularly for foundational courses [1]. Although a large body of research indicates that active and collaborative instruction [2] coupled with various means to encourage student engagement invariably led to better student learning outcomes irrespective of academic discipline [3],[4], traditional lecture-based instruction is still the norm in higher education STEM courses. To improve engagement and learning in introductory foundational STEM courses, this NSF-supported project has been working with cohorts of faculty who teach the core Science, Math and Engineering courses in the first two years of the engineering curriculum.The project was designed to engage and support faculty cohorts over three years to change their instructionalpractices with the goal to increase the use of active learning approaches and facilitate development of deepand transferable learning.

A combination of regular meetings and workshops served as the primary vehicle to support faculty adoption of evidence-based practices. Weekly meetings took place during the summer when all faculty had a light teaching load. Discussions focused on two major publications: How Learning Works. Seven Research-Based Principles for Smart Teaching [5] and How People Learn [6] supplemented by various other resources including videos of exemplary practice and literature on discipline-based education research [7], [8]. Second, all faculty enrolled in an on-line learning course: *An Introduction to Evidence-Based Undergraduate STEM Teaching*. Third, regular meetings during the academic year provided opportunities to highlight key instructional practices (e.g., cross-course connections, metacognitive strategies) and have faculty share how these strategies are implemented in their course. Fourth, workshops provided opportunities to learn from and interact with experts in the field on topics such as active learning, knowledge building, and principles of teaching and learning.

In this paper, the role of full-time teaching faculty is explicitly examined because these non-tenure track faculty are largely responsible for the core introductory courses of the engineering curriculum at our institution, and increasingly key contributors to the education enterprise at research universities across the country. The teaching-track faculty operate with different constraints to those on tenure-track. They have limited-term employment contracts and their reappointment is more heavily influenced by student course evaluations than that of tenure-track faculty, who have research performance as a significant factor. While this creates risk for teaching-track faculty changing their teaching, they are more likely to see teaching professional development, teaching innovation and associated research engagement as enablers of their academic success. It was expected therefore, that they would have a strong interest in learning about and adopting the evidence-based teaching practices that are the focus of the project, with an added potential benefit of them becoming project champions. Drawing on information from faculty surveys, interviews and reports or presentations and student surveys we characterize the project's impact on teaching faculty's implementation of active-learning approaches, use of strategies to promote development of deep and transferable student knowledge and efforts to support the spread of evidence-based approaches to their faculty peers.

## Approach

The project has engaged three cohorts of faculty, with each cohort receiving summer support for three years beginning summer 2016 (N=9), 2017 (N=5), and 2018 (N=6). 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 Engineering Thermodynamics, Engineering Mechanics, and Electrical Circuits. All thirteen of the core courses have been impacted to some degree.

Of the 20 faculty participants, 5 were tenured or tenure track and 15 were teaching track. Although all teaching faculty attended meetings for at least one year, only 10 of the 15 teaching faculty have fully engaged for at least 3 years during the project. Primary reason for limited attendance was either health-related (faculty and/or family member) or job related (assigned to non-core course, left the university, additional responsibilities outside of teaching).

Cohort 1 teaching faculty all had some knowledge/experience with evidence-based teaching practices, had attended workshops on the topic, and/or participated in department level curricular changes and had little/no experience outside of academia. In contrast, most Cohort 2 and 3 teaching faculty came to the university after more than 20 years in industry or other nonacademic positions. These faculty benefited from a more targeted set of discussions focused on learning with understanding. Important here was attention to what students bring to the learning environment (prior knowledge), organization of facts and ideas around a conceptual framework to facilitate its use in various contexts (connections within and across courses), and helping students reflect on what they do or do not understand (metacognitive strategies) [6].

Faculty and student data were collected over the five years of the project. Three sources of faculty data include interviews (subset each year beginning Spring 2016), reports/presentations (subset each year beginning Fall 2016) and teaching practices survey (Spring 2018, Spring 2019). Two sources of data on student perceptions of the learning environment include an end-of-course survey (Spring 2017 through Fall 2020) and a mid-course survey (Fall 2018 through Fall 2020). In what follows, we draw on these sources of data to describe general patterns of changes in instructional practice for the 10 teaching faculty who participated in the project for 3 years. As we describe summary findings qualitatively for a small group of faculty, no data are included here.

## Results and Discussion

### *Implementation of Active-Learning Approaches*

Prior to the start of the project, 8 of the 13 core courses were taught as large lectures. The four-course calculus sequence had multiple sections of approximately 40 students who attended lecture twice per week and problem-solving demonstrations by a graduate teaching assistant (TA) on a weekly basis. One engineering course had multiple coordinated sections of about 40 students per section. Students in this course attended lectures three times per week. The remaining 8 courses consisted of 2 lectures per week and 1 recitation or lab where students work together on problem solving typically under the direction of a TA. Characteristic of all the 13 courses was an effort to cover a large amount of material deemed necessaryfor success in future courses, reliance on multiple-choice exams designed for fast grading, little opportunity for peer-to-peer discussion or interaction during lecture, and relatively more emphasis on procedural rather than conceptual understanding particularly by students [9].

With advocacy from the FOUNDATIONS project, the School of Engineering and Sciences in conjunction with its curriculum committee, responsible for all changes to the undergraduate core and individual programs, has supported significant reorganization of 5 of the 8 large lecture core courses. In each case, these large lecture courses (N=100 to 200 students) were divided into smaller sections (approx. 50 students per section) with support from a graduate teaching assistant and/or an undergraduate peer leader during each of the three weekly meetings. Important here is that the 3rd class session each week is set aside for group problem solving.

Reducing lecture time and increasing instructional activities that involve students in doing things and thinking about what they are doing was a major focus of the project. This was and is particularly challenging for those who teach large lecture courses of 100 or more students. Nevertheless, most faculty recognize the merits of this approach and are making progress, particularly in the course-related, smaller-sized labs or recitations. It is here, and not in large lectures, that students have consistent opportunities to discuss with each other their varying approaches to solving a given problem. They may even come to the board to explain their solution to the entire class. Progress is also being made in smaller lectures (40-50 students). Here faculty use clickers to keep students engaged and to monitor student understanding; some have students discuss clicker responses with their peers before responding to the clicker question a second time. Although two of the faculty who teach large lecture sections were initially resistant to using clickers in class in large part because they did not see how they could facilitate peer to peer discussion among 100 to 200 students, they have recently adopted a strategy for monitoring student understanding on a weekly basis. Using Google forms, they pose a small set of multiple-choice items to the students at the end of the week and thenbegin the next week with a review and discussion of responses. Rather than have students discuss their responses in groups, students are asked to voluntarily share the thinking and reasoning that led them to choose a given response option. Using Google forms is particularly useful because the responses can be displayed in a pie chart so everyone can see and subsequently hear why each response option was chosen and why it was correct or incorrect. This provides a nice opportunity for all students regardless of their response, to better understand key content from the previous week so they can build on that understandingas the course progresses.

Faculty have indicated that well-prepared peer leaders are an essential component of active learning as they facilitate discussion and students' problem-solving activities in class. Engaging peer leaders (e.g., upper-class undergraduate students) to assist in the learning activities in core courses, was an optional project component available to all participating faculty. The project supported and tracked their involvement through faculty interviews and surveys, although faculty took responsibility for selecting, preparing, and monitoring their performance. Faculty surveys indicated that those who taught large lectures did not see a need for peer leaders, while most of those who met with their class 3 times per week relied on peer leaders to facilitate problem solving during the class period set aside for this purpose. As expected, there was some variation in how peer leaders were prepared (e.g., overview of course versus statement of role), expectations (e.g., office hours versus in class support only, rotating around class versus waiting for students to ask for help) and how they were monitored (e.g., weekly meetings or written summaries of challenging problems following each class and/or ad hoc reports from peer leaders when they perceived a problem). Despite the specifics both faculty and students have provided positive feedback regarding peer leader contributions although some faculty have acknowledged the need for additional preparation.

*Strategies to Promote Deep and Transferable Learning*

Beginning with Cohort 1 and continuing with Cohorts 2 and 3, FOUNDATIONS faculty spent considerable time identifying/articulating the key concepts for their course. As part of this effort, they developed an understanding of how their course connects to the other core courses, rethought the rationale for the content they teach and subsequently reduced that content to allow more time to focus on key concepts. Further, faculty became aware of what students should know when they start a course (prior knowledge), variationin nomenclature across courses, and the contexts in which key ideas (e.g., energy, optimization, forces) emerge in various courses. With this understanding, faculty began to draw students' attention to key concepts through multiple examples, point to the relevance of the concept in previous or future courses, and in other ways (e.g., compare and contrast, use of real-world examples) help students to connect their knowledge and develop a deep understanding of the subject matter.

To support learning with understanding (i.e., deep learning), the project has emphasized the need for faculty to challenge students' existing conceptions early and often. Nevertheless, faculty generally rely on their knowledge of student conceptions from years of experience teaching their course; there is generally no explicit effort to assess prior knowledge. Three courses do use concept maps (beginning and end of course) to examine prior knowledge and student documentation of how concepts are related. However, these maps have not been utilized to inform instruction in large part because faculty do not have a quick and easy wayto review/summarize the information.

Metacognitive strategy use, although introduced to each cohort, has only been implemented more recentlyas a direct result of explicit attention to its importance over a series of meetings. The specific methods vary, but the most popular ones include such activities as "exit tickets," "muddiest point" statements, lecturesummaries, and weekly reports. All ask the students in one way or another to identify what they have learned and what they feel they do not sufficiently understand. During FOUNDATIONS meetings, the faculty shared what they did, when they did it (e.g., daily, weekly), how they did it (e.g., Google forms, Canvas quiz) and the results of their efforts (typically percentages of students giving various responses). These meetings served to encourage others to adopt a strategy when they heard from their peers about the advantages of their approach, positive student feedback, benefits to the instructor (understanding of areas of student difficulty), and awareness of how little time these strategies require.

*Efforts to Support the Spread of Evidence-Based Approaches*

A central challenge for the project has been to engage all FOUNDATIONS faculty in research about their practice following the work of the discipline-based education research (DBER) community. Although faculty read some of the DBER literature and discussed data and/or lack thereof for various innovations, they perhaps needed more explicit discussions of how they could measure change in their course. Similarly, faculty conference presentations and/or publications or other strategies for sharing project experiences and outcomes have been far less than was expected at the outset of the project. In contrast, following the move to remote learning, 8 of the 10 faculty volunteered to share best practices internally either through participation in Teaching Practices or Assessment task forces and/or preparation of webinars describing strategies that have been successful for engaging students in the courses they teach.

In the courses that were restructured to reduce class size, the FOUNDATIONS faculty who led that effort took on the responsibility of mentoring all the non-FOUNDATIONS faculty who taught one or more sections of that course. For example, in one course, a FOUNDATIONS faculty coordinates the efforts of five faculty as part of a large lecture course reorganization. All of these faculty use peer leaders to promote in-class discussion, engage students in problem solving, and provide pre-class worksheets and weekly quizzes to scaffold learning.

## Summary and Conclusions

Faculty interviews, surveys, and progress reports in conjunction with student course surveys indicate important changes in instructional practices including: (a) Increased use of peer-to-peer learning; (b) Reorganization of large science lectures into smaller, more student-centered sections that favor pre-class worksheets, weekly quizzes, and group problem solving; (c) Decrease in faculty-led lectures to accommodate student led problem solving and reporting out of their solutions in class. In this context, peer leaders have been a notable strategy found successful during the project. To promote deep and transferable knowledge the faculty have articulated critical course concepts, reduced course content, and discussed how key concepts are connected across courses. Further they have increased efforts to highlight connections within and across courses during instruction. Project faculty have formally shared knowledge and experience gained from the project with their peers internally most notably through webinars and committee participation and this forms an important spread path for further adoption. More informally they are initiating spread, such as in coordination of non-project faculty in large multi-section courses.

There were differences in the implementation of strategies between those who taught large lecture courses and those who taught smaller sections. Those who taught smaller sections were more likely to adopt active learning strategies from the beginning of the project; some were using clickers to engage students in discussion before the project started. It took a little longer for those teaching large lectures to integrate opportunities for student participation/discussion during class. Long term strategies to support faculty change allow all faculty time to implement strategies that work for their circumstances.

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