Identifying Learning Barriers for Non-major Engineering Students in Electrical Engineering Courses

Qaiser Malik, Punya Mishra, Michael Shanblatt
Michigan State University
East Lansing, MI 48823
Email: malikqai@msu.edu, punya@msu.edu, mas@msu.edu

Abstract
Students in undergraduate engineering programs do not perform equally well in their non-major engineering courses as they do in courses that are in their major. In order to better understand the reasons for this lower level of performance, we have embarked upon a study in an Electrical Engineering (EE) course offered to non-EE majors. The objectives of this study are to assess student perceptions and attitudes towards learning a non-major engineering subject and also to measure their understanding of the subject's core concepts. Two instruments have been developed: a survey questionnaire given to the entire class and a concept map assignment for one-on-one student interview sessions. This paper discusses the development of these instruments and presents analyses of the data collected from the course students in two successive semesters. Our findings so far reflect that non-major engineering courses need to be made more relevant and conceptually grounded along with a refocusing of the course content. Additionally, the development of reliable subject specific instruments (survey and concept map) as used in this study could be the basis for a broader framework which could be used for other engineering courses.

Introduction
One key objective of university undergraduate engineering programs is to offer the interdisciplinary coursework (*i.e.,* service courses offered to non-major engineering students), for preparing qualified engineering graduates to be successful and productive in their future careers.[1] This is also validated and prescribed as one of the essential program outcomes as defined in the ABET Criteria 2000.[2] As a result almost all engineering institutions offer service courses to non-majors through their respective departments. It is usually the responsibility of the department to ensure that such courses remain relevant. In this context the department needs to be aware of the expectations from such courses and should be able to fulfil all the requirements of an interdisciplinary course.[3] The salient ones are: 1) The course must prepare the students to efficiently solve the interdisciplinary problems as expected by industry for entry level engineers;[4] 2) The course must adequately cover the relevant portion of syllabus for professional certification/registration; 3) The teaching strategy must keep pace with the emerging technologies; 4) The course should generate enough interest to motivate the students to master engineering concepts not directly related to their chosen field.[5,6]

This paper presents the preliminary outcome of an ongoing study conducted on engineering students in a non-major course in Electrical Engineering (EE). Students in undergraduate engineering programs do not perform equally well in their non-major engineering courses as they do in courses that are in their major.[7] The aim of this study is to better understand the reasons for lower levels of performance in non-major engineering courses. We accomplish this by assessing student perceptions and attitudes towards learning, and measuring their understanding of core concepts related to a specific topic. Two instruments have been developed for the purpose: a survey questionnaire for the entire class and a concept map assignment for one-on-one interview sessions with randomly selected students from different achievement groups.

Research Context

Electrical engineering basics have always been important to other fields of engineering and technology.[8] Moreover, the interdependence among different engineering disciplines is increasing.[9] A variety of today's emerging technologies critical to economic development are the off-shoots of various branches of EE.[10] The interconnectivity of EE with other engineering disciplines demands that our universities train engineering professionals who are fully competent in all aspects of EE relevant to their work. To meet these challenges, the Electrical and Computer Engineering Department of Michigan State University (MSU) offers ECE-345 "Electronic Instrumentation and Systems", a 2+1 credit course for all non-EE majors. The course has a heavy intake (80-90 students each semester) from mechanical, civil, bio-systems, and other engineering majors. The classes are delivered in a traditional manner through lectures, labs and published notes that are also available to the students on a CD. The course is passively managed through Angel, a course e-management system, to the extent of posting of homework assignments, solutions and individual grades. Like a typical service course, it is rotated among the department faculty on a 1-2 year cycle.

ECE-345 covers a select combination of a wide variety of topics from the core courses of the department. It aims at introducing the breadth of EE while providing hands-on experience in building electronic circuits using state-of-the-art test and measurement equipment. The 50 minute lectures, delivered twice a week, cover topics in components, circuits, instrumentation, circuit laws and applications, frequency response, operational amplifiers, semiconductor devices and digital logic. A textbook is also specified that covers most of the course content. A three-hour lab session each week is integrated with the lectures and designed around building practical circuits with the knowledge gained in class. It is a fast paced course that is considered to be highly demanding and challenging.

Some of the observations based on faculty experience, routine course evaluations by students, and consistent with previous research are:[7] 1) A general lack of interest by students due to non-major nature of the course; 2) Low priority by department/instructors (service course syndrome); 3) Fast and superficial topic coverage; 4) High student-teacher ratio; 5) No clear link between the subjects taught and the students' fields of study (at least as perceived by the students).

Research Instrumentation

To focus our research we have telescoped our study to the topic of the Bipolar Junction Transistor (BJT), the most complex topic of the course that requires deeper understanding of basic EE concepts. BJTs started the semiconductor revolution in 1947 and have gone on to become, in present form, ubiquitous in today's electronic equipment. Therefore, understanding transistor basics is essential for non-major students. The course syllabus allocates a mere 1.5 lecture hours which makes it challenging for the instructor to do justice with this important topic. The past results indicate that a majority of the students do not perform well in this topic.

There are clearly two main focus areas of this study that require reliable and valid instrument(s) for measurement and evaluation:

(a) **Student perceptions and attitudes about the course**: Literature review[11-14] reveals a wealth of knowledge including a variety of standard instruments to measure student perceptions and attitudes towards learning in a course setting. Therefore, collection of reliable and valid data through the use of existing instruments is a relatively easy option. A careful selection of the instruments with appropriate modification would meet our needs for measuring the student perceptions and understandings.

(b) **Student understanding of the course content**: Measurement and evaluation of understanding of the course content is a unique context that requires a *content specific instrument.* Such an instrument obviously is not readily available in the literature. One has to rely on the subject specialists and education experts to develop such an instrument. More importantly, such an indigenous effort would require a number of iterative trial sequences to establish its validity and reliability before actually using it for the research.

Two instruments have been developed after a thorough literature search and several consultation sessions with the education experts/subject specialists:[11-14] a survey questionnaire for the whole class and a concept map for one-on-one sessions with a selected group of students.

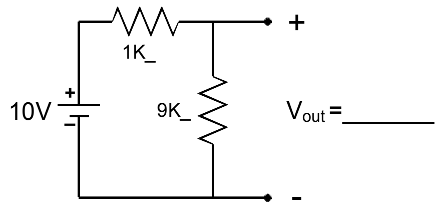
Survey Questionnaire

The survey questionnaire is comprised of 40 questions sub-divided into four sections. Sections 1, 2 and 4 were developed from the available literature to collect data on student perceptions and attitudes. These sections include multiple choice questions presented with a 5-point Likert scale. Section 3 is indigenously developed for measuring student understanding of course content. The questions in this section are mostly in the form of small numerical problems. Each section of the survey instrument is briefly explained below:

- ***Section 1 General information/perception:*** *C*ollects the background and demographic information about the subjects including their age, class status, major, cumulative GPA, etc. Two examples of this section are:
    - *Hours per week I typically spend studying for this course including homework.*
    - *Difficulty level of this course relative to my other major courses.*
- ***Section 2 My perception of my understanding of course content:*** Measures the student perceptions and attitudes about the course, *i.e.,* extent to which it meets the course objectives, quality of lectures/textbook/home assignments, course evaluation system, learning cycle, etc. Two examples are:
    - *Lectures are monotonous; a verbatim repetition of instructor notes.*
    - *The course material is intellectually stimulating.*
- ***Section 4 My opinion on instructional methods and use of technology:*** The section measures student perception of instructional methods and the use of technology including in-class vs. on-line teaching, effectiveness of Angel, use of multimedia and computer tools, etc. Two representative questions from this section are:
    - *ANGEL is effectively being utilized in the course delivery.*
    - *In my opinion the use of multimedia and web technologies would have resulted in a deeper understanding of the core concepts of ECE-345.*

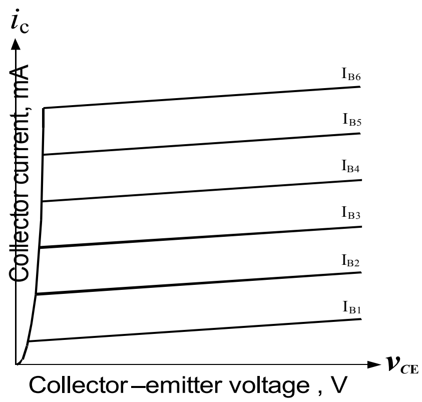
- ***Section 3 Evaluation of conceptual understanding*:** This section of the survey questionnaire is unique as it relates to the subject content. It measures the understanding of the core concepts and their relationship to the selected topic (BJT module). The section has twelve problems in two categories (six per category): the *standard* problems and the *inferential* problems. The problems in both the categories can be solved without using a calculator or complicated mathematics.
  - ***Standard problems:*** Standard or textbook type problems are similar to those covered in the course (in lecture, home assignments and exams) with slight variation in numerical values and problem setup. Students have been given enough practice on like problems. Two typical examples are:

    Q#25 Find 'V_{out}', as indicated, for the following circuit:

    Note: *This is a typical voltage-divider-network problem. Students were given similar problems in lecture, homework assignments and on exams.*

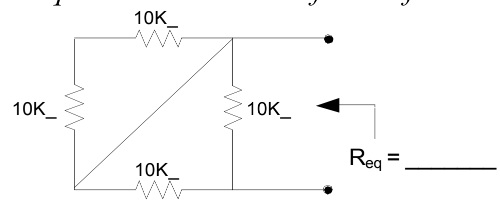
    Q#30 Indicate the cut-off, active and saturation regions on the following i-v characteristic curves for a BJT:

    Note: *These are typical i-v characteristic curves for the BJT. Students have been using these curves to identify the three operating regions of a BJT. A similar problem was assigned in the homework.*

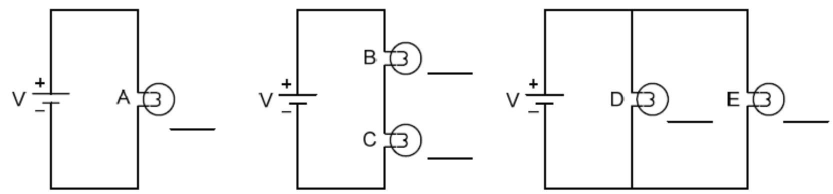
  - ***Inferential problems*:** Inferential problems require a step further to the understanding of core concepts and their interrelationship. These can be the applications of the concepts discussed in class. Students had not seen such or similar problems in class, home assignments or on exams. However if the concept is understood, a student should be able to solve these problems with ease. Two examples are shown below:

Q#22 Find the equivalent resistance for the following resistive network:



Note: *This series-parallel network has a shorted link across the diagonal. The problem looks simple but requires a deeper insight of open and short circuits. Students were given these concepts and solved the problems with short and open terminals but they had not seen a similar circuit before.*

Q#24 Rank and label five bulbs (A, B, C, D, E), connected in the following three circuits, from the brightest to the dimmest ('1' means the brightest, same number means same brightness). Assume all bulbs are identical, and batteries are identical ideal sources:



Note: *These are current divider networks. Students understand that current divides in parallel networks while it remains constant in series networks and that the bulb brightness is current dependent in accordance with Ohm's Law. This problem is the application of these concepts and their inter-relationship. Students had not seen a similar problem but had been calculating the amount of current flow and voltage drop in like circuits.*

Testing and Evaluation: To ensure reliability and validity, each question of the instrument was thoroughly reviewed and extensively pilot tested on a group of faculty experts and upper level graduate students in EE. Section 3 in particular has been critically reviewed and refined several times based on the feedback from pilot testing. The survey instrument has been administered in two successive semesters. The data has been collected (n=107) from the population of two courses (N=177). For simplicity in descriptive analysis, the 5-point Likert scale was collapsed into two levels, *i.e.,* 'Agree' and 'Disagree'. This was done by adding the score on 'Strongly Disagree' with 'Disagree', the score on 'Strongly Agree' with 'Agree', and dropping the score on 'Neither Agree Nor Disagree'. Problems in Section 3 were graded on a 0-5 scale (except a few questions with 0-3 and 0-6 scale) with '0' meaning 0% and the highest number meaning 100%.

Survey Results

Student Perceptions (Sections 1, 2 & 4): Evaluation of the data reveals interesting results. Some of the important ones are listed below.

- 98% students belong to the age group 18-23 years with majors in mechanical (72%), bio-systems (11%), materials (9%), and applied (7%) engineering.

- The majority of the participants (89%) consider the course as difficult. They are split on the issue of its usefulness (~ 50%).
- 68% devote three or fewer hours per week on self study including home assignments.
- The majority (89%) consider the course lectures to be monotonous while 77% perceive the course material to be stimulating.
- 78% rely primarily on instructor notes to understand concepts. 32% think that consulting the textbook enhances learning.
- Though students have no exposure to online courses in engineering at MSU, the majority (93%) opine that use of multimedia and web technologies, access to additional material through online resources, and web based tools would enhance understanding.

Student Understanding of Core Concepts (Section 3): The statistical data collected in Section 3 represent a sharp contrast between the understanding of standard and inferential type problems. The student scores on the four example problems in two categories are graphically represented in Figures 1 and 2 below. The majority (80% and 79%) of the students scored full marks in the two standard problems (Figure 1). The inferential type problems show a very different picture; only 11% and 15% students could manage to score full marks (Figure 2).

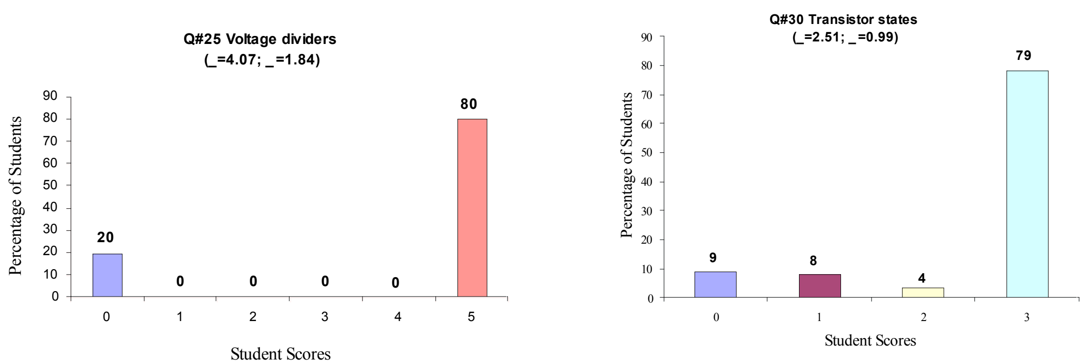


Figure 1: Response on standard problems.

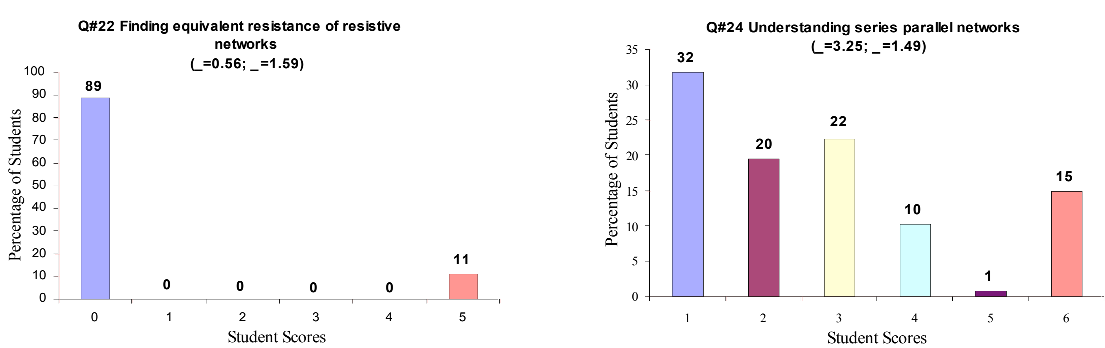


Figure 2: Response on inferential problems.

The statistical data from all twelve problems in this section further substantiate these results. On the average, 68% of the students scored full marks in the standard or textbook type problems while a mere 15% could manage to score full marks in the inferential type problems.

These results indicate that students appear to be focused on rote learning of textbook problems, but face difficulties when asked to apply the concepts into somewhat newer contexts. It must be emphasized that the inferential problems were not extremely difficult, nor did they need any extra knowledge on the part of the students. All that was needed was an understanding of the conceptual underpinnings of the ideas and the ability to apply them.

A survey, such as the one implemented here, offers insight into the fact that students seem to have problems applying the concepts they have learned. However, it is difficult using instruments such as these to identify the nature of student understanding. For this purpose we conducted a qualitative analysis of student understanding by working with a smaller representative sample of students. In this part of the study focus was not on their problem solving ability but rather on "mapping" their understanding of the relationships between key concepts. Our methodology and results of this part of the study are reported in the next section.

Concept Mapping

Why Concept Mapping? Concept mapping emerges directly from David P. Ausubel's assimilation theory of meaningful verbal learning.[15] The underlying basis of the theory is that meaningful (as opposed to rote) human learning occurs when new knowledge is consciously linked to an existing framework of prior knowledge in a non-arbitrary, substantive fashion. In rote learning, new concepts are added to the learner's framework in an arbitrary and verbatim way, producing a weak and unstable structure that quickly degenerates. The result of meaningful learning is a change in the way individuals experience the world; a conceptual change. Concept maps have been used for over 25 years in research and classroom practice to reveal and assess the structure and complexity of knowledge held by students in the sciences and other disciplines.[16] An important benefit of using concept mapping as an assessment method is its ability to detect or illustrate students' deep content understandings as well as their misconceptions when they create a personal explanation of content matter.[17]

Expert Map for BJT: To investigate and develop an expert map for the selected topic of BJTs, we formed a group of experienced faculty of the department. The group selected a set of sixteen concepts for the topic to which another four were added for redundancy. An expert version of the map was developed in Inspiration®. Inspiration® is currently among the most popular concept mapping software programs.[18] Several trial runs were conducted with EE faculty experts to finalize the expert map before it was put to test. The final map is shown in Figure 3.

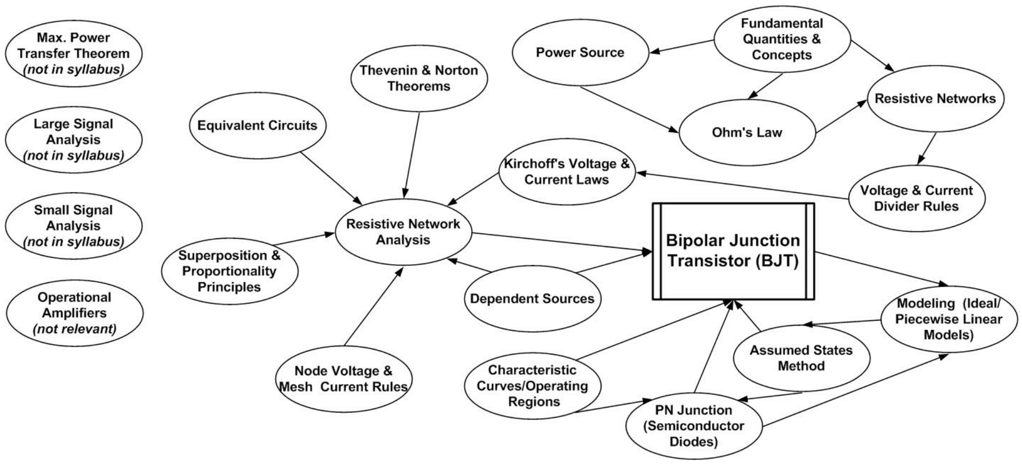


Figure 3: Expert concept map for BJT module.

Testing and Evaluation: The concept mapping sessions were administered one-on-one to twenty randomly selected students from five achievement groups. The groups, formed on the basis of academic performance in the course, were: Excellent (above 90%), Good (80-90%), Average (70-80%), Fair (60-70%), and Poor (less than 60%). Each session (of 30-40 minutes) included a briefing on the concept mapping technique and practice on the use of the Inspiration® software package. The participants were encouraged to 'think aloud' as they developed the concept map so as to keep the interviewer informed about what's going on in their mind.* We focused primarily on the qualitative aspects of students' concept maps with emphasis on the accuracy and validity of the knowledge students represent. While comparing each participant map with the expert map we asked the following questions:

- Are the most important concepts depicted?
- Are the links among concepts scientifically acceptable?
- Is there a substantial amount of branching hierarchy and cross-linking?
- Do any of the propositions suggest that the student subscribes to significant misconceptions?

Concept Mapping Results

The interaction with the students during the interview sessions and study of the individual concept maps brought about some possible answers to lower performance in inferential type problems. The major findings are:

1. ***Participants often lacked deep conceptual understanding of foundational ideas***. Most of the student participants in the five achievement groups missed out some important basic concepts from their concept maps. An example of a participant from the Excellent group (class performance: 92%) is shown in Figure 4. The student oversimplifies the map and misses out some of the foundational ideas, *e.g.,* Assumed States Method, Modelling, Resistive Network Analysis, etc. (highlighted as shaded blocks in Figure 4). The missing blocks and the interconnection pattern in the concept map signify gaps in learning.

** This paper does not offer any analysis of the 'think aloud' protocols.*

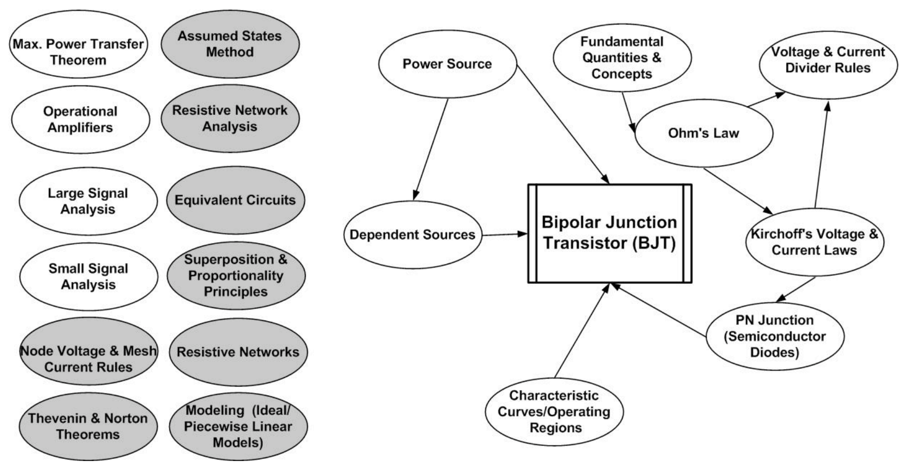


Figure 4: A student map example: missing the foundational ideas.

2. ***Even, in cases where concepts were considered to be interrelated, the participants did so without sound reasoning.*** Figure 5 shows the map of a student participant from Average group (class performance: 78%). The student has connected everything with almost every other thing. It shows significant misconceptions of basic concepts and their interrelationship.

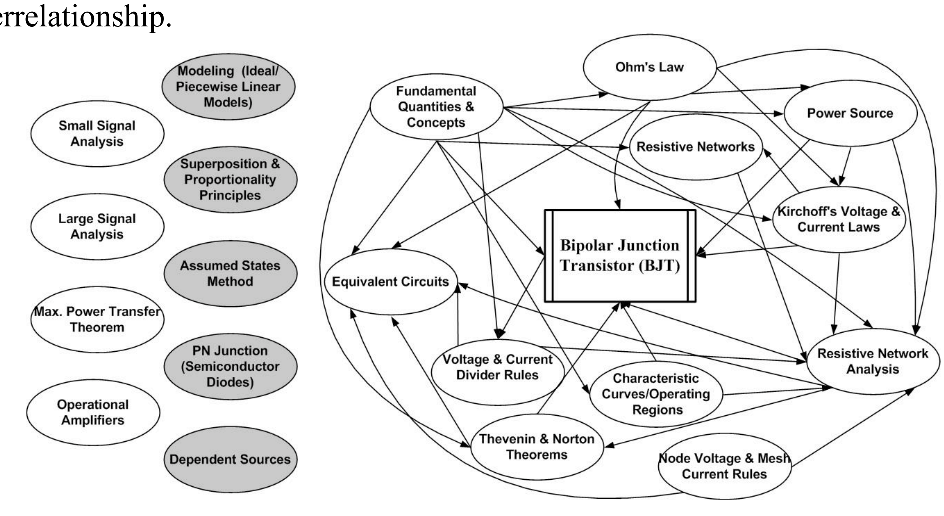


Figure 5: A student map example: almost everything connected to everything.

Conclusion and Future Directions

Students in undergraduate engineering programs do not perform equally well in their non-major engineering courses as they do in courses that are in their major. This ongoing study presents the measurement and evaluation of student perceptions and attitudes towards learning, and understanding of core concepts related to a specific topic. This is accomplished through the development of two instruments: a survey questionnaire for the entire class and a concept map assignment for one-on-one interview sessions with a selected group of students.

The survey indicates that students emphasize rote learning or are focused on solving textbook type problems. The concept maps suggest that students lack deep conceptual understanding of foundational ideas. Even in cases where concepts are considered to be interrelated, the participants do so without sound reasoning.

The study completes the first step of an overall project aimed at formulating a strategy for improving the teaching of service courses at the undergraduate level. The next step will involve an intervention in the learning process to enhance students understanding. This may require restructuring of the course content, development of some online modules and/or making better use of e-learning tools. We plan to implement these changes in a systematic manner and then conduct further studies in order to better understand student knowledge of core concepts. Finally, we suggest that the development of reliable and valid subject specific instruments (survey and concept map) as used in this study could be the basis for a broader framework which may be used for other pedagogical studies related to engineering education.

References

1. J. Bordogna, E. Fromm and E. W. Ernst, "Engineering education: innovation through integration," *Journal of engineering education,* vol. 82, no. 1, pp. 3-8, 1993.
2. ABET Criteria 2000, Accreditation Board for Engineering and Technology, Baltimore, MD, www.abet.ba.md.gov, and www.ele.uri.edu/faculty/daly/**criteria**.**2000**.html.
3. S. A. Zekavat, C. Sandu, G. Archer, and K. Hungwe, "An evaluation of the teaching approach for the interdisciplinary course electrical engineering for non majors, " *Proceedings of 2004 ASEE conference*, Salt Lake City, UT, June 2004.
4. D. M. Pai and R. A. Deblasio, "Enhanced learning from an industry-university partnership," *Journal of industry and higher education,* pp. 224-228, Aug. 1997.
5. D. A. Kolb, "Experiential learning: experiences as the source of learning and development," Prentice-Hall, Englewood Cliffs, NJ, 1984.
6. J. N. Harb, S. O. Durrant, and R. E. Terry, "Use of the Kolb learning cycle and the 4MAT system in engineering education," *Journal of engineering education*, vol. 82, no. 2, Apr.1993.
7. D. Qian, "Improvement of an electrical engineering course offered to non-electrical engineering majors," *Proceedings of 2006 ASEE conference*, Chicago, IL, June 2006.
8. S. A. Zekavat, K. Hungwe, and S. Sorby, "An optimized approach for teaching the interdisciplinary course electrical engineering for non majors," *Proceedings of 2005 ASEE conference*, Portland, Oregon, June 2005.
9. F. Bronet, R. Eglash, G. Gabriele, et al., "Product design and innovation: evaluation of an interdisciplinary design curriculum," *International journal on engineering education*, vol. 19, no. 1, pp. 183-191, 2003.
10. U. Roy, "Preparing engineers for future with collaborative technology," *Journal of computer applications in engineering education*, no. 2, pp. 99-104, 1998.
11. M. E. Besterfield-Sacre, C. J. Atman, and L. J. Shuman, "Student attitudes assessment," *Journal of engineering education,* vol. 87, no. 2, pp. 133-141, Apr. 1998.
12. M. E. Besterfield-Sacre, and C.J. Atman, "Survey design methodology: measuring freshman attitudes about engineering," *Proceedings of 1994 ASEE conference*, pp. 236-242, June 1994.
13. S. D. Creighton, E. W. Ernst, J. H. Gibbons, et al., "A continuous quality improvement system: an on-going assessment process within the college of engineering and information technology at U.S.C," *Monographs in engineering education excellence*, University of South Carolina.
14. G. Cerro, "Measuring performance in engineering education."
15. D. P. Ausubel, J. D. Novak, and H. Hanesian, "Educational psychology: a cognitive view," New York, Holt, Rinehart and Winston, 1978.
16. J. D. Novak, and D. B. Gowin, "Learning how to learn," Cambridge University Press, 1984.
17. J. D. Novak, D. B. Gowin, and Johansen, "Using concept mapping as an assessment method," *North Central Regional Educational Laboratory*, 1983.
18. A. Arruarte, J. A. Elorriaga, and U. Rueda, "A template-based concept mapping tool for computer-aided learning," *Second IEEE international conference on advanced learning technologies (ICALT'01)*, 2001.