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Summer Faculty Immersion: A Program with the Potential to Transform Engineering Education

Morales-Brignac, Juan C. [1]

Universidad del Turabo, Gurabo, Puerto Rico

Abstract

This paper describes a faculty development program that was recently funded by the U.S. Department of Education as part of a $4.34 million Title V, Hispanic Serving Institution (HSI) - STEM grant to Universidad del Turabo in Puerto Rico. The overarching goal of the grant is to increase the graduation rates of Hispanic engineering students. The specific objective of the faculty development program is to ignite innovative teaching in engineering and physics courses to assist students in achieving deep learning of fundamental engineering concepts. The summer program was proposed as a solution to recent research findings that show that, although innovative teaching methodologies are available and well researched, adoption by faculty is rare because it exceeds substantially the normal course preparation. The summer session will start with a two-day workshop on inductive learning methodologies by a highly esteemed researcher and innovator in engineering education. It will be followed by a one-month immersion to continue studying additional learning methodologies, and to prepare the innovations for two courses per faculty member. The effects of the innovations will be assessed to determine the efficacy of the proposed methodology. Details of the summer faculty immersion program, as well as the assessment plan,

are presented in the paper. Additional features of the grant, which complement the summer immersion program, are also presented.

Introduction

All the engineering faculty members in the university at which the study is taking place - Universidad del Turabo in Gurabo, Puerto Rico - participate in an outcomes assessment process that systematically evaluates the efficacy of engineering courses (Morales, 2009). Courses have generally improved as a result of the process. In addition, the ABET "a through k" outcomes (ABET Criteria, 2012) are satisfied, as evidenced by recent and successful ABET accreditation visits (ABET Programs, 2012). Still, it was observed that the outcomes assessment process had not yet resulted in truly transformative improvement strategies in individual courses (Morales, 2009). The learning experiences in engineering courses are still based on lectures, in which students play a passive role, in combination with the traditional deductive style of teaching which begins with theories and progresses to application of those theories. The concern is that the process of learning fundamental engineering concepts is not taking place at the desired depth. Many students continue having difficulty applying fundamental concepts to the solution of engineering problems. This is evidenced by relatively low passing rates in mid-level curriculum courses and low passing rates in engineering licensure exams. The low passing rates in engineering licensure exams, as compared to USA national average passing rates, is a pervasive issue in all the engineering schools in Puerto Rico (Gisela, et al., 2007).

The push for relevant learning experiences, as well as the need to acquire deep levels of conceptual knowledge, was expressed by Litzinger (2011), who indicates *"...that engineering education* *should encompass a set of learning experiences that allow students to construct deep conceptual knowledge, to develop the ability to apply key technical and professional skills fluently, and to engage in a number of authentic engineering projects. Engineering curricula and teaching methods are often not well aligned with these goals*". In addition, Borrego (2010) states that "*despite decades of effort focused on improvement of engineering education, many recent advances have not resulted in systemic change,*" in a recent article that addresses the challenges of diffusing engineering education innovations. Clearly, these are nationwide concerns.

At Universidad del Turabo School of Engineering (UTSOE), 96% of the engineering faculty have expressed that they are receptive to transformative teaching strategies that are based on engineering education research results (Morales, 2009). Two principal issues impede the transformation to more innovative teaching/learning techniques. First, most UTSOE faculty members have limited or no background in pedagogy and instructional methodologies, and second, most faculty have very limited time to create and adopt innovative strategies. These two limitations are typical of the majority of engineering schools. The National Research Council report on transforming Science, Technology, Engineering, and Mathematics (STEM) education validates this position by stating that support is required to implement *"innovative SME&T course development that exceeds substantially the normal course preparation commitment"* (NRC, 1999). It also states: *"The authoring committee recognizes that implementing the visions of this report could require new funds or shifts in the allocation of resources."* The issue of faculty time and funding, among others, is also mentioned by Borrego (2010).

In this study, the lack of course preparation time has been addressed by concentrating the efforts in the summer (month of June), while the faculty is free from their regular duties. For this reason, the program has been named the Summer Faculty Immersion Program (SFIP). The issue of funding was addressed by submitting the idea as a proposal to the US Department of Education, under the Title V, HSI – STEM provisions. The project, which incorporates additional activities, was selected to receive a $4.34 million award from 2011 to 2016.

The expectation is that the SFIP will accelerate the adoption of innovative teaching/learning activities, resulting in deep learning experiences for students. Deep learning implies that the concepts that are learned are not easily forgotten and can be transferred to new situations. Deep learning of fundamentals should, in turn, improve the passing rates in mid-level curriculum courses as well as in the licensure exams. In addition, other outcomes will be impacted by adopting innovative teaching methodologies, such as the ability to work in teams and an ability to engage in life-long learning, among others.

Deductive vs. Inductive Learning Methodologies

Most engineering schools use the traditional deductive style of teaching combined with lectures. The following list summarizes the deductive learning methodology (Prince and Felder, 2006).

<u>Deductive Learning Methodology</u>

1. The professor presents general principles and theories.
2. The professor derives the mathematical models.
3. The professor provides examples and applications.
4. The student does homework assignments to practice derivations and applications.
5. The student sits in exams to demonstrate acquired knowledge.

A weakness of the traditional deductive learning methodology is that students may miss the practicality of the material being taught in class. Concepts and theories are sometimes presented in a vacuum, that is, they are taught without a real-world context. Typical questions a student could ask are "*Why am I learning this material?*" or "*Is this material useful in real-world engineering applications?*" The students may lose interest and motivation in the class.

One of the objectives of this study is to explore and apply the opposite style: the inductive style of teaching and learning. The inductive methodology is summarized below (Prince and Felder, 2006):

Inductive Learning Methodology

1. The professor starts with a real-world engineering problem, of interest to the student, instead of starting out by presenting theories and principles.
2. A need arises to generate data, constraints, procedures, theories and principles to analyze the scenario and solve the problem.
3. Once the need-to-know is established, the professor presents the necessary information to develop the new knowledge, or the professor guides and assists students to discover new knowledge on their own.
4. Inductive learning methodologies are characterized as constructivist methodologies, that is, methodologies in which students construct their own versions of reality instead of simply absorbing the versions presented by the professor.

In essence, the inductive method brings to the forefront the real-world application, which is of interest to the student. It provides the context upon which the theories and principles are presented.

Inductive Teaching-and-Learning Methodologies

There are several methodologies for inductive teaching and learning. The following methodologies have been summarized from Prince and Felder (2006):

1. Inquiry Learning
    a. Structured Inquiry: students are given a problem and an outline on how to solve it.
    b. Guided Inquiry: students are given the problem but they must figure out the solution method.
    c. Open Inquiry: students must formulate the problem for themselves and figure out the solution method.
    d. The curriculum should progress from level a to c, as shown above.
2. Problem Based Learning
    a. Students are presented with an open-ended, ill-structured, authentic (real world) problem.
    b. The problem is analyzed to determine the learning needs required to develop a solution to the problem.
    c. Professors act as facilitators to develop the new knowledge required to solve the problem.
    d. Faculty should start by providing a high degree of support to students (scaffolding). The scaffolding should be gradually removed to allow students to develop the ability to infer for themselves and to develop higher-order learning.

e. The need may arise to complement the problem-based-learning activities with lectures and homework to ensure the development of all the specific learning objectives of the course.
f. Excellent methodology to develop the ability to work in teams.

3. Project-Based Learning
    a. Similar to problem-based learning but results in the fabrication of a final product.
4. Case-Based Teaching
    a. Historical or hypothetical cases that involve solving problems or making decisions, or both, are analyzed.
    b. An opportunity is provided to present dilemmas and situations that students may face in their professional careers.
5. Just-in-Time Teaching (JiTT)
    a. JiTT combines web-based technology with active learning methods in the classroom.
    b. Students individually complete web-based assignments a few hours before class in which they answer questions, and the instructor reads through their answers before class and adjusts the lessons accordingly ("just in time").
    c. Encourages students to prepare for class, helps teachers identify students' difficulties in time to adjust their lesson plans, and sets the stage for active engagement in the classroom.

Additional information, including references that provide insight on inductive teaching and learning methodologies, may be found in Prince and Felder (2006).

Active Learning

It has been shown that when the inductive approach to teaching and learning is used, the typical course is essentially turned end for end, that is, the real-world application or situation serves as the starting point of the discussion. Principles and theories are presented only after the need to know has been established. The expectation is that students will have more interest and motivation to learn the associated principles and theories once the context and the relevance has been clearly established. However, once a problem or case has been posed, learning still needs to occur. Active learning methodologies may be used as an alternative, or as a complement to the traditional lecture. Prince (2004) defines active learning in a general sense as "any instructional method that engages students in the learning process". It strictly limits the definition to activities introduced in the classroom. Homework assignments, by virtue of being conducted outside of class hours, are not considered active learning under this definition. Borrego (2010) defines "student-active pedagogies", as follows: "*Students are actively engaged with course material in the classroom. Examples of classroom engagement include: performing mini-experiments in the classroom and interpreting results, (and) working in pairs or groups to address questions about the material and challenges posed by the instructor*". Inductive learning methodologies are essentially active although passive lectures may be used to present the material once the need to know has been established. The SFIP will promote the use of active learning methodologies within the inductive approach.

Related Structures: Interactive Engineering Learning Centers (IELC)

The SFIP will be fully complemented by two Interactive Engineering Learning Centers, IELC 1 and IELC 2. Interactive experiences foster the discovery of what works, as well as what does not, thus unveiling typical fallacious traps that are common in the learning process of new engineering concepts. In this modality students learn to discern the true from the false, and become able to provide the correct arguments to support a stated position, i.e., critical thinking skills are sharpened. Licensure exams, which only use multiple choice questions, often include fallacious choices to trap unwary licensure candidates.

The IELC 1 has been designed with see-through glass walls in a central location within the UTSOE. It will house 49 new computers and will focus on interactive learning activities based on small-scale educational products and computer simulations. It will be staffed by nine tutors who will be available to offer assistance to any engineering student. The faculty members who participate in the SFIP will hold some office hours at IELC 1 ("IELC hours"). The presence of faculty members in IELC 1 will clearly establish their availability to continue assisting students outside of the classroom in an informal environment. Four acoustically insulated booths have been designed for individual tutoring sessions. Larger areas will also be available for larger tutoring sessions. Students will be able to access these spaces to conduct individual study sessions when they are not being used for tutoring sessions.

With its glass walls and central location, IELC 1 will potentially become a showcase of interactivity. Faculty, tutors and students will interact with innovative educational products and software in an atmosphere that is conducive to achieving deep learning.

IELC 2 will add 1,600 ft^2 of new space to fabricate and test the *"authentic engineering projects"* (Litzinger, 2011) of students in capstone courses and students who are members of the Multidisciplinary Entrepreneurial Program for Innovation (MEPI). The location of IELC2 has been selected at a spot just outside the Machine Shop to facilitate the transportation of fabricated parts from the shop to the assembly areas enclosed in IELC2.

The key to achieving sustainability of the innovations is based on the creation of a virtuous circle between the faculty, tutors, students, courses, the SFIP and the IELCs, i.e., they will reinforce each other in a positive manner. The combination of the interactive learning centers and the Summer Faculty Immersion Program represents a model of the Teaching and Learning Centers recommended in the NRC report under Vision 5 (NRC, 1999).

Design of the Summer Faculty Immersion Program

The program will train seven faculty members every summer, during the month of June, for the five-year duration of the grant (summers of 2012 through 2016), for a total of 35 faculty members. It will run nominally from 8:00 am to 5:00 pm on weekdays and will be directed by the author. Each faculty member will receive a stipend equivalent to one-month's salary. In addition, each faculty member will have a $3,500 budget to buy educational materials for their innovated courses.

The primary deliverable at the conclusion of each summer will be the creation of plans for transforming two courses that must be taught innovatively in the following Fall semester. The plan will consist of providing the detailed activities for each of the 30 class sessions in the semester (one hour and thirty minutes each session, for a total of 45 hours per semester) to cover all of the specific learning objectives of each course. Any additional assessment techniques that become necessary to measure effectiveness, besides the regular course assessment, will also be included in the plan.

By the end of the grant, most of the faculty members from the School of Engineering and the Physics Department of Universidad del Turabo will have participated in the immersion program. The mix of faculty from Engineering and Physics is considered an important part of the project since, in general, the two groups work separately. This project will provide the opportunity for both groups to work side by side during the summer to achieve a common goal. The three graduate students that will receive full scholarships to work as tutors in IELC 1 will also have the opportunity to participate in the SFIP. This is a direct recommendation of the NRC report and it is based upon the fact that graduate students will become the faculty members of the future (NRC, 1999).

The SFIP will build upon the assessment culture that was successfully developed at UTSOE while creating the ABET-required outcomes assessment process. All the engineering course syllabi have been revised and specific learning objectives have been identified for each course. Course assessment is conducted on each learning outcome of every engineering course. 100% of the faculty have begun the transition to teaching based on the specific learning objectives of the course instead of teaching based on a list of topics. By the end of the summer, each faculty member shall have identified active learning components and inductive methodologies for all the specific learning objectives of two courses. These will be distributed among the 30 class sessions, as mentioned previously. The SFIP will develop competence in these methodologies by providing time for the faculty members to practice the new techniques with their peers. In other words, the inductive and active learning techniques will be learned within the same environment, with all the participants actively engaged in the process.

An interesting set of active learning experiments and challenges that will receive attention in the SFIP is the NSF-funded project "Using Everyday Engineering Examples (E^3) in the Classroom" (Patterson, 2011). The use of familiar real-life objects and situations has been shown to improve the deep learning experiences of students (Patterson, 2011). One of the examples shown in the Patterson webinar is a skateboard (an actual skateboard is brought to class). Students are grouped into pairs and are then asked to draw the free-body, shear force and bending moment diagrams of the skateboard while loaded with a rider.

Most textbooks show schematics of real-world applications as boxes, sticks or amorphous objects. For example, a beam in a building may be shown as a horizontal stick with two supports - a triangle and a circle; a boiler may be shown as a rectangular box with a zigzag line inside. These are important representations used in engineering; however, they are abstract idealizations of real objects. Students must be able to draw the idealization given a real object and, given an idealization, the student must be able to understand and visualize what it means as a real object. Undoubtedly, if students lose the meaning of the idealizations, they will encounter difficulties learning the concepts at a deep level.

The skateboard example may be extended to emphasize the connection between the real object and the idealizations. Using the "guided inquiry" inductive methodology the student may be asked, *why, when calculating static deflection, are a triangle (hinge) and a circle (roller) used to represent the skateboard supports instead of two circles, which are obviously better geometrical representations of the wheels?* (Answer: static instability, i.e., two rollers would allow for accelerated motion in a problem which requires statics.) Or, *why not use two triangles (hinges) as supports?* (Answer: the system would become statically indeterminate.) Another extension may be to idealize the weight of the rider as a single concentrated load applied at the middle of the board to calculate the maximum deflection of the board. Determining upper and lower bounds to the answers of engineering problems develops good engineering judgment. In many cases these limits can be obtained using simple formulations and relatively quick, “back of the envelope” calculations, if the engineer has developed a deep knowledge and understanding of engineering fundamentals. Other guided inquiries may be: How will the deflection of the board change when two concentrated loads are used to represent both legs of the rider? How does the location of the load (feet of the rider) affect the deflection of the board? Is a two-dimensional idealization of the skateboard sufficient to evaluate all possible cases? All of these questions can be formulated and solved, and qualitatively checked by conducting simple experiments with the real object. The IELC 1 will also provide these interactive experiences.

Achieving the connection between idealized models and the real object, which students can see and touch and experiment with in the classroom, is considered a virtue of the E^3 exercises. At the SFIP, the faculty will have the opportunity to learn about a wide variety of everyday examples that have been used successfully and that are posted in the internet. Faculty will also have the opportunity to ideate their own everyday examples, or extend the existing ones, as has been done above in the case of the skateboard. The selected examples will address specific learning objectives of the course, as defined in the course syllabus.

Carnegie Mellon’s successful Open Learning Initiative (OLI), which provides access to innovative web-based educational materials (Steif, 2009), will also be covered during the summer. Interactive exercises include simulations that help to elucidate physical phenomena, activities that allow practice of problem solving procedures with help and feedback, and tests of students’ comprehension. High, statistically significant learning gains were found by Steif while conducting a Statics course.

The SFIP will provide the space and the time necessary to explore several additional innovations in engineering education that have been proven successful through research. As the project progresses through its five-year period, new innovations that are published in the research literature will be included.

The program will kick off every summer with a two-day workshop by the external consultant, Dr. Michael J. Prince, who has authored several papers on engineering education research. Dr. Prince, an engineering professor and co-Director of the National Effective Teaching Institute, has delivered approximately 100 faculty development workshops at the local, national, and international levels. The summer program will then continue under the direction of the author. The following typical daily activities will be covered, although not necessarily in order, and not all will be included in every session:

1. Review of SFIP objectives and expectations for the daily session.
2. Discussion of any pending items from the previous session.
3. Seminar discussions of papers selected from the engineering education research literature that are relevant engineering education innovations (inductive learning methodologies, active learning, deep learning of concepts, computer-based technology in the classroom, how people learn, among others).
4. Discussion of engineering education innovations such as the E^3: Everyday Engineering Examples program (Patterson, 2011). Discuss and develop modifications of the E^3 examples and possible new examples.

5. Preparation of "guided inquiries" on E^3 examples that incorporate questions which are typical of the Fundamentals of Engineering Exam (FE Exam). PR Law 173, which regulates engineering practice in Puerto Rico, is one of the most stringent in the US as it does not incorporate industry exemptions in the "practice of engineering". As a minimum, engineering practitioners must pass the FE Exam and obtain the Engineer-in-Training (EIT) certificate from the PR Board of Engineers and Land Surveyors. Consulting professionals require a Professional Engineer (PE) license from the board.
6. Learn about online courseware activities such as Carnegie Mellon's Open Learning Initiative (OLI), which provides nearly-free access to innovative web-based educational materials (Steif, 2009).
7. Conduct individual planning sessions by each faculty member to adapt the new material into two or more of their courses. The plan will consist of providing the detailed activities for each of the 30 class sessions in the semester (one hour and thirty minutes each session, for a total of 45 hours per semester) to cover all of the specific learning objectives of each course. Faculty members will also be encouraged to reexamine the wording of the specific learning objectives in their course syllabi to achieve more precise statements that accommodate the innovative techniques.
8. Evaluate additional assessment techniques that may become necessary to measure effectiveness of the new methodologies, besides the regular course assessment, and include them in the plan for the innovations of each course.
9. Teaching sessions by each faculty member. Each faculty member will have the opportunity to try the new techniques in front of their peers, who will play the role of students. The teaching sessions will be recorded to provide feedback to the faculty members.

10. Group discussion sessions to consider the possibility of developing problems which can be shared/integrated in different courses using the problem based learning methodology. Each course would develop the areas which fall within its specific learning objectives. For example, an ill-structured definition of a real-world application may be to design a motorcycle's brake system. A set of specifications may be worked out with the students actively participating in class (maximum speed, maximum braking distance from top speed conditions, weight of the motorcycle, wheelbase, wheel geometry and weight, among others). A need will arise to learn and apply fundamental engineering principles, which can be developed with "guided inquiries" to engage students in the classroom. Each course in the curriculum would then limit its discussion to the relevant topics, for example, a *Dynamics* course may discuss issues related to calculating braking distance, and the forces required to accomplish it; a *Mechanics of Materials* course may analyze the stresses in the components to assure that they are below the allowable stress limits to avoid failure; a *Design of Machine Elements* course may consider the merits of alternative brake designs and work out the details of the system; A *Heat Transfer* course may consider heat dissipation issues during braking. The SFIP provides an ideal atmosphere to establish coherence within the discipline (mechanical engineering, electrical engineering, etc.). It may be achieved by discussing the same cases in several courses throughout the curriculum, with each course addressing the particular issues related to its specific learning objectives.
11. Discuss the schedule for the next day.
12. Rate the quality of the daily session through a faculty survey.

Assessment of the SFIP

Once the summer program concludes, the innovations will be implemented in the Fall term immediately following the summer session. The author and the external consultant, Dr. Michael Prince, will provide on-going support to faculty members during the regular academic year to gain feedback and to adjust the innovation. Leaders from NSF-funded engineering education coalitions have learned that this on-going support to faculty members is a critical issue to achieve sustainability in the adoption of the innovation (Borrego, 2010). The author and other faculty members of Universidad del Turabo will be invited to visit the innovated courses to observe and assess the innovations. The assessment will be strictly performed for continuous improvement purposes, not as an evaluation tool for contractual purposes.

The outcomes assessment program that is already in place in UTSOE will continue to be used. The plan contains a direct assessment component conducted by each faculty member on student work (the assessment must withstand peer review), and an indirect assessment component that is based on the opinion of students (Morales, 2009). The assessment is conducted every semester. The failure rates in the courses that are impacted will also be used as a measure. The goal is to reduce failure rates in the impacted courses by 50%. The passing rates in the Fundamentals of Engineering Exam (FE Exam) will also be used as an assessment instrument. The goal is to double the current passing rates in the FE Exam. The basis for achieving both goals is grounded in developing a solid and deep understanding of engineering fundamentals.

Final Remarks and Recommendations

This paper has described a project that has the potential to accelerate diffusion of educational research into educational practice through a Summer Faculty Immersion Program (SFIP). If the project is successful, recruitment and retention of students should improve through increased student interest in an engineering career. Graduation rates should also improve as a result of increased passing rates in typical bottleneck courses at the middle level of the curriculum.

The following remarks are offered to colleagues who may be interested in exploring a similar approach:

1. Ideally, a process to conduct course assessment should be in place. Course assessment engages faculty to improve their courses in a structured and quantitative manner. It also requires the faculty to concisely and precisely define specific course learning objectives, not just a list of topics to be covered. Focusing on specific learning objectives, and then fitting the topics to match the learning objectives, is a solid first step in transitioning to the inductive approach of teaching and learning. A significant amount of time and persistence is required to develop a methodology for course assessment, and the subsequent integration of its results to obtain program-level assessment; however, funding is not required. Once the step of performing course assessment is taken, the potential for true transformation follows logically since the faculty members are already fully engaged in the process of evaluating and improving their courses.
2. The implementation of this program requires a significant amount of funding because the faculty members are paid in the summer (one month) to participate in the program while they are free from other obligations. In addition, funding is required to purchase educational materials related to the innovations. A solid argument that may be used to request funding is to have in place a course assessment process that already fully engages the faculty in the process of evaluating and improving their courses.

3. The implementation of the SFIP requires coordination with the faculty to avoid conflicts regarding summer plans. In this case, the SFIP will meet during five consecutive summers which allows faculty members to plan accordingly and reserve a spot a few years ahead of time.

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