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

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Introduction

Universities nationwide, especially those with a research focus, are challenged to improve the quality of teaching and the skills and professionalism of their faculty in the teaching domain. In this context, the authors undertook a five-year project, funded by the National Science Foundation EHR/IUSE program, to support transformation to evidence-based teaching and learning practices in the core mathematics, science and engineering courses taken by all engineering students in their first two years at Stevens Institute of Technology. Strategies to support faculty change include ongoing discussions of the principles of teaching and learning and discipline-based education research; trained undergraduate 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.

The project has two foci. The first is to provide support and recognition to enable faculty who teach the critical early core courses to adopt evidence-based practices and target deep and transferable learning within and across disciplinary domains. Evidence-based instructional practices are defined as those derived from research on cognition and how people learn [1-3]. Examples include presenting authentic real-world problems for students to solve, providing in-class opportunities for peer-to-peer learning, and supporting self-directed learning. These practices are designed to enable students to master core academic content, think critically, solve problems, apply learning to new contexts, and become active agents in their own learning.

The second is systemic change and organizational transformation – i.e., to create a climate where effective teaching is expected, supported and rewarded; thereby transforming teaching and creating a culture whereby effective teaching is highly valued. Research on the adoption of evidence-based instructional practices has demonstrated that during early-stage implementation individuals' perceptions of evidence-based instructional practices, and their perception of the extent to which the institutional context expects, supports, and rewards the use of evidence-based instructional practices, are key determinants of adoption [4-9].

Approach

In this project, we investigate and assess the effectiveness of a strategy that simultaneously targets both individuals and the organizational environment, and progresses from defined or prescribed changes to emergent or adaptive changes. The role of full-time, non-tenure stream teaching faculty is explicitly examined, firstly because teaching faculty are largely responsible for the core introductory courses at Stevens Institute of Technology, and such faculty are increasingly key contributors to the education enterprise at research universities. Secondly we wish to contrast how they perceive and embrace evidence-based approaches versus the tenure-stream faculty who are balancing their research focus with their teaching focus and may perceive and respond to situational and cultural impediments to change differently. We also wish to test the idea of teaching-stream faculty as early adopters who can then help with diffusion of

evidence-based practices to their faculty colleagues. The evaluation of the success of the project will look at changes at the faculty level, the student level and the system (university) level.

Using a cohort model, nine faculty who teach core courses are invited and initially supported in the summer to participate as a Foundations Faculty for three years. During this time, they meet with other participating faculty to discuss research on teaching and learning and how this applies to their classroom, exchange strategies for incorporating evidence-based practices into their course(s), participate in workshops, conduct research on their own practices and share the results.

To maximize the impact of changes in teaching practices, the project targets the introductory core courses of the engineering curriculum (Table 1), currently followed by approximately 70% of undergraduates at the university, about 650 students per year. Students in basic sciences and computer science programs, another 15% of the population, take a subset of the courses, **s**o the program will impact ~85% of undergraduates at Stevens, of whom 28% are women and 12% underrepresented minorities. For clarification of Table 1, a core thermodynamics requirement is met through three "flavors', mechanical (ME 234), chemical (CHE 234) and general engineering core thermodynamics (E 234). The 4-credit Calculus 1 (MA 121, MA 122) and 2 (MA 123, MA 124) courses are split into two sequential half-semester 2-credit modules, with also a pre-calculus module (MA 120) for entering students with weaker preparation. This modularization is an innovation that preceded the Foundations project and provides progress flexibility that has enhanced student success. It should also be noted that engineering students at Stevens do not officially elect their major until late in the third semester, so all follow a core sequence then typically take two technical electives defined by the major in semester four.

Table 1. Core Courses and Sequence (Engineering) included in the Foundations Project

Discipline	Semester			
	First	Second	Third	Fourth
Mathematics	pre-Calculus (MA 120), Calculus 1 (MA 121;122)	Calc. 2 (MA 123; 124)	Calc. 3 (MA 221)	Calc. 4 (MA 227)
Science	General Chemistry 1 (CH 115)	Gen. Chem. 2 (CH 116) *or* Biology (BIO 281) *and* Physics: Mechanics (PEP 111)	Physics: Electricity & Magnetism (PEP 112)	
Engineering Sciences	Introduction to Programming (E 115)		Mechanics of Solids (E 126) *and* Circuits & Systems (E 245)	Thermodynamics (E 234, ME 234 or CHE 234)

Beyond the summer support provided by the project to the faculty members who teach the critical early core courses, other support strategies include: ongoing discussions of principles of teaching and learning and discipline-based education research; trained peer assistants to facilitate active learning pedagogies in lectures and recitations; student midterm course evaluations as formative feedback; and advocacy with colleagues internally and externally to catalyze diffusion

beyond these early courses. Monthly meetings combined with workshops that target specific aspects of evidence-based practices (e.g., cross course connections, transfer, deep learning), and research on their own practices provides the Foundations faculty with substantive knowledge necessary to successfully effect change in their practice.

Assessing Project Impact

The extent of faculty participation and classroom transformation is examined through the lens of limiting factors analysis (LFA), which shifts the focus from looking solely at short-term outcomes to an analysis of those factors that need to be in place if the project is to remain effective over the long term, then addressing those factors and assessing the results. The methodological approach is through repeated sets of interviews with participating faculty, department heads, and university administrators each year of the project.

A faculty teaching practices survey, administered midway through each semester, is being introduced in the Spring 2018 semester to examine faculty perception of strategies to support student learning, including use of teaching assistants (TAs) and peer mentors, study guides, online resources such as homework tutors, and feedback on student work. The survey is being administered to all faculty members who teach the core courses, allowing comparisons between Foundations and non-Foundations faculty. Classroom observations are also being conducted for faculty who have participated for two years and will provide rich descriptions of the nature of faculty-student interaction. The results are not yet available. However, as part of the Limiting Factors Analysis research, a teaching practices survey was given to the first cohort of Foundations faculty after approximately one year of involvement. The results from that small group are shown in the Results section Table 2 below and discussed.

Student transformation is being measured through midterm and end-of-course surveys, again comparing those in sections taught by Foundations faculty to those taught by non-Foundations faculty. The midterm surveys are being conducted for the first time in the Spring 2018 semester and these initial results are therefore not yet available. Traditional measures of retention may not show change because retention rates are high at the university. Key questions include: To what extent do students embrace active-learning strategies? Are students more receptive to particular strategies than others? Are there gender differences?

Beginning in the Spring 2016 semester, three questions were added to the end-of-course student evaluation surveys for all core courses listed above, regardless of faculty participation in the project. Questions focused on motivation to learn material, perceptions of active learning opportunities, and cross course connections. Students were asked the extent to which they agree or disagree with each question on a scale from 1 (Strongly Disagree) to 5 (Strongly Agree). Data from these student assessment questions in Spring 2017 are shown in the Results section Table 3.

The extent of system and overall faculty transformation is measured by a campus-wide survey designed to understand the perceptions of faculty across academic disciplines with respect to: (1) the value and utility of various teaching practices to promote student learning and (2) the institutional factors that promote/inhibit effective teaching. So that the survey data could serve as a baseline against which progress in achieving the program goals may be measured, survey data

was collected prior to intervention of the Foundations project team to influence the faculty's understanding, acceptance, or adoption of evidence-based instructional practices. A "diffusion of innovations model" is applied to research the institutional transformation process, but with an expectation that only Stage 1 Depth and the transition to Stage 2 Spread can be accessed during the project. Some results of the baseline survey are in the Results section Table 4 and discussed.

Results and Discussion

Faculty Practices

During their first year on the project, faculty revised one or more aspects of a core course they regularly teach. Faculty members drew on the seven principles of teaching and learning introduced during the project kickoff meeting as a starting point for thinking about changes [1].

Table 2. Changes to Faculty Teaching Practices

Change to practices identified for implementation by Foundations faculty, their perceived level of change and the percent of faculty making those ratings (only those changes that 50% of more of the faculty identified are included)	**No change needed or already changed**
Have worked to **reduce the content** to focus on the most important topics.	63%
Tell students what I expect them to learn for each lesson.	63%
Provide electronic quizzes that give students **immediate feedback** on their understanding.	63%
Try to **surface misconceptions/misunderstandings** during class.	50%
Show students **more than one way to reach an answer**.	50%
Have students work in **collaborative groups or pairs** to solve problems or complete assignments.	50%
Have students work on **real-world problems** or contextual examples.	50%
Hold all students in a **group accountable** for group projects.	50%
	Moderate Change
Provide means for students to **ask questions outside of class** (i.e., discussion forum, chat).	50%
Use peer mentors to support student problem solving and/or reflection.	50%
	Big Change
Teach strategies for solving problems rather than ways to solve a specific problem.	63%
Ask students to reflect on the process they used to solve a problem or resolve an issue.	63%
Make adjustments during the course based on informal student feedback.	63%
Design assignments and/or classroom work to **elicit student prior knowledge**.	50%
Show students more than one way to reach an answer.	50%
Provide students with a **mix of individual and group work in class**.	50%
	Future Change
Provide **feedback to peer mentors** on the effectiveness of their instructional strategies.	88%
Provide **feedback to TAs** on the effectiveness of their instructional strategies.	75%
Coach peer mentors on strategies to elicit student input/thinking.	75%
Coach peer mentors on strategies for facilitating group work.	75%
Use peer mentors to support student problem solving and/or reflection.	50%

Important here is prior knowledge, structure of knowledge, motivation, mastery, goal-directed practice and feedback, and monitoring. For example, knowing that students' prior knowledge can help or hinder learning, faculty had their students construct a concept map to demonstrate their understanding of relationships among key concepts. Further, to maintain student interest and motivation, faculty engaged students in discussion of problems in contexts relevant to their lives.

Table 2 shows results from the teaching practices survey given in April 2017 to eight Foundations Cohort 1 faculty who began with training and review of their teaching practices in Summer 2016. This survey was part of the Limiting Factors Analysis research which also includes regular interviews with faculty. The survey asked the faculty about evidence-based practices that they had identified for implementation in their courses and their perceived level of such change. As the survey had only eight respondents, too few for statistical analysis, the results are therefore presented as frequencies and need to be read cautiously. Only items where 50% or more of respondents identified a practice in a category of change are included.

The first set of items in Table 2, where over half or more of the respondents felt they had already changed or did not need to change, reflect the ongoing work in the Mathematics department for calculus courses and the Mechanical Engineering department to streamline the content of some of the Foundations courses, as well as some of the changes that respondents had already implemented. Some of these changes preceded the Foundations project. There were only two items where 50 percent or more of the respondents reported "big" change. The first was due to the increased use of Canvas as a learning management system and the second to the introduction of peer mentors through the project. There were more items where 50 percent or more reported "moderate" change. These were all items that had been introduced or reinforced through the project. Finally, there were many items where half or more reported that they planned to change. These were all related to the use of undergraduate peer mentors, introduced through the project, and the recognition that both graduate TAs and undergradute peer mentors were an essential component of the ecology of learning, a recognition that had come to the fore during the year. The 50 percent who expected to use peer mentors in the future might have done so earlier—as had the 50 percent who reported this as a major change—but had not yet had the opportunity to do so.

Student Responses

Table 3 shows the results of the three supplemental questions added to end-of-course evaluation surveys taken by students for the 13 core courses in Spring 2017. Responses were received from 1439 students in 49 sections. The overall response rate was 56% with a wide range of 10% to 86% by course section.

Of the 1439 respondents: 34% were female and 66% were male, with 36% in sections taught by Foundations faculty and 64% in sections taught by Non-Foundations faculty. Of the 49 sections 29% were taught by Foundations faculty and 71% were taught by Non-Foundations faculty. In comparing courses taught by Foundations faculty and Non-Foundations faculty, the mean scores for all questions on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree) were all greater than a neutral 3. With some variation in the size of the effect, but all meeting the significance test, the Foundations faculty had mean scores that were greater on average than for Non-Foundations

faculty on all survey questions except Q1D. The latter is not surprising in that it was expected that getting a good grade is a major motivator for students and not likely dependent on teaching approach. The biggest difference was for Q2, which pointed to the beneficial impact of the active learning approaches adopted by Foundations faculty. Gender differences were mostly non-significant, except for questions 1B and 2 for which male students rated a little higher than female students.

Table 3. Student responses to supplemental course evaluation questions

End-of-Course Student Evaluation Question	**Foundations Faculty** (N=519)		**Non-Foundations Faculty** (N= 911)	
	Mean	SD	Mean	SD
Q1. I was motivated to learn the course material because:				
A. I am interested in the subject.	3.9*	1.1	3.7	1.2
B. The professor made the subject interesting.	3.8*	1.1	3.5	1.3
C. This subject is a prerequisite to other courses in my major.	4.2*	1.0	4.1	1.1
D. I wanted to get a good grade in the class.	4.6	0.6	4.6	0.7
Q2. Opportunities to actively participate in class helped me understand the course material.	4.1*	0.9	3.6	1.2
Q3. It is clear to me how this course is related to my other courses.	4.1*	1.0	3.9	1.1

*NOTE: all questions have the same response options. (1=Strongly Disagree, 2=Disagree, 3=Neither Disagree nor Agree, 4=Agree, 5=Strongly Agree). *Significant differences p<.05*

Organizational Transformation

Consistent with the literature, the Spring 2016 campus-wide baseline survey in summary showed that evidence-based practices were generally perceived by faculty as not supported or rewarded, not easy to implement, and require development of new skills. Where faculty had a more positive view it was correlated with perceived relative advantage and compatibility with current practices.

While the data are not shown here, the baseline survey results showed the existing use of evidence-based instructional practices was modest and did not vary significantly with respect to non-tenure track or tenured/tenure track status, total years of full-time teaching experience, whether the faculty member teaches large or small section sizes, or for faculty in the School of Engineering & Science (SES) whether the faculty member predominately teaches engineering core courses or not.

Perception results from the faculty baseline survey are given in Table 4 for faculty in the School of Engineering & Science (SES). It presents the range, mean, standard deviation, and Cronbach alpha for all measured variables for SES respondents. All variables were on 5-point scales with "5" representing a higher degree or frequency of the measured variable. All the measured variables evidence acceptable psychometric properties. It should be noted, relative advantage evidences

some range restriction. This may make it more difficult to detect a relationship where indeed one may exist. Cronbach's alpha for the measured variables ranges from .68 to .95. With one exception, these values are all above .70 which is deemed acceptable scale reliability for research [10].

Table 4: Baseline Faculty Survey
Descriptive Statistics for Theoretical Variables – SES Respondents (n = 74)

Measured Variable	**Min**	**Max**	**Mean**	**SD**	**Cronbach Alpha**
Values Compatibility	1.67	5.00	4.41	.74	.89
Relative Advantage	3.00	5.00	3.69	.86	.75
Climate for Implementation	1.00	5.00	2.71	.91	.95
Compatibility with Existing Instructional Practices	2.00	5.00	3.52	.83	.92
Ease of Use	1.00	4.00	2.91	.63	.68
Use of Evidence-Based Instructional Practices	2.00	5.00	3.70	.49	.79

Several points are noteworthy in Table 4. The mean value of 2.71 on the climate variable indicates a rather weak climate for implementation. This means the use of evidence-based practices is not generally perceived as expected, supported, or rewarded within the School of Engineering and Science. The mean value of 2.91 on the ease of use variable means SES faculty perceive the adoption and use of evidence-based instructional practices as not easy to implement, requiring the development of new skills and understandings. The mean values of 3.69 and 3.52 on relative advantage and compatibility with existing instructional practices, respectively, imply that SES faculty perceptions of evidence-based instructional practice are fairly "lukewarm" rather than positive. It should be noted that at this point in time, active intervention to create more favorable perceptions has not occurred. Therefore, these data represent the baseline data against which progress may be measured.

As noted above in Figure 2 for the faculty teaching practices survey part of the Limiting Factors Analysis (LFA) research, in addition to changes to their course delivery, well-prepared peer mentors and TAs are an essential component of the ecology of active learning. In their interviews as part of the LFA, faculty indicated that student feedback suggested reluctance to accept curricular changes, preferring instead to attend lecture and memorize content, a strategy that has been successful for them in the past with respect to good grades. The data in Table 3 show good grades are the primary motivational factor for students and any threat to that from implementing evidence-based approaches has to be addressed in getting student support.

The Foundations project has sponsored a number of workshops in the 2016/2017 and 2017/2018 academic years in which experts were brought to campus to give an in-depth workshop related to evidence-based teaching practices for Foundations faculty. As part of the strategy to promote

diffusion of these practices, each of the experts was also asked to provide a more general workshop on their area of expertise open for all university faculty to attend.

A significant institutional transformation outcome that has occurred already through engagement and advocacy by the project team with institutional senior leadership, and in turn their recognition of the potential benefits to the institution of success of the project approach, has been the incorporation of an explicit goal to implement evidence-based teaching practices in the University's most recent revision of its strategic plan. This places some responsibility on academic leadership and we plan to examine how that impacts the climate for change.

Summary & Conclusions

The Foundations project is designed to improve teaching and learning at a research university through adoption of evidence-based approaches. The strategy is to initiate this through a focus on the teaching practices in the foundational core courses of the undergraduate engineering curriculum. From this base we plan for diffusion to promote adoption in the broader faculty community through assessment of success, faculty advocacy and through administrative support. To date, one or more faculty members teaching in 10 of the 13 foundational core courses has implemented changes to the course content and their own pedagogy. Changes include use of concept maps to gauge prior knowledge and highlight cross course connections, review of the needed content and the way the course objectives and outcomes are communicated to students, peer-to-peer learning to support effective problem solving, and greater use of formative assessment. Limiting factors that are perceived to impede adoption of evidence-based approaches are being identified through regular faculty and student feedback so they can be addressed.

This paper has focused on the baseline perceptions and practices of the faculty in general and the results from the first year of implementing the project with faculty Cohort 1 on their practices and on student responses. At the university level, ongoing efforts by the PI and other project members have been instrumental in changes to the university's strategic plan to embrace evidence-based teaching and a more holistic evaluation of teaching. This is an important development that will significantly assist the institutional culture change that is a key component of the project.

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