The Role of Collaborative Reflection on Shaping Engineering Faculty Teaching Approaches

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ABSTRACT

Over the last several years, engineering faculty and learning scientists from four universities worked in collaboration to develop educational materials to improve the quality of faculty teaching and student learning. Guided by the How People Learn (HPL) framework, engineering faculty worked in collaboration with learning scientists to develop learner-centered, student-focused instructional methods. In consultation with learning scientists, engineering faculty carried out educational inquiry in their classrooms aimed at investigating student learning and enhancing instruction. In this paper we discuss the extent to which faculty engaged in these collaborative endeavors and how their teaching approaches differed as a result of their level of engagement. Study findings reveal the role that collaborative reflection plays in shaping teaching approaches. Results from this study provide insights for researchers and other practitioners in engineering and higher education interested in implementing engineering faculty development programs to optimize the impact on teaching.

Keywords: collaboration, faculty teaching approaches, reflection

I. INTRODUCTION

The past decade has experienced an increase in funding to support small and large-scale efforts to enhance and reform engineering education. The increase in external funding has supported efforts that span the engineering education enterprise including curricula development activities (e.g., Roselli and Brophy, 2006; Baker et al., 2007), assessment methods research (e.g., Olds, Moskal, and Miller, 2005), and investigation of the development of professional skills (e.g., Shuman, Besterfield-Sacre, and McGourty, 2005), to name just a few.

The current study takes place in the context of one of the large-scale funded efforts to reform teaching and learning in the field of biomedical engineering education. In this case, the funding was provided to engineering departments; however, the research was education-focused. The investigators recognized that in order to carry out effective research, the participants needed to be inclusive of not only the engineering faculty, but also individuals who had expertise in learning science principles, assessment, curricula development, and research methodologies appropriate for education research. Thus, the work was organized such that teams of individuals with different but relevant expertise worked together to carry out the research. This approach is consistent with Wankat et al.'s (2002) claim that "multidisciplinary collaboration between engineers and non-engineers is essential if the scholarship of teaching and learning in engineering is to attain a suitable level of professionalism" (p. 9).

To maintain consistency within our multidisciplinary collaborations, and to guide our education reform efforts, we followed the pedagogical principles as described in the How People Learn (HPL) framework (Bransford, Brown, and Cocking, 1999). The HPL framework outlines four principles for structuring the classroom setting to provide a productive learning experience for students. Specifically, the HPL framework suggests that classroom environments be: 1) learner-centered, 2) knowledge-centered, 3) assessment-centered, and 4) community-centered. Briefly, a learner-centered approach attempts to expose students' prior conceptions and connect new learning to them; a knowledge-centered approach promotes conceptual understanding and organization of the knowledge; an assessment-centered approach gives frequent opportunities for formative feedback; and a community-centered approach uses students' peers in the learning and also attempts to connect students to the way professionals might work. Bransford et al. (1999) suggested that HPL could be a vehicle to enhance students' ability to learn and transfer concepts across settings and time. Pedagogy consistent with the HPL framework emphasizes the overlapping concepts of learner-centered, knowledge-centered, assessment-centered, and community-centered education.

In our multidisciplinary collaborations, engineering faculty worked together with learning scientists to develop course materials and assessments, to evaluate student learning, and to co-author education research articles. These collaborative efforts could be described as a "real-time" process of faculty development situated within the actual classroom environment as the teaching/learning takes place. The collaborations also consisted of ongoing reflection and discussion to interpret how the HPL principles can be effectively applied to address particular learning and teaching goals (McKenna et al., 2003).

Our study documents faculty approaches to teaching over a five-year period. We are interested in how ongoing collaborations with learning scientists can potentially influence faculty approaches to, or conceptions of teaching. Specifically, our research investigates three primary questions: 1) what is the nature of the engagement of faculty with the education-focused research collaborations with learning scientists? 2) To what extent does a faculty member's level of engagement with the collaborative efforts impact his or her approaches to teaching? 3) What are engineering faculty conceptions of teaching as defined by Prosser and Trigwell's (1999) categorization of approaches? Examining the impact on faculty conceptions of and approaches to teaching is important since it can be linked both directly and indirectly to student learning. Furthermore, if education reform is the goal, university faculty are critical participants and perhaps are the most influential factors in shaping educational change. Therefore, understanding engineering faculty approaches to teaching, and characterizing the nature of the collaborative activities that help shape their teaching approaches, shed light on efforts aimed to improve faculty development in higher education. Furthermore, since this study was focused within the discipline of engineering, our findings contribute to the literature on disciplinary differences in university teaching and learning (Lindblom-Ylanne et al., 2006; Neuman, 2001; Neuman, Parry, and Becher, 2002).

Results indicate that "level" of participation in specific educational activities was a contributing factor in characterizing faculty approaches to teaching. In particular, faculty teaching approaches and strategies fall into a spectrum where the engagement levels identify the degree to which those approaches and strategies are learner-centered/student-focused. Specifically, higher levels of engagement coincide with more nuanced ways of reflection, and results indicate that collaboratively reflective activities have been shown to impact faculty teaching approaches from a focus on knowledge transmission to an emphasis on conceptual change.

II. Related Literature

The education enterprise consists of many interrelated processes. In somewhat simplified terms, an engineering classroom is comprised of learners, teacher(s), and curricular materials. Since our study was designed to focus specifically on the teaching aspect of the enterprise we turn to the literature to make the link between teaching approaches and student learning, and to characterize specific teaching and learning approaches.

A. Linking Teaching Approaches to Student Learning

Research focused on faculty teaching approaches suggests that a student-centered, learner-focused teaching approach promotes deeper and more meaningful student learning, and that there is a relationship between faculty approaches and student learning (Gow and Kember, 1993; Kember and Gow, 1994; Trigwell, Prosser, and Waterhouse, 1999; Prince and Felder, 2006). For example, in his review of literature regarding faculty teaching approaches, Kember (1997) states that there is a relationship among student conceptions of learning, learning approaches, and learning outcomes.

Trigwell, Prosser, and Waterhouse (1999) investigated the relationships between the ways teachers approach teaching and the ways their students approach learning. They found that qualitatively different approaches to teaching are associated with qualitatively different approaches to learning. That is, university faculty whose teaching approaches are student-centered and learner-focused, encourage their students to adopt significantly deeper approaches to learning. Conversely, faculty whose teaching approaches are content-centered and teacher-focused promote a surface learning approach in students.

Similar claims have been made by several others in the engineering education community. For example, Prince and Felder (2006) conducted an extensive overview of "inductive teaching methods" such as inquiry learning, problem-based learning, and case-based teaching—all of which are considered to be learner/student-centered approaches. They conclude in unequivocal terms that "collective evidence favoring the inductive approach over traditional deductive pedagogy is conclusive ... inductive methods promote adoption of a deep approach to learning ... intellectual development ... and helping students acquire the critical thinking and self-directed learning skills that characterize expert scientists and engineers" (Prince and Felder, 2006, p. 135). In addition, Hake (1992) has conducted extensive research, in particular with physics students, that indicates that student-centered approaches such as peer discussion and the Socratic method have been effective in guiding students to construct a coherent conceptual understanding of Newtonian mechanics.

Consistent with the student-centered and learner-focused approach is Astin's (1999) "student involvement theory." According to Astin's theory, the greater a student's involvement in college, the greater the amount of student learning and personal development. As Astin states, "the principal advantage of the student involvement theory over traditional pedagogical approaches is that it directs attention away from subject matter and technique and toward the motivation and behavior of the student" (p. 529).

Finally, Smith et al. (2005) provide an overview of "pedagogies of engagement," a term used to describe teaching practices that encourage student-faculty contact, cooperation among students, and active learning. In their overview, Smith et al. explain that student-centered pedagogies of engagement, such as cooperative learning, promote student outcomes in three major categories: academic success, quality of relationships, and psychological adjustment to college life.

Therefore, the literature provides compelling evidence to support the relationship between faculty approaches to teaching and meaningful student learning. Consequently, if the ultimate aim of instruction in higher education is to help promote meaningful student learning, faculty teaching approaches become a critical aspect in determining the quality of student learning.

B. Characterizing Student Learning Approaches

Several research studies have categorized student approaches to learning as deep, surface, and achieving or strategic (Biggs, 1978, 1999; Entwistle and Ramsden, 1983). Students who have deep approaches to learning focus their attention on the overall meaning or message in a class session, text, or situation. They view the knowledge they gain as relating the ideas together and creating their own understanding and personal viewpoints. Students with deep learning approaches are more likely to explore the subject beyond the immediate requirements and they are more likely to have positive attitudes toward learning.

Students who have surface approaches to learning focus their attention on the details and information in a class session or a text. The ultimate aim is often associated with remembering and reproducing the information that would help them pass the examinations. Students with surface learning approaches are more likely to have negative attitudes toward learning.

Students who have achieving or strategic learning approaches often engage elements of both the surface and deep approaches. They mainly focus on completing the given task in the most efficient and organized manner. They identify the assessment criteria and develop strategies to pass the examinations to attain the highest possible grade. They are alert and responsive to the cues they pick up about the nature of the course tasks and demands made upon them. While students with strategic approaches often represent the characteristics of a good student, their focus on results means that even students who are inclined to take a deep approach will at times feel this is less strategic than employing a surface approach if, for example, the teaching and assessment practices suggest that rote learning and reproduction of facts will meet the requirements more effectively. Self esteem and competition are crucial in their learning and motivate their strategic study practices.

The literature suggests that quality learning is associated with deep approaches to student learning. Moreover, it is suggested that particular approaches to teaching can influence students to take a deep approach where other approaches to teaching may lead them to take a surface approach (Biggs, 1999). As such, there have been recent efforts in higher education to promote those practices and approaches to teaching which encourage students to adopt deep learning approaches (Light and Cox, 2001).

C. Characterizing Faculty Teaching Approaches

Broadly speaking, faculty teaching approaches are often categorized under two distinct orientations. For example, Kember (1997) identified these two approaches as (a) student-centered/learning-oriented and (b) teacher-centered/content-oriented. A teacher-centered orientation focuses on a faculty member's knowledge corpus and the disciplinary content knowledge, and the ways to transmit that knowledge. A student-centered orientation takes a developmental approach toward students and their conceptions of knowledge, aiming at changing students' conceptual understandings and approaches to study.

Trigwell and Prosser (2004) found five qualitatively different approaches to teaching that identified the key aspects of variation with respect to the strategy adopted and the intention underlying the strategy. The five approaches Trigwell and Prosser identified are provided below:

(1) teacher-focused strategy with the intention of transmitting information to students,
(2) teacher-focused strategy with the intention that students acquire the concepts of the discipline,
(3) teacher/student interaction strategy with the intention that students acquire the concepts of the discipline,
(4) student-focused strategy aimed at students developing their conceptions, and
(5) student-focused strategy aimed at students changing their conceptions.

Trigwell and Prosser (2004) maintained that an approach is not an innate characteristic of an individual. Approaches are dependent on context and can vary over time. This has implications for how one interprets the scale. As one develops a conceptual change approach, the scale becomes hierarchically inclusive: for example, approach 3 subsumes approaches 1 and 2. That is, the intention that students acquire course concepts employing interactive techniques includes, for example, the goal of providing information to the students. The hierarchy of approaches does not describe a process of developmental stages. For a teacher to move from approach 1 to 5, she might not need to go through each precise step.

In addition, a teacher who is aware of and takes approach 5 in one context could shift to approach 2 or 1 in a very different context. A teacher who teaches an upper level seminar might take a different approach to teaching than when teaching a large freshman lecture course. Teachers who are only aware of the lower level approaches, however, do not, normally shift to higher level approaches. As a scale of teaching, the five approaches to teaching provides a framework related to student learning outcomes for describing the sophistication and the development of faculty teaching. Studies of faculty development have shown positive changes can follow from participation in intensive formal programs (Gibbs & Coffey 2001; Light et al., 2008), but little research has looked at resultant faculty approaches to teaching in collaborative contexts focused on educational innovation.

In this study, we used the framework introduced by Prosser and Trigwell (1996, 1999) to investigate faculty approaches to teaching. Similar to other studies, Prosser and Trigwell (1999) discuss the characteristics of university faculty teaching approaches identified by two distinct approaches: Information Transmission Teacher Focused (ITTF) and Conceptual Change Student Focused (CCSF). The ITTF approach is one in which a faculty organizes lectures around a taxonomy of concepts or topics to be covered. In this approach, faculty design their instructional materials based on the availability of resources, or their individual knowledge base. Lectures are used to present, or transmit, the subject matter. Students often take an exam at the end of the instruction that enables the instructor to perform summative assessment of student performance. The success of the instruction is judged on the extent to which students' responses to the exam items are consistent with the textbook or the faculty's perceptions.

In contrast to the ITTF approach, the CCSF approach organizes the subject matter around students' pre-understanding instead of the textbook or teacher's knowledge corpus. Prior to and during instruction, faculty often ask questions such as "What do my students know or not know?," "How can I best achieve my teaching goals?," and "How can I evaluate achievement?" Students' capabilities, interests, and limitations are key elements that shape faculty teaching strategies.

Consistent with the CCSF approach, faculty utilize a variety of teaching methods to see which ones work more effectively for students' conceptual development. Group work, challenge-based instructional strategies, and the use of technology to foster students' participation and interest are some strategies that focus on students' active participation in learning (Prince and Felder, 2006;

Faculty affiliation	# of faculty participated	Gender	Academic Status			
			Assistant Professors	Associate Professors	Professors	Lecturer/ adjunct faculty
University A	17	2 (female)	1			1
		15 (male)	6	1	8	
University B	11	3 (female)	2	1		
		8 (male)	3	1	4	
University C	8	2 (female)	1	1		
		6 (male)	1	3	2	
University D	3	2 (female)			1	1
		1 (male)			1	
Others	15	3 (female)	2	1		
		12 (male)	6		6	
Total	54	12 (female) 42 (male)	22	8	22	2

Table 1. Faculty participants' demographics.

Smith et al., 2005; Kolikant, McKenna, and Yalvac, 2005; Roselli and Brophy, 2006). In the CCSF approach, the assessments are often more open-ended and qualitative so they capture students' conceptual understanding instead of purely factual information and/or rote memorized tasks and procedures.

The ITTF and CCSF categories present two opposing ends of a continuum of teaching approaches, and as suggested above, research in higher education suggests that there are varied approaches that fall between the ITTF and CCSF approaches.

III. Methods

A. Research Questions

The current study explored the extent to which the engagement in the collaborations with learning scientists impacted engineering faculty conceptions of and approaches to teaching. The following questions guided our research:

1) What is the nature of the engagement of faculty with the education-focused research collaborations with learning scientists?
2) To what extent does a faculty member's level of engagement impact his or her approaches to teaching?
3) What are engineering faculty conceptions of teaching as defined by Prosser and Trigwell's (1999) categorization of approaches?

B. The Study Context

In 1999, the U.S. National Science Foundation funded an Engineering Research Center (ERC) constituting four U.S. institutions. The ERC was organized such that learning scientists and engineering faculty worked in collaboration, locally and across institutions, to develop, implement, and evaluate learning science design principles and teaching methods aimed at improving teaching and meaningful student learning in engineering education. Most of the design principles and teaching methods were derived from the HPL framework (Bransford et al., 1999). The HPL framework has been applied to a range of engineering education settings (e.g. Birol et al., 2007; Greenberg, Smith, and Newman, 2003; Yalvac et al., 2007; Linsenmeier et al., 2008).

C. Participants

The participants of this study were engineering faculty who engaged in the work of the ERC. All engineering faculty who were associated with the ERC were asked to participate in the study. Approximately 95 percent of the faculty completed the study instruments. The remaining 5 percent had either left the program during the data collection or were on sabbatical and could not be reached. For comparison purposes, we also collected data from faculty who were not formally affiliated with the ERC activities. The "non-ERC" faculty participants were recruited at meetings, workshops, and other outreach activities. To explore potential differences in faculty's teaching approaches, we collected data from ERC faculty ($n = 24$) and non-ERC faculty ($n = 30$) at various time intervals. Non-ERC faculty responded only once but in some instances ERC faculty responded two or three times, depending on how long they had been involved in the ERC. Data from the non-ERC faculty enabled us to determine if the ERC faculty approaches differed from faculty at peer institutions who had not participated in such an ERC collaboration. Overall, we collected data in dozens of locations across the U.S. during 1999 to 2005.

Participating faculty demographics are represented in Table 1. The total number of female faculty was 12, and male faculty was 42. Overall, our study sample consisted of 22 assistant professors,

Subscale	Associated items
Conceptual change/student focused – Intention (CCSFI)	I feel that the assessment in this subject should be an opportunity for students to reveal their changed conceptual understanding of the subject.
	I encourage students to restructure their existing knowledge in terms of the new way of thinking about the subject that they will develop.
	I feel that it is better for students in this subject/course to generate their own notes rather than always copy mine.
	I feel a lot of teaching time in this subject/course should be used to question students' ideas.
Conceptual change/student focused –Strategy (CCSFS)	In my class/tutorial for this subject I try to develop a conversation with students about the topics we are studying.
	I set aside some teaching time so that the students can discuss, among themselves, the difficulties that they encounter in studying this subject.
	In teaching sessions for this subject/course, I use difficult or undefined examples to provoke debate.
	I make available opportunities for students in this subject course to discuss their changing understanding of the subject.
Information transmission/ teacher focused – Intention (ITTFI)	I feel it is important that this subject should be completely described in terms of specific objectives relating to what students have to know for formal assessment items.
	I feel it is important to present a lot of facts in classes so that students know what they have to learn for this subject/course.
	I think an important reason for running teaching sessions in this subject/course is to give students a good set of notes.
	I feel that I should know the answers to any questions that students may put to me during this subject/course.
Information transmission/ teacher focused – Strategy (ITTFS)	I design my teaching in this subject with the assumption that most of the students have very little useful knowledge of the topics to be covered.
	In this subject/course I concentrate on covering the information that might be available from a good textbook.
	I structure this subject/course to help students to pass the formal assessment items.
	In this subject/course, I only provide the students with the information they will need to pass the formal assessments.

Table 2. List of items from ATI subscales.

eight associate professors, two lecturer/adjunct faculty, and 22 professors. For anonymity the participant universities are designated as A, B, C, and D and all fall under the doctoral/research university-extensive Carnegie classification category. Finally, this study was formally approved by our Institutional Review Board and all study participants provided written consent to be included in the study.

D. Data Collection and Analysis

We utilized the *Approaches to Teaching Inventory* (ATI) designed by Prosser and Trigwell (1999). The ATI is a five point Likert-scale designed to capture the differences in the way faculty in higher education approach their teaching and their students' learning. The reliability and the validity of this instrument were carefully examined and tested, and details are provided by Trigwell and Prosser (2004). The ATI contains 16 items that are divided into two sub-scales. Eight questions describe an approach that is student-focused with an emphasis on perceiving teaching and learning as a process of conceptual change (CCSF). The other eight items describe an approach that is teacher-focused with an emphasis on teaching and learning as knowledge transmission (ITTF).

Faculty engagement levels (total n)	Description of the activities completed
Non-ERC faculty (n = 30)	*No participation* with learning scientists or other ERC collaborative activities, might have attended one formal meeting, seminar, or workshop.
Minimal engagement (n = 11)	Affiliated with one of the ERC institutions. Minimum involvement, attended more than one formal meeting, seminar, or workshop.
Moderate engagement (n = 18)	Moderate involv ement, attended several formal meetings, seminars, and workshops. Worked with learning scientists in the *design, implementation, and pre-assessment* of course materials.
Extensive engagement (n = 12)	In addition to the moderate engagement, have worked closely with learning scientists and *systematically assessed* their designed interventions, *re-iterated* their teaching methods, *presented* study findings at conferences or *published* in education-focused academic journals, and *consulted* with other faculty in their design efforts.

Table 3. Engagement levels and the activities associated with each level.

The two sub-scales are further segmented into questions relating to intention and strategy. By doing so the survey separates faculty intentions to teach a certain way from the strategies that one actually uses when teaching a particular class. For example, one may have high intentions to teach in a student-focused way that emphasizes conceptual change but employ more knowledge transmission teaching strategies. The sub-scales of the ATI enable us to capture potential differences between intention and strategy as well as differences between CCSF and ITTF approaches to teaching. Table 2 provides all items from the ATI, categorized by each of the sub-scales.

We also collected faculty demographic information and developed a faculty involvement scale to capture level of engagement in the ERC. We used the level of engagement as the independent variable for examining response patterns to the ATI survey. Faculty completed the involvement scale at the same time they completed the ATI.

Determining one's level of engagement was necessary to answer our research question, "To what extent does a faculty member's level of engagement impact his or her approaches to teaching?" Full descriptions of the engagement levels are provided in Table 3; however, we note that the distinguishing characteristic of the extensive engagement level is the extent to which faculty *reflected* upon their design efforts in a formal and explicit way. Faculty experienced the influence of their design efforts, communicated them with others, held their work up to a peer-review process, and reiterated their designs to improve student outcomes.

For the analysis we grouped the survey items into four subdimensions as previously described. These groups were: (a) conceptual-change student-focused *intention* (CCSFI), (b) conceptual-change student-focused *strategy* (CCSFS), (c) information-transmission teacher-focused *intention* (ITTFI), and (d) information-transmission teacher-focused *strategy* (ITTFS). In order to compare student-focused versus teacher-focused approaches, we also analyzed the data based on the two major groupings: CCSF and ITTF.

IV. Findings

The independent t-test analysis revealed that the minimal engagement level faculty ($n = 11$) approaches to teaching were not significantly different from the non-ERC faculty ($n = 30$) approaches ($t(39) = 1.253$, $p = 0.218$ for CCSF; $t(39) = -0.171$, $p = 0.865$ for ITTF). This result indicates that faculty with a minimal level of engagement have approaches to teaching similar to their peers from other academic institutions. Therefore, the ERC faculty are not particularly distinct from other engineering faculty in terms of entering the program with more sophisticated teaching approaches. After establishing that the non-ERC faculty are similar to the minimal engagement level ERC faculty, the following analysis focused on comparing the three ERC categories.

We computed an independent t-test analysis for the minimal engagement level faculty ($n = 11$) and the moderate engagement level faculty ($n = 18$), and did not find any significant differences ($t(27) = -0.671$, $p = 0.508$ for CCSF; $t(39) = 1.08$, $p = 0.29$ for ITTF). This finding implies that moderate engagement with education-related activities (as defined in Table 3) does not influence faculty teaching approaches. When we analyzed faculty with extensive engagement ($n = 12$) and the other two groups (minimal engagement and moderate engagement), we observed statistically significant differences between minimal and extensive engagement levels ($p < 0.05$). Table 4 shows the means for ATI subscales for each level of engagement, and statistical analysis between extensive and minimal levels.

Sub-scales	Mean by engagement level Min $n = 11$	 Mod $n = 18$	 Ext $n = 12$	Comparison between minimal and extensive levels t-test	 p value
CCSF-Intention	3.3	3.2	3.7	-1.556	0.135
CCSF-Strategy	2.6	3.0	3.2	- 2.677	**0.014***
IITF-Intention	3.0	2.8	2.4	1.882	0.074
ITTF-Strategy	2.9	2.5	2.1	4.233	**0.000***
CCSF-overall	2.9	3.1	3.4	- 2.741	**0.012***
ITTF-overall	2.9	2.7	2.3	3.152	**0.005***

Table 4. Means for ATI subscales for each level of engagement, and statistical analysis between extensive and minimal levels. Statistically significant differences are highlighted with a star (*).

Despite relatively low *n*'s we found significant differences between the minimal and the extensive levels of engagement for both the overall dimensions CCSF and ITTF. That is, faculty with extensive engagement in reflective education activities showed more favorable approaches toward learner-centered, student-focused teaching and faculty with minimal engagement toward a more knowledge transmission, teacher-focused approach. Effect sizes associated with these changes—1.15 and 1.32 respectively—are considered to be large (Cohen 1988). In addition, the results indicate that extensively engaged faculty teaching *strategies* align with learner-centered, student-focused approaches when compared to faculty with minimal engagement.

It is interesting to note that faculty in the moderate engagement category did not show significant differences in their teaching approaches as compared to minimal engagement faculty. Nor was there a significant difference between moderate engagement and extensive engagement. One interpretation might be that participating in education activities as characterized by the moderate level led faculty to move only an incremental step in the continuum from ITTF to CCSF (see Figure 1). The locations of the rectangles for each of the three groups of faculty in Figure 1 loosely illustrate the overall differences between the groups as determined from their responses to the ATI. For example, the results of the minimal engaged faculty place them closer to an ITTF approach. On the other hand, the results of the moderately engaged faculty position them slightly further along toward a CCSF approach, and the results of the extensively engaged faculty locate them much more closely to CCSF approach to teaching than the other two groups.

While not significant, the differences between the minimal and moderate categories on the CCSF and ITTF sub-scales were both in the desired direction with effect sizes of 0.28 and 0.43 respectively, considered small but potentially meaningful. Similarly, the differences between extensive and moderate engagement were in the desired direction on both CCSF and ITTF sub-scales with effect sizes of 0.5 and 0.69 respectively, considered of medium magnitude (Cohen, 1988).

V. Discussion

The study findings indicate that level of participation in collaboratively reflective educational activities was a contributing factor in characterizing faculty approaches to teaching. In particular, faculty teaching approaches and strategies fall into a spectrum where the engagement levels identify the degree to which those approaches and strategies are learner-centered/student-focused. Furthermore, the level of engagement in education related activities seems to impact the nature of one's teaching approaches. For example, faculty with a moderate engagement level attended many meetings, engaged in conversations with learning scientists, and even applied some HPL principles in the design of their teaching materials. Yet, we did not find significant differences in their approaches to teaching. Their response pattern to the ATI survey was not significantly different from the minimal or the non-ERC faculty.

One explanation for this finding is that moderately engaged faculty did not reflect on their teaching and HPL learning materials to the extent that "extensive" faculty did. Extensively engaged faculty collected and analyzed data on student performance, and used this data to further refine their instructional practice. In addition, all extensively engaged faculty have co-authored educational articles on their ERC research activities and presented findings at professional conferences.

Without this type of documentation and reflection on their students' cognitive outcomes and/or desirable attitudes, moderately engaged faculty might have not been convinced that a more learner-centered teaching approach is indeed beneficial. It may be that many of the engineering faculty would agree that a learner-centered teaching approach is preferable to an information-transfer approach, the present study's findings suggest, however, that achieving a conceptual-change/student-focused teaching approach requires more than desire or belief.

Bowden (1988) points out that significant changes to teaching and learning require considerable efforts over a lengthy period of time. Our findings shed light on an important factor that might play a significant role in shaping faculty approaches to teaching. Faculty were more likely to have a conceptual

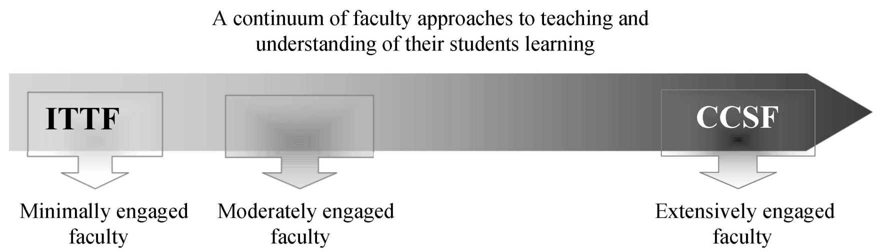

Figure 1. One possible spectrum for faculty with different teaching approaches.

change approach to teaching after engaging in several educational activities such as implementing their newly designed student-centered teaching strategies, evaluating the effectiveness of their interventions, reflecting upon their findings through professional publications and peer-review, and more importantly reiterating the designed methods in subsequent classes. Those opportunities to think about their design endeavors and reflect upon them with input from learning scientists might have led faculty to view teaching and learning from a more critical perspective and have impacted their teaching approaches significantly. However, as Bowden (1988) maintained, for faculty to adopt significantly different approaches to teaching it requires consistent engagement with and commitment to educational inquiry.

Light and Cox (2001) state that "knowing and communicating are virtually inseparable and made possible through socially constituted utterances that characterize language in the stream of life" (p. 24). After a review of epistemological stances ranging from realist perspectives to radical constructivist orientations, Light and Cox conclude that "knowing" is not separated from "communicating." In this framework, meaning is viewed as coming into being through dialogue. In that respect, communication and dialogue are essential to making meaning in professional and academic life and lies at the heart of professional development. In the context of the ERC, meaning making and critical dialogue occurred in large part through the ongoing collaboration between engineering faculty and learning scientists. In particular, each served as an interpreter of their area of expertise: the domain faculty interpreted the subject matter and the learning scientists interpreted the learning theory and suggested strategies for classroom practice. In this way each shared their respective expertise to accomplish a mutually defined goal (Kolikant, McKenna, and Yalvac, 2006).

Our findings are aligned with Light and Cox's description of the reflective professional. The faculty who engaged in collaborative reflection about their design endeavors, communicated their findings with others through peer-to-peer and professional contexts, and reiterated their design on the basis of the communications they made, showed a significant difference in their approaches to teaching in comparison to their peers who did not engage in those activities. Reflective thinking, communicating, and reiterating encourages faculty to be reflective professionals and thereby simultaneously promotes developing sound learning science understandings.

Furthermore, we relate our findings, in particular the issue of reflection, to Kolb's (1984) model of experiential learning. Kolb states that learning is best conceived as a process, not in terms of outcomes, that is, "ideas are not fixed and immutable elements of thought but are formed and re-formed based on experience" (p. 26). Kolb has suggested that learning is a four-stage process involving the four learning modes of concrete experience, reflective observation, abstract conceptualization, and active experimentation.

In Kolb's terms our collaborations served as concrete experiences where faculty actively experimented with developing new curricular materials. However, as Kolb suggests, it is not just experience that contributes to learning; it is the coupling of experience and experimentation with reflection and abstraction that combines to form a holistic adaptive learning process. Therefore, the extensively engaged not only engaged in the concrete and experimental modes, but also reflected on their experiences and, based on these reflections, abstracted principles of teaching and learning. In this way, the collaborative reflections provided a mechanism to support a holistic learning experience as described by the modes presented in Kolb's model, and this reflective experience contributed to the response patterns of the ATI.

To add even more clarity, Mezirow (1998) has described the concept of critical reflection as distinct from reflection. That is, critical reflection is the process of analyzing, reconsidering, and questioning to add depth and breadth to the meaning of one's experience. The extensively engaged faculty participated in a process of critical reflection in collaboration with learning scientists. Each of the partners played a key role in order to elicit the type of dialogue necessary to probe for deep understanding of pedagogy and how it relates to subject matter.

Enhancing faculty approaches to teaching is only one aspect of the call to reform engineering education. One ultimate goal is to create a learning environment to enhance students' learning. As mentioned earlier, the literature supports the relationship between faculty approaches to teaching and student learning outcomes. Since teaching is inextricably linked to learning, it is critical to understand the nature of engineering faculty approaches to teaching. Furthermore, it is not only important to characterize faculty approaches but to also understand the nature of activities that help shape them. The results from the current study contribute to characterizing the nature of activities that contribute to enhancing teaching.

VI. Summary and Future Research

This study suggests that faculty engagement level in reflective and collaborative education-focused activities is a significant factor that contributes to their adoption of more student-centered teaching approaches. Our study showed significant differences between extensively engaged faculty and minimally engaged faculty. These differences suggest that reflective pedagogical activities have significant impact on changing faculty approaches to teaching from an information-transmission to a conceptual-change approach. However, arriving at this level of change requires not only a commitment to changing course materials/teaching, but also critical reflection on and refining practices based on assessment data.

The current study focused on the opposing ends of the conceptual-change vs. information-transmission spectrum. An extension of this work would be to examine the trajectory of change in teaching approaches, that is, to investigate the process of change. In future work we will examine the trajectory of change in faculty's teaching approaches by focusing on case studies, using both quantitative and qualitative data, of specific faculty.

Even though there is considerable literature on varied faculty teaching approaches, we suggest there is more work to be done to characterize the nuances of teaching approaches that are effective with engineering teachers and learners. Results from this study and future studies have the potential to shed light on effective teaching approaches due to the disciplinary nature of engineering. Furthermore, this work contributes to the growing body of literature focused on exploring the nature of multidisciplinary collaborations within engineering education and engineering education research (e.g. Borrego and Newswander, 2008).

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