Session 1532

Making Technological Paradigm Shifters: Myths and Reality Experiencing the Electrical Engineering Learning Community (EELC) at Iowa State University

Mani Mina
Department of Electrical and Computer Engineering
Iowa State University

Introduction

During the second half of the 20th century, teaching technology to the engineering freshmen has posed tremendous challenges. The main challenge can be summarized in the following question: What can we teach the freshmen in engineering disciplines that will be useful and instructive for their future? In many introductory courses teaching practical tools can be risky. The fear is to have obsolete tools by the time the students graduate. Consequently, in many schools during the last few decades of the 20th century, the emphasis has been on mathematical and scientific concepts. Such an approach would build a good foundation for the future classes. It would also be a fundamental concept that will remain the same by the time the students graduate. Finally, with that approach from the first class the serious and intellectually capable students would be encouraged to stay with the program and the rest to change fields. In fact, this approach sounds attractive to many of my colleagues, especially those who are focusing on having "strong" (which mostly means mathematically capable) students in senior-level classes. However, it is not the most effective pedagogical approach. The problem my colleagues are facing with students' backgrounds and preparation is not exactly due to lack of mathematic capability, but due to lack of interest. Careful observation of our undergraduate students shows that a good number of engineering students have been either overwhelmed or even discouraged out of the programs due to the heavy emphasis on pure mathematical approaches and very little hands-on teaching. The author believes that this method has affected many students' performance, creativity, and interest in the field.

Recently, some progressive programs have been working on integrating hands-on and technical problem-solving schemes into their freshman classes[1-3]. When the students see applications and develop their interests dealing with hands-on problems, they would be ready to learn the mathematical aspects of the field. Consequently, in this approach the students will have better reasons to learn the mathematical concepts since they are conveyed to them in a practical context. The idea is to encourage students to know their field and the basics of engineering in a positive, dynamic, and practical environment. This approach has proven to be much more effective than other approaches.

At the Department of Electrical and Computer Engineering at Iowa State University we have chosen to solve the problem by offering a new problem-solving course based on authentic learning theories. The course is designed to breed new students with new ways of thinking and problem-solving skills. Our approach incorporates the hands-on practical projects from early days of the program. In addition, we actively make students aware of their own learning process and work with them with a learning theory originally developed and proposed by Habermas and Grundy[4-5]. The goal is to make lifelong learners. We believe we have a practical, effective, and innovative way of achieving our goals. Two groups of students have completed the newly deigned course. The early results indicate the validity of our approach. In addition, the class is becoming very popular among the students. Every year new students are encouraged to enroll in our Electrical Engineering Learning Community (EELC) by recommendations from our previous EELC members.

This paper, which is the first report of our experiment, reviews the highlights of our approach and our early findings. We briefly present some of the outcomes, issues in achieving our goals, and future plans.

Motivation

In the changing technological environment of the early 21st century, all technical and non-technical challenges appear to have multidimensional aspects. On the technical road to success, it is no longer sufficient to be able to solve isolated technological problems. The engineers and technologists of tomorrow need to be armed with the habits, problem-solving approaches, and learning capabilities that are far beyond any other time in human history. They need a dynamic *active-knowledge-base*, which includes an array of tools, concepts, critical thinking habits, team-building skills, and effective communication methods. The necessary *active-knowledge-base* is a moving target, rooted in the fundamentals of engineering and communication, and enhanced by a rate of change that is unprecedented in human history.

It is the author's belief that the new age requires new ways of training. Engineers have to be problem solvers, team builders, and technological shape-shifters. They need to comprehend the advanced aspects of their areas of expertise. However, the knowledge of the facts and concepts are not sufficient. Their knowledge needs to be complimented by additional learning skills. They need to be lifelong learners in their respective fields. They also need to value the interdisciplinary understanding of the links between their field, other technical disciplines, and society. This challenge provides us with a unique opportunity to design, implement, and experiment with new ways of training and mentoring the engineers of tomorrow. The purpose of our EELC is to provide an educationally nurturing environment to a group of freshmen and observe how such an enhanced environment helps them face challenges within their university experience. Currently a third of our freshman class is enrolled in the community.

The cognitive approach

We implement the ideas originally developed and proposed by Habermas and Grundy[4-5] as the three steps of cognitive development. Our innovative approach is introducing students to complicated engineering concepts while consciously following the three basic cognitive approaches: technical, practical, and emancipatory interests. The authentic learning that is based on the three basic cognitive approaches is fascinating, and a number of great books and articles on the subject are available. However, a complete discussion about the ideas and details are beyond the scope of this article. The following is a brief and functional explanation of the concepts. The following definitions and explanations are presented to provide the essence of the ideas and help the reader become familiar with the terms.

In some views of modern learning theories, curriculum design and all aspects of learning can be viewed in three stages. The first stage is the technical aspects of learning, where the students learn the concepts. At this stage students sometimes memorize and follow the taught rules. A good example is the mathematical and physical concepts that an engineering student needs to know. Newton's laws of motion and ohms law belong to this category. Initially, students are expected to learn, know, and start using them. Students will learn the concepts, see the solution methods, and repeat them. This stage is called the theoretical stage.

The second is the practical stage, where the students take the theoretical skills and apply them to problems. The problems for this stage are simplified. The multidimensional nature of the real problems is considerably reduced at this stage. This will allow the student to work with the theoretical constructs in the scope of limited applications. In the engineering disciplines, homework problems and well-defined narrow-scoped projects represent this stage. Most of the engineering students end up spending a lion's share of their undergraduate educations on the first two stages.

The final stage is termed the emancipatory interest stage. During this stage the student is encouraged to move from asking the "what" to the "why" questions. In this final stage the student has to drop all mental constraints and scrutinize every problem, the premise, and the fundamentals of the subject. The author believes that the real active learning only takes place when the students start to investigate the multidimensional aspects of practical problems. By in-depth and careful examination of the problem, reasonable solutions are created. This stage is called the emancipatory stage because the students should think openly without any boundaries.

In the third stage the problem is examined and is broken down into tasks and subtasks. At the same time the milestones for the project are defined, the evaluation criteria is also considered and planned. From the electrical engineering system design standpoint, this is where the design team has to focus far and beyond the simple circuit design. The design team needs to think about specific applications, packaging, mechanical integrity, and other perspectives. It should be noted that this is also the point in the industry that marketing concepts also are included in the design project. Many engineering students only show interest in the engineering design aspect of the projects. That indicates the engineers' lack of emancipatary thinking. In fact, very few students in a typical engineering program manage to practice the third stage of cognitive development.

One can argue that a true design with all of the aspects of a practical problem is almost impossible to simulate during the engineering undergraduate program. The only tool that will help students to be ready, flex their thoughts, and keep their sharp skills intact is the third stage of learning, the emancipation stage. During this stage, armed with critical thinking, students in active teams will examine the requirements, the limitations, and the paradigms that would stop them from growth and advancement. In our program the students and the teaching team focus most of the activities and discussions on this stage.

The team and the approach

The teaching team consists of instructor(s) (faculty in the Department of Electrical and Computer Engineering), the undergraduate advising team, a couple of selected graduate students, and numerous selected undergraduate leaders. This team works closely with the students to make sure the students are learning and maturing in their field. As a part of our innovative approach, the students are introduced to the three cognitive approaches and are required to apply them in all aspects of the course.

A vital requirement for the team is a good understanding of the three stages. In order for this method to work, the teaching team needs technical background as well as a good conceptual understanding of the three congestive learning stages. Effective mentoring is the key to success of this program. The mentoring is the responsibility of the teaching team. In particular during the third development stage (emancipatory), the students need mentoring in both technical understanding of electrical engineering and practical leadership in the cognitive approach. Our experience shows that without good mentoring, EELC students will be confused and loose interest in the field of study.

Paradigm shifters

A paradigm is defined as a set of beliefs, questions, and developed concepts that make one see the world. Paradigm shifting is the process of changing the perspective and approach when facing a problem. In order to shift a paradigm, one needs to review and renew the concepts, perceptions, interpretations, and methodologies of facing the problem. Thomas Kuhn in *The Structure of Scientific Revolutions* originally introduced this. Khun's model explained how scientific theories developed and advances were made in science and technology. He proposed that scientific revolutions take place when one actively questions, challenges, and changes one's perspective about the fundamental concepts[6]. This idea was also utilized by Stephen R. Covey in *The 7 Habits of Highly Effective People.* Covey used the power of paradigm shifting to refine habits and improve everyday approaches. Covey utilized the power of paradigm shifting to help develop new habits and escape the gravity pull of the old habits[7].

Technological paradigm shifters primarily understand what the problem is at hand. They know the technology and the available solutions with reasonable detail. They know how to think about the problem at hand and work within the box. However, to shift the paradigm they need to mentally reach out of the box to change their perspectives. They will examine new concepts and see the problem from new perspectives. That is how they can achieve innovative solutions. Our goal in EELC is to train a new breed of engineer with such capabilities. An important task for the mentors in EELC is to identify good habits and help the students to develop and sharpen their habits and approaches in studying, learning, thinking, and problem solving.

Making paradigm shifters

The author believes that our process of emphasizing learning with the three cognitive stages is the right path to develop the technological paradigm shifters. Once the students understand and practice the emancipation, changes start to take place. They start questioning the basis of their knowledge, their actions, their needs, as well as the problems. This creative scrutiny is the necessary requirement for paradigm shifting. The students understand the value of the emancipation by the end of the first term. During the second term they apply the emancipation process when dealing with more difficult problems such as research and hands-on projects that they choose with their mentors.

While working on various problems, students need to work in teams and go through systematic problem solving steps[8]. Their driving force is their interests and their power of questioning and learning. They need to identify what they have to do, what they can learn on their own, as well as what they need help with. They are evaluated based on their solutions, their communication, their methodology, and their level of creative thinking. Each student needs to prepare a separate report regarding their learning and their contribution. The students go through this process in different projects with different mentors. Consequently, they develop good habits in learning, posing questions, setting objectives, examining the problem at hand, and thinking out –of the box.

The basic premise
Our basic premise from the first day in class is summarized in the following quotation by E. Hoffer: "In a time of change, it is the learners who inherit the future. The learned usually find themselves equipped to live in a world that no longer exists." We make sure that this premise is repeated many times in various contexts.

To be a learner, we expect the students to develop their learning skills. Such skills include personal learning as well as team learning. We also emphasize and provide active learning examples. It is known that for a majority of the people learning is inversely correlated to their *comfort zones.* Learning is usually maximized when we are out of our comfort zones. Students are required to work out of their comfort zones. Each student has different tolerance levels and limits of *comfort zones.* As a part of this class we work with them to identify and improve the limits of their comfort zones. In order to emphasize out-of-comfort-zone learning, the faculty, graduate assistants, and the undergraduate leaders will engage in various projects that are out of their respective comfort zones. Seeing the mentors work out of their comfort zones teaches the students more effectively. If we are in the process of teaching the students how to learn, nothing is more educational than actually learning with them. Consequently, by creating an active learning environment where students work closely with the mentors, EELC creates a dynamic environment with unique synergy to train self-learning students.

The following is a list of typical projects that students have done during this class. The mentors' and students' interests primarily define the criteria of selection of the projects. In the following projects the students had to research and understand the concepts, learn more in-depth understanding of the requirements, and implement their solutions. In some cases the first attempts were kits available from various electronics suppliers. Following the kits the teams modified the projects to learn more.

1. Tesla coils (various kinds)
2. Jacob's ladder (various kinds)
3. Digital die (different approaches)
4. FM transmitter
5. AM/FM radio
6. Sensor systems for house security
7. Inductive launching system
8. Inductive heating system
9. Stunt gun

10. Fiber optic communication systems
11. Wireless video transmitter
12. Wireless communication system

The class

The class focuses on getting students to understand and appreciate mastery in their field. To encourage learning and thinking openly each lecture starts with a short thought-provoking presentation. The presentations could include quotations by industrialists or scientists, a musical piece, a poem, a part of a book by master scientists like Richard Feynman, etc. The presentation is followed by a brief discussion. Then the technical part of the class starts. During the technical part the class examines various tools and concepts and their application in engineering problem solving. The following represent the major headings for the items covered in the two terms:

1. Programming tools: C and Matlab
2. Mathematical tools: trigonometry, vectors, matrices, complex numbers, phasors, etc.
3. Engineering concepts: Faraday's law and application, Ohms law, Kirchhoff laws, Ampere's law, and Lenz's law with their appropriate engineering application; we also emphasize the concept of power
4. Modeling concepts: Linear modeling, numerical modeling
5. Word and logical problem-solving methodology
6. Electrical engineering concepts: explain energy manipulation with discrete elements; filters, transformers, discrete elements, and circuits

In the laboratory students utilize tools like C programming and Matlab to solve engineering problems. They also work on circuits, systems, and practice basic electrical engineering measurements. They need to work with partners, evaluate the partnership, and qualify their effectiveness in their reports. Students are encouraged to change partners frequently to learn other people's perspectives.

Finally there is a demonstration part of the laboratory. Demonstrations consist of opening up electronic and electrical instruments. Transformers, VCRs, CD players, blenders, electric motors, laptop computers, hard drives, and other equipment are taken apart. The focus is learning and explaining how each instrument and their sections function. During the demonstrations we talk about the role of the electrical engineers in the design of the instrument that is being studied. We discuss expertise that was needed to make the design and manufacturing. It is important for the students to understand the complicated and demanding manufacturing requirements. During the demonstrations we explain why designing consumer instruments requires engineering talents from various fields.

By the end of the first term the students will start to make their own circuits (like bridge rectifiers and simple transformers, digital die). Then groups identify projects and start working on them. At the end of the two terms the students participate in an EELC open house. During the open house groups demonstrate their projects. Everyone in the department is invited to the open house. Most of the guests include undergraduate students in electrical and computer engineering, as well as graduate students and the faculty. The visitors are encouraged to talk with the student teams and ask them questions. Finally, the instructor and the teaching team get feedback from the visitors and the student members of EELC. This is a great closure to the whole academic year of introduction to problem solving and electrical engineering.

Emancipation: A great problem to have

It is very important to let the students ask as many questions as they desire. Occasionally we find the questions to be immature, irrelevant, and vague. It is important to be patient with the questions. An ill-imposed question is indicating a missing concept. It is the responsibility of the teaching team to help the student identify and fix ill-imposed questions. If the undergraduate leaders as well as the graduate students have too many difficulties with the questions, they should seek the instructor's help. Ignoring questions and loosing patience with students who have immature questioning skills will result in an emotional reaction that can halt students' progress for a long time.

Successful emancipation practice by the students about the middle of the second term can result in some interesting problems. Our experience shows that during the second term at different stages students start to question the validity of the class, our methods, and our teaching approach. This can possibly be viewed as threatening to members of the teaching team. They may label it as a serious problem or lack of respect by the students. However, such probing questions are probably the most important part of the students' emancipation. It is only natural for the students to question things that they begin to understand well. The students bless the class, the structure, and the "mentors" with such a reaction. They question the whole class due to effectiveness of the approach. The student members are not defiant; they are showing great learning.

If the case of such questions, the author recommends the following:

1. Let all of the questions be heard.
2. If extra time is needed, the teaching team should make time out of the class.
3. Encourage the students to ask freely. Emphasize the emancipation practice.
4. Expand the question if it is not well posed; help the students make it better and more logical.
5. Work with the students to come up with a valid set of related questions.
6. Encourage team level brainstorming.
7. Examine what the students have learned from the class, and see if it helps answer the questions.
8. Discuss possible answers and aspects of the answers. It is very common at this point that the students' discussions lead to good logical answers.
9. If the questions are valid and can help the class, the instructor needs to consider the points and implement them.
10. If the points will not help or will not match our goals, they should be clearly explained to the students.

A good example is when they see the reasons for learning all of the mathematics related to the complex numbers and Euler's equation. This question is always asked when the subject gets a little cumbersome. Even with numerous examples in filter theory, wave theory, and other applications, there are some students who still do not see why they should learn the subject. It is the author's opinion to let the students know their question is valid and they should seek answers as they learn more about electrical engineering. They should keep the question in their mind.

They should keep asking the question throughout their careers and see if they find better answers. The important point for the student is to keep asking the question and not let the unanswered question stop their learning. Such questions will make them ready for deeper understanding. We clearly explain to the class that if generations of electrical engineers decided something is important, it probably is. If one does not agree with that and would like to challenge it, one needs to first show reasonable mastery of the item. Paradigm shifters are not those who fail to do something, so they create the shifts. They are capable of doing it well; however, due to their maturity they create new ways to do it better.

Results

EELC has completed two successful years. The following are some of the results that we have been collecting. Based on our assessment that are results of one-on-one interviews with the students, we believe the program has been showing good results.

Three of the mentors who have graduated are still in touch with the community as well as selected student members. They are trying to recruit them for summer co-ops. About one third of the students who finish the EELC have requested getting involved as student leaders. This shows a reasonable success for EELC as a dynamic learning community.

One of the most interesting parts of the community is the fact that the teaching team is learning as much as the students. The community approach is to use a diverse team to bring diverse approaches and activities. During the 2000-2001 there were six undergraduate assistances and only two of them were regularly paid. The other four never processed their time sheets since they thought this is more of a learning experience for them than for the students. We have the same problem during the 2001-2002 year.

The following are some important facts about our achievements. More than 90% of the students who started with EELC are in the electrical engineering program. The college-wise retention is about 70%. Over 80% of students in their second year are doing well in their classes (they claim to have As or Bs in all classes) and over 50% would like to be involved with the EELC and participate in the activities. Over 85% of the students are looking forward to difficult classes and would like to be challenged. This shows on their interactions with the professors of the respective classes. They define their excitement with technical challenges and solving problems. Some of the faculty in the second- and third-year classes are indicating that the EELC students show different approaches, ask questions more actively, and show more effort to learn and be involved. Finally, over 90% of the students in the second year would like to see EELC extend beyond the first year. We value the above results greatly and realize that they are based on limited numbers (the total of 60 to 70 students). Our goal is to expand the program, implement better assessment, and observe the students even after their graduation.

Future work

The author is working closely with the Department of Electrical and Computer Engineering and the College of Engineering at Iowa State University to be able to expand this class to the whole undergraduate population. With an efficient utilization of the resources, this learning style and the premise of the EELC can be expanded to all students. Currently EELC contains only a third of the freshmen students in electrical engineering. The process requires a diverse teaching team that is lead by dynamic instructors together with selected graduate and undergraduate students.

We are also currently working with the Department of Education at Iowa State University to have better assessment schemes to be able to quantify the students learning. Currently the assessment is mostly by the teaching team, which includes tests, homework, project reports, numerous one-on-one interviews, and meetings with the students and the groups. On some occasions a guest faculty is invited to spend time with the students and do an independent assessment. On such occasions we have only received positive assessments with encouragement and great suggestions. As the size of the project increases, better and more objective measurement schemes are needed.

Conclusions

The Electrical Engineering Learning Community has been designed and implemented based on an authentic teaching and learning theory proposed by Herman and Grundy. The three phases of learning (theoretical, practical, and emancipitory) help the students work more effectively and become self-learners from the very early days of their carriers. Students practice the process repeatedly in various activities and projects. During the class they learn about their strengths and challenges to develop their team-building skills. The main goal is to create dynamic, self-learning, and excitable students who look for challenging projects. The students work closely with the teaching team. The mentoring power of the teaching team is one of the key items for the success of the program. During the implementation of the authentic learning theory and in particular the emancipation stage, the students will be able to identify major paradigms as well as possible methods of shifting the paradigms. We believe that technological paradigm shifters are naturally grown in an open and dynamic learning group such as our EELC.

References

1. "Innovations in Teaching, Learning and Assessment", by C. Hudson, IEE International Symposium on Engineering Education , Volume: Day1 , 2001, PP. 11/1-11/5.
2. "Research on learning style: applications in the physics and engineering classrooms**",** J. D. Jenson and D. Morrison, IEEE Transactions on Professional Communication, Volume 44, Issue 4 , Dec. 2001 PP. 234 –242.
3. **"**Teaching technology success skills with motivation**",** *E. M. Rothkopf,* Frontiers in Education Conference, 1994, Twenty-fourth Annual Conference. Proceedings , 1994, PP.175 -178
4. "Curriculum: Product or Praxis", by Shirley Grundy, The Falmer Press, 1987.
5. "An Introduction to Theories of Learning" by B. R. Hergenhahn and M. H. Olson; Prentice Hall 1997.
6. "The structure of scientific revolutions" by Thomas S. Khun, University of Chicago Press, 1989.
7. "The 7 habits of highly effective people", by Stephen R. Covey, Fireside, 1989.
8. "Engineering problem solving with C", by Delores M. Etter and Jeanine A. Ingber, Prentice Hall, 2000.

Biographical Information

MANI MINA is an adjunct assistant professor and the coordinator of the electrical engineering learning community (EELC) at the Department of Electrical Engineering and Computer Engineering at Iowa State University. He has been a recipient of several teaching and research awards. His research interests include optical networking and communication, and innovative methods of teaching technology. He is a member of ASEE, IEEE and ASNT.