

Cultivating Evidence-Based Pedagogies in STEM Education

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Cultivating Evidence-Based Pedagogies in STEM Education

Abstract

In this paper, we report the findings of a study that explored the changes in STEM faculty's approaches to teaching and understanding of student learning because of their participation in an ongoing STEM education project. This three-year project is funded by the department of education and aimed at cultivating evidence-based pedagogies in STEM undergraduate education at an Historically Black College and University (HBCU) in US. Four STEM faculty members who were the study participants designed evidence-based instructional strategies that were learner-centered and student-focused. The faculty implemented these strategies in their undergraduate courses and systematically collected data from their students to capture the impact of the newly implemented strategies on students' learning outcomes and experiences. With consultation from the learning scientists of the project, the faculty analyzed the student data collected and reported the findings of their research studies. In the following semester, the faculty participants iterated their design efforts. Participants' approaches to teaching and understanding of student learning were captured prior to the project activities and one year after their participation in the project activities. Both quantitative and qualitative data were collected. Analyses revealed that faculty have improved their teaching approaches from a knowledge-centered and teacher-focused orientation to a learner-centered and student-focused orientation.

Introduction

Science, Technology, Engineering, and Mathematics (STEM) education has attracted a recent interest across the US colleges and universities. Several higher education institutions have formed STEM education focused programs (e.g., Arizona State University, University of California Berkeley) and a couple has established engineering education focused programs (e.g., Purdue University, University of Michigan, Ohio State University, and Virginia Tech). There are ongoing efforts to build STEM education focused programs in some other campuses (e.g., Texas A&M University, University of Georgia, and University of Florida).

The overarching goal of forming STEM education focused programs across the US campuses is to enhance the quality of the college students' STEM learning experiences and attract diverse student populations to choose STEM as their careers. For this purpose, the STEM faculty, who are the major actors in the students' learning experiences, play a central role.

It is critical to ensure that STEM education faculty in general and engineering education faculty in particular in the university levels are well informed about the evidence-based pedagogies. Evidence-based pedagogies are often the ones that are student-centered and learner-oriented. An essay published by the National Science Foundation, How People Learn [1] effectively communicates the characteristics of an ideal learning environment as (a) knowledge-centered, (b) learner-centered, (c) assessment-centered, and (d) 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" [11]. Active learning, cooperative learning, peer-led team learning, peer instruction, problem-based learning, project-based learning, inquiry-based learning, and challenge-based learning are among the research based instructional strategies that are student-centered and learner-oriented [6, 19, 20]. Without the knowledge of the best-practices in education and how people learn, the university faculty will not be able to design an ideal learning environment for their students. It is no surprise that majority of the students, particularly women, drop the STEM fields early in their careers in the college. The traditional instructional strategies employed in the STEM fields might be responsible for abating students' motivation and interest in STEM fields, particularly for women and minority students. A more welcoming and engaging learning environment designed and implemented by the university faculty will encourage women and minority students' motivation and interest in the STEM fields.

Project Rationale and Study Purpose

In order to close the socio-economic gap between the minority students and the others, it is essential to improve the quality of the education in minority serving institutions. Any improvement on STEM students' learning experience and their quality of education will have a positive impact on the US's economy and well being. However any additional improvement on the minority students' learning experience and their quality of education will have substantial impact on closing the socio-economic gap that US struggles for decades. The present study took place at a selected HBCU in US for an overarching goal of improving students' learning experiences and outcomes. For this purpose, authors have proposed a project to widen the implementation of evidence-based pedagogies in STEM education at an HBCU in US and systematically capture the changes in STEM faculty's approaches to teaching and understanding of their students' learning. The project was funded by the department of education and initiated in 2015. The purpose of the study we present here was to explore and document the changes in STEM faculty's approaches to teaching and understanding of learning because of their participation in the project activities.

Literature Review

Widening research-based pedagogies in higher education and transforming the culture of faculty's teaching have been a major objective [14, 15, 16, 17]. For this purpose, numerous projects were set [6, 9, 12, 13, 18, 25, 26]

An in-depth and longitudinal study conducted at an NSF funded Engineering Research Center showed that university faculty are persistent to change their teaching approaches no matter they had attended numerous professional development activities over couple years [11]. Faculty who reported dramatic changes in their teaching approaches were the ones who worked in collaboration with the learning scientists and systematically designed their own evidence based instruction in their own classrooms; collected data from their students with the help of the learning scientists, and published their educational design study results in journals or presented at educational conferences. The essence of the transformation faculty went through was the

“reflection” they did [10], as they interacted with their colleagues at the conferences or during the peer-review phases of their manuscripts.

The authors noted that the participating faculty’s iterative design efforts were the most critical [11]. In the second round implementing their instructional designs, the faculty were more likely to fully engage in metacognitive and self-reflective thinking regarding their approaches to teaching and understanding of student learning. When university faculty actively engaged in educational research and became the agents of transforming the culture of STEM education in their institutions, the desired outcome was more attainable and the transformation sustained.

Research Question

The research question that guided the investigations of this study was: “What are the changes in STEM professors’ approaches to teaching and understanding of student learning before and after the project activities?”

In the project activities, STEM professors designed and implemented evidence-based instructional strategies, systematically evaluated their students’ learning outcomes and experiences with the newly implemented strategies, reported the findings of these evaluations on academic settings, and iterated the design efforts in the upcoming semesters. The learning scientists consulted the participating STEM professors in their instructional design efforts, collecting data from the student, analyzing and reporting the data, as well as iterating the design efforts in the upcoming semesters. The project was initiated in Spring 2015.

Methods

The design of this investigation was a multiple-case study [3, 22] with four cases. Four STEM faculty’s approaches to teaching and understanding of student learning were the units of analyses. Each faculty member’s pedagogical orientation (that involved faculty’s approaches to teaching and understanding of student learning) was a case under investigation. Both quantitative and qualitative data were collected from each of the four STEM professors.

Participants

The four STEM professors who were also the Co-PIs of this funded project were the study participants. They represented four different departments in the university: Computer Science, Electrical Engineering, Mechanical Engineering, and Engineering Technology. The demographic characteristics of our faculty participants are presented in Table 1.

Table 1. Demographics of the study participants

Participant	Sex	Rank	Typical courses taught	Course level	Student enrollment per semester
A	Female	Associate Professor	ELEG 3073 & 3071 Microprocessor Systems and Lab	Sophomore /Junior	40
B	Male	Associate Professor	ELET 1123 & 1121 DC/AC Circuits and Lab	Freshman	25
C	Male	Associate Professor	COMP 1223 Computer Science II	Freshman	30
D	Male	Associate Professor	MCEG 1021 Mechanical Engineering Drawing	Freshman	60

Our four study participants were also the co-investigators in the project. The study participants were invited to participate in the research aspect of this study. All participants volunteered participating and they signed the human consent forms approved by the university's Institutional Review Board (IRB) office prior to completing the research instruments.

Research Instruments

To capture the changes in participating faculty's approaches to teaching and understandings of student learning, we utilized two research instruments; an Approaches to Teaching Inventory (ATI) and a Semi-structured Faculty Interview Protocol.

Approaches to Teaching Inventory (ATI)

Approaches to Teaching Inventory (ATI) is a 16-item and 5-point Likert-scale designed by Prosser and Trigwell in 1996 [23]. ATI captures the academic's teaching approaches to the extent to which they are information transmission-teacher focused or conceptual change-student focused, that are the two main dimensions of the scale [24, 25]. The items in the ATI and the sub-dimensions are listed in the Appendix A. The ATI generates quantitative data about the faculty's teaching approaches and understanding of student learning.

Semi-structured Faculty Interview Protocol.

Our project team designed a semi-structured interview protocol in order to explore STEM faculty's approaches to teaching and understanding of student learning [3, 5]. The interview questions listed in the protocol were written open ended in order to capture a wide range of responses from the participants. Because the protocol was semi-structured, we anticipated asking questions (emerging questions) that were not in the protocol during the conversations with the faculty. When the interviewee answered any of the questions in the protocol without being asked, the interviewer did not ask those questions again. The interview protocol items are listed in Appendix B.

Data Collection

The learning scientists of the project team met with the individual faculty at their offices in Spring 2015 to collect pre-data from the faculty. After the faculty participants were introduced to this research study and questions about their participation were answered, they reviewed and signed the human consent forms to indicate their volunteered participation. Next we conducted individual interviews with the faculty using the questions listed in the semi-structured interview protocol (Appendix B). We asked some warm-up questions before posing the listed interview questions. Each interview lasted around 45 to 60 minutes and the conversations were audio-recorded. After the interviews were conducted, each faculty completed the paper copy of the ATI instrument (Appendix A). The learning scientists of the project collected the completed ATI instruments.

The four STEM professors designed evidence-based instructional strategies that were learner-centered and student-focused over the Summer 2015 semester. In Fall 2015, they implemented their evidence-based instructional strategies in their classrooms. Among the strategies designed and implemented were student-led recitation hours, discussion of current events, peer-teaching, peer-tutorial design, and peer-courseware design. To explore the impact of these newly implemented strategies, faculty identified existing research instruments from the literature and/or developed research instruments from scratch and collected data from their student. Among the research instruments our faculty used were Life-long Learning Scale, Engineering Attitude Scale, Student Demographic Questionnaires, and Student Exit Surveys [4, 8, 28].

The learning scientists in the project consulted the individual faculty in choosing and designing the research instruments. After collecting data from their students, the faculty analyzed the data and reported their findings. The learning scientists also consulted the faculty in the analyses and reporting phases. The project team met bi-weekly to review the project progress as well as each of the faculty members' educational research design findings. As appropriate the faculty recommended suggestions to one another during the project meetings. The faculty and the learning scientists collaborated in most aspects of these design efforts and the analyses of the student data. In Spring 2016, faculty iterated their evidence-based instructional design and implemented either modified versions of their own design or implemented another instructional design. The evaluation instruments were also being modified according to the design modifications.

In Spring 2016, one of our learning scientists conducted mid-interviews with the faculty. Each interview lasted around 45 minutes. The conversations were audio-recorded. The faculty completed the ATI instrument the second time in Spring 2016 and their responses were collected by the learning scientists of the project.

The project activities are still ongoing. We anticipate that the project will complete in Spring 2018. We will collect data from the faculty participants two more times, once in Spring 2017 and once in Spring 2018. In this paper we report the findings from the pre-administration and mid-administration of the two research instruments. The faculty participants engaged in the

project activities over one year between the pre and mid-administrations. The findings we report in this paper reflect the changes in the STEM faculty's approaches to teaching and understanding of student learning over a year period. Faculty implemented their first evidence-based instructional design in Fall 2015 and iterated their design efforts in Spring 2016.

Data Analyses

The mean scores of the faculty's responses to the ATI instrument and its sub-dimension items were computed and reported. The interview recordings were transcribed verbatim. Our learning scientists analyzed the transcriptions using constant comparative method [7]. We read the transcriptions three times and coded the incidents interviewees communicated. We used open coding, axial coding, and selective coding strategies to develop the main categories [3].

Findings

Our findings indicated that the four STEM professors' approaches to teaching and understanding of student learning had already begun evolving. Both quantitative results from the ATI instruments and qualitative results from the analyses of the faculty interviews indicated the trajectory of faculty's improved approaches to teaching and understanding of student learning.

ATI Findings

ATI instrument was a five point Likert-scale with 16 items. Eight items in the instrument capture the respondents' "Information Transmission- Teacher Focused" (ITTF dimension) teaching orientation. Other eight items in the instrument capture the respondents' "Conceptual Change- Student Focused" (CCSF) teaching orientation.

Up to date our four STEM faculty completed the ATI twice, once in Spring 2015 and once in Spring 2016.

In Spring 2015, the participants' average scores (Prof A, Prof B, Prof C, Prof D) in the ITTF items (N=4, M= 3.3125) and in the CCSF items (N=4, M= 2.875) were respectively: 3.125 and 3.125 for Prof A; 3.125 and 2.125 for Prof B; 3.75 and 3.75 for Prof C; and 3.25 and 2.5 for Prof D. All scores are out of five. A high average score in the ITTF items indicates that the respondent's teaching orientation is "Information Transmission-Teacher Focused" where a high average score in the CCSF items indicates that the respondent's teaching orientation is "Conceptual Change-Student Focused."

In Spring 2016, the participants' average scores (Prof A, Prof B, Prof C, Prof D) in the ITTF items (N=4, M= 3.2187) and in the CCSF items (N=4, M= 3.8125) were respectively: 3.625 and 3.875 for Prof A; 4.0 and 3.625 for Prof B; 3.375 and 3.75 for Prof C; and 1.875 and 4.0 for Prof D.

When the average scores of the faculty's responses to the ITTF items between Spring 2015 and Spring 2016 implementations were compared (Figure 1), it was observed that faculty's

intention to teach through “Information Transmission-Teacher Focused” approach was declined ($N=4$, $M_{Pre}=3.312$, $M_{Post}=3.218$).

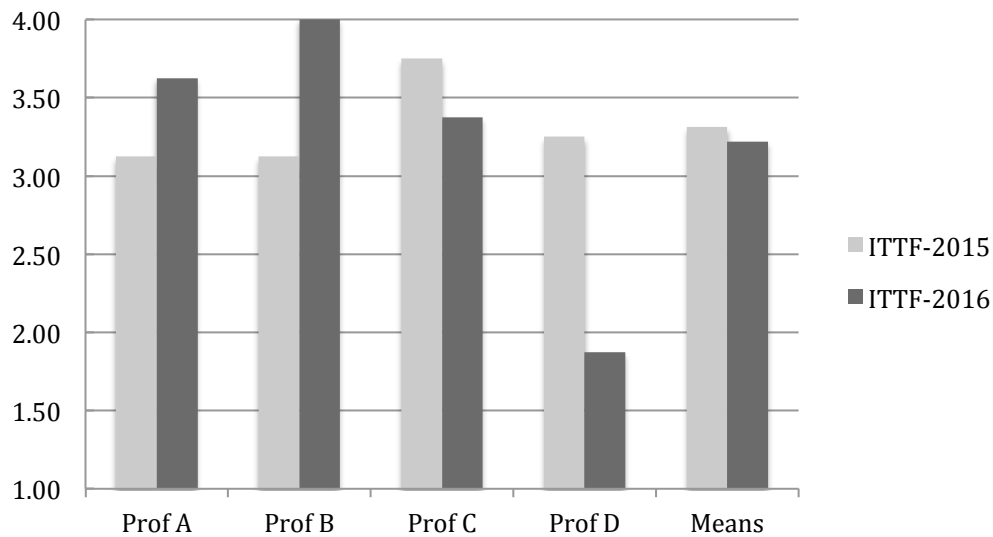


Figure 1. Means of the professors’ responses to the “Information Transmission-Teacher Focused” (ITTF) items in the Approaches to Teaching Inventory (ATI) in 2015 and 2016.

When the average scores of the faculty’s responses to the CCSF items between Spring 2015 and Spring 2016 implementations were compared (Figure 2), it was observed that faculty’s intention to teach through “Conceptual Change- Student Focused” approach was increased ($N=4$, $M_{Pre}=2.875$, $M_{Post}=3.812$).

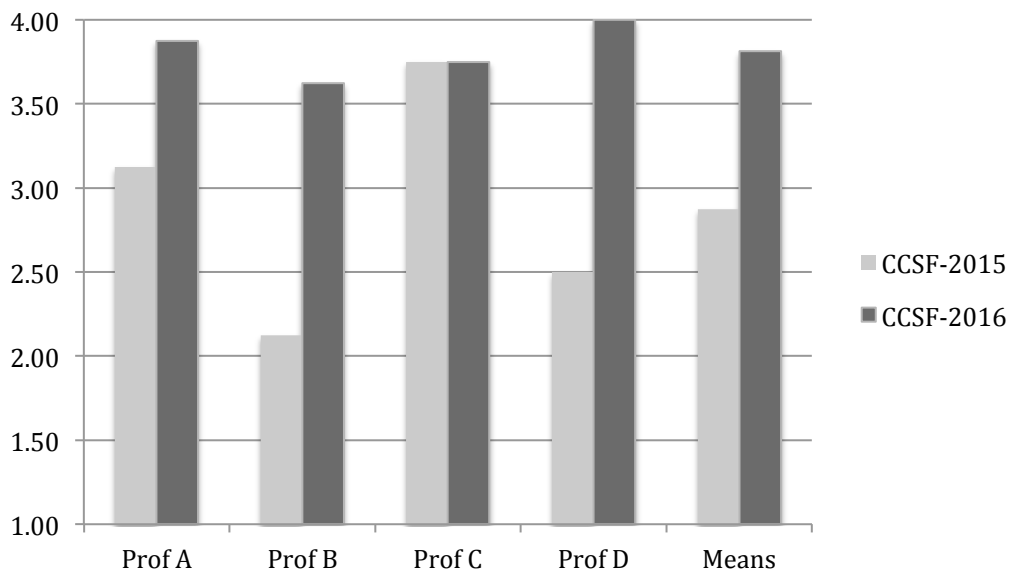


Figure 2. Means of the professors’ responses to the “Conceptual Change-Student Focused” (CCSF) items in the Approaches to Teaching Inventory (ATI) in 2015 and 2016.

These findings are encouraging for us because they show that our project activities have positively affected our STEM faculty's approaches to teaching and understanding of student learning. After one year in the project time line, our faculty participants have been more inclined to hold a student-centered teaching approach than a teacher-centered approach.

The project objective has been to expand and enhance faculty members' conceptual-change, student-focused teaching orientations and lower their information transmission-teacher focused orientations. Evidence-based pedagogies promote student-focused teaching approaches to increase students' persistence in STEM fields. A more student- focused instruction requires less emphasis on teacher-focused approaches that often results in a sole purpose to transmit information to students. At the completion of the project in Spring 2018, we anticipate that our STEM faculty will significantly enhance their CCSF teaching approaches where their ITTC teaching approaches will significantly decline.

Summary of the Interview Findings

In our first interviews in Spring 2015, faculty had defined learning as teaching the content knowledge and the skills necessary for the students to be successful in the field. Faculty's understandings of student learning were traditional and towards information-transmission approach. In Spring 2016 interviews, faculty expressed positive experiences with their evidence-based instructional design efforts and conveyed more of a student-centered teaching approach.

In Spring 2016 interviews, faculty participants reported that they asked their students to work in groups and learn the course content in collaboration with other students. According to the faculty, students' interest in learning was increased because of working in groups and through peer-teaching and peer-tutoring activities. Because of the increase in students' interests in learning the course content and working in groups, faculty members received fewer questions from the students. One participant told us that:

"I think the students ask me less because they can ask each other first and learn from each other first. Only when they work as a team and they still can't solve the problem then maybe ask me. But traditionally, every student works out his own problem and if he cannot solve it, he has to ask me. In the traditional way students ask more questions. In this way [a student-centered teaching approach], students don't ask me as much as the traditional way."

STEM faculty became more inclined to guide their students in learning instead of teaching them the content step-by-step. One participant responded in the interviews:

"I just gave them guidance but didn't involve that much as I know the content. My role is to guide them what to do [in the student-centered instructional strategy]."

One of our faculty participants noted that motivation and bounding were critical as he explained:

“From my observations, there were a couple of changes in students. One is motivation because students knew they were going to teach to the rest of the class so they really had to prepare and I even saw some students had notes prepared for the teaching exercise. The motivation, students really paid attention. Because it was a group exercise, I saw that the students helped each other and they worked together. This activity created a bonding for the students. I saw after the teaching exercise, they still studied together as a group through the whole semester. So this exercise created a bonding for the students and this is another observation. Some students said they really liked to teach and it was fun.”

Our STEM faculty participants reported that after implementing evidence-based pedagogies in two semesters in their courses, they became more comfortable with the teaching orientation that is student-centered and learner-oriented. One faculty told us at the Spring 2016 interviews:

“In the beginning of this project, I was afraid of losing control doing these exercises [peer-teaching in class] but after two semesters of implementations, I feel I can give control to the student as long as I guide the students so I’m even feeling comfortable to let the student teach the whole class the course contents.”

Conclusion

Multiple efforts were undertaken to improve engineering professors’ teaching approaches. A review of literature revealed that engineering professors’ teaching approaches improved the most when they fully engaged in educational research. Professors’ teaching approaches significantly evolved from a knowledge-centered and teacher-focused orientation to a learner-centered and student-focused orientation when they designed and implemented their own evidence-based instructional strategies in their classrooms, collected data from their students, analyzed the data collected, and reported the findings in academic settings. Professors’ self-reflection on educational research and meta-cognition in evidence-based pedagogies were central, and instrumental, for their changes in approaches to teaching.

In this study, STEM professors and learning scientists have worked together over one year to transform the culture of STEM education at a an HBCU in US. The overarching goal has been to increase the historically underrepresented students’ participation in STEM fields by enhancing the quality of the undergraduate engineering education at the selected HBCU.

The project is still ongoing and in this paper we reported the findings from the first year’s investigation. Our findings indicate that four STEM professors participated in the project activities have already improved their teaching approaches from a knowledge-centered and teacher-focused orientation to a learner-centered and student-focused orientation. These findings are encouraging to us because in the second and third year of the project implementation, we may find more evidence indicating the same trajectory. Because our faculty members have not yet published journal articles about their educational research endeavors and not all of them presented at an educational conference, it is possible that there is still room for improvement at their approaches to teaching and understanding of student learning.

This study has several implications for other practitioners and university administrators who are interested in widening the implementation of evidence-based pedagogies in STEM education. Instead of providing professional development workshops or other training activities to the STEM faculty, administrators may want to consider teaming up the STEM faculty with the learning scientists so that the STEM faculty will engage in educational research activities in their own classrooms and publish their findings. The critical aspect of that collaboration is that the STEM faculty should have the formal opportunities to reflect upon their design efforts in academic settings and iterate their design efforts. Faculty's meta-cognitive awareness and self-reflection of their teaching could be triggered through engaging them in authentic educational research activities. The evidence-based pedagogies were prescribed and well documented in the literature. However, each faculty's pedagogical orientation is very unique and very personalized that it is quite unlikely for any one other than the course instructor to truly transform the faculty's approaches to teaching and understanding of student learning.

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Appendix A- List of items from Approached to Teaching Inventory (ATI)* subscales.

Subscale	Associated Items
Conceptual change/student focused - Intention	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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.

* Trigwell and Prosser (2004).

Appendix B- Semi-Structured Faculty Interview Protocol

This interview protocol was designed to capture the STEM professors' approaches to teaching and understanding of student learning. The below questions guided the conversations with the participants. The warm-up questions are not listed below. Emerging questions might have been asked during the conversations.

1. What are your teaching goals? In other words, why do you teach?
2. How do you define an effective instruction?
3. In your opinion, what is the role of the teacher in the learning process?
4. In your opinion, what is learning?
5. What are the most important things you would like your students to learn in class?
6. Tell me specific example/instance when your students were effectively engaged in the learning process? How do you know that?
7. What strategies do you employ to engage your students?
8. How do you conceptualize/structure your instruction to make it more effective for your students?
9. What skills are essential to be an effective professor?
10. How do you know when your students learn something?
11. Would you like to elaborate on anything that we might have missed or did not deal in sufficient details?