Tuna B. Tarim, Martin Di Federico, Pui-In Mak

Circuits and Systems Education: Viewpoint of GOLD and Industry

Abstract

This paper discusses Circuits and Systems (CAS) education, its strengths and shortcomings, and areas that need improvement from the perspective of two GOLD (graduates of the last decade) members and one industry member. The GOLD members highlight the need for hardware experiments, and *active* education methods such as self-learning through practices, and the importance of lab work to relate theory to practice, and also discuss the impact of new emerging technologies on educational reforms, also suggesting ways to get industry involved in the formulation of a new multi-discipline education curriculum. The GOLD members also discuss the impact of globalization on the CAS education in less- developed countries and the role of the IEEE CAS Society on the subject matter. The author from industry discusses the importance of CAS education, and contrary to the general belief, points out the importance of understanding the fundamentals of electrical engineering in industry. The author also discusses the importance of being flexible in a work environment, and establishing a broad knowledge in engineering to have a positive impact in the company.

1. Introduction

The Circuits and Systems (CAS) Education Panel and Workshop held during the 2008 International Symposium on Circuits and Systems (ISCAS) are two events organized to draw the Society's attention to current practices in CAS education and how to improve it. The panel and workshop brought together people from different parts of the world who are passionate about education. It created an environment to allow the sharing of experiences of participants. The panel and workshop discussed current practices in CAS education and several misconceptions, as well as the main issues and potential solutions.

During the CAS Education Workshop, two Graduates of the Last Decade (GOLD) members of the IEEE CAS Society and an IEEE CAS member from industry shared their experiences with the attendees, discussed the need for laboratory work, importance of self-learning through practice and discussed ways to get industry more involved in the education curriculum. This paper is an extended version of the thoughts of these GOLD and industry members to point out the current practices in CAS education and what can be done to improve it.

This paper is organized as follows: Section 2 presents the viewpoint of two GOLD members from two different regions: 9 and 10. Section 4 gives the opinions of a CAS member who works in industry. Section 5 summarizes the views presented in this paper.

2. Viewpoint of GOLD Members

The first half of this section focuses on the undergraduate education. The study attitudes of modern students are stated first. The effectiveness of different learning methods is then discussed. The importance of laboratories, the role of the teaching assistants (TAs) and the idea of self- learning through practice are also presented. The second half points out the impact of new emerging technologies on educational reforms, gives suggestion to get industry involved in the formulation of a new multi-discipline education curriculum, and discusses the impact of globalization on CAS education in less developed countries and finally the role of the IEEE CAS Society, on the subject matter.

2.1 Study Attitudes of Modern Students

Students are different in many ways: their studying habits are different, they learn differently, and they pay attention to different things. Some students need minimum amount of assistance with teaching and can obtain their degree without any or little help from the professors or teaching assistants (TAs). Other students are more insecure and cannot work on their own. These students need more assistance from their professors and TAs. Another group of students knows just enough to get by in classes and they never get into the details to understand the fundamentals. Since these students have no proper understanding of the basics, they face a lot of problems dealing with more advanced courses. This is a serious problem that needs to be addressed.

2.2 Learning Methods

Learning is a cognitive process and the knowledge must be analyzed and integrated by the learner. This activity requires a mental effort from the students.

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Students learn when they read, write, assemble circuits, and discuss circuits and systems behavior. Several factors influence the educational achievement of students, such as motivation, background, organization, intelligence, and teaching methodologies. The teaching methodology implemented by the professor is very important for the development of the student. A good teaching methodology must consider several points:

- ***Personal:*** As mentioned previously, all students are different and the appropriate teaching methodology depends greatly on the students.
- ***Progressive:*** It should not be expected that all students will understand everything after explaining the first time. It is important to ensure that the students understand the basics before teaching them more advanced topics.
- ***Active:*** Professors should let the students be involved in the learning process. The more the students is able to practice, the more and faster they will learn.

There are several activities and/or methodologies that are used by professors with pros and cons, such as lectures, audio-visual presentations, demonstrations and observations, debriefing, problem solving skills, small group discussions, projects, guided practice and laboratories, and class exams.

- ***Lecture:*** Most professors assume that lecturing is nothing more than talking about a specific topic to a group of students. Good lecturing, however, also requires knowledge of the material that is being presented, implementation examples as well as theory, and perhaps the most important things among all, awakening the interest and curiosity of the students.
- ***Book:*** Textbooks can be more comprehensive. Textbooks containing a learning plan for students and teaching plan for instructors [1] are helpful to synchronize the expectation of the transmitter (instructor) and the receivers (students) before/during the lectures. Instructors should have an open teaching plan available for the students, while students should review the course material prior to the lecture, or even before enrolling in the course. Books that can offer supplementary websites [1], [2] are even better for self-learning, because students can easily find the SPICE netlists discussed in the book. The traditional blackboard teaching is still very effective for undergraduate courses. In particular for the courses related to circuit design, students follow the instructor step by step on the blackboard. Nevertheless, it is time efficient to project the figures from a computer program and highlight the key points [1].
- ***Audio visual presentation:*** The perception is that audio visual presentations are easier for professors since they follow a certain document to present. Students might find audio visuals to be less effective because there is usually too much information that makes it difficult for the student to assimilate.
- ***Demonstrations and observations:*** This does not require a lot of participation from students, therefore though stimulating, will probably remember just a few things from the demonstrations and observations.
- ***Debriefing:*** Sometimes this activity does not work because the students are scared to interact and feel especially pressured if the professor forces a student to answer a question.
- ***Problem solving:*** This methodology helps the students get involved. This can sometimes take too much time. It is important to give the students the time that is necessary to assimilate the information.
- ***Small group discussions:*** Temporary groups are formed for the purpose of discussing a specific topic or problem. This is a very good tool because it forces the students to defend their point of view, which is very helpful in the assimilation process.
- ***Guided practice:*** Sometimes it is necessary to teach the students how to “start” the solution of an exercise. However, it is also important to let the students use their creativity and think about the solutions on their own.
- ***Laboratories:*** This is a very important part of circuits and systems learning process. The students get involved with the circuits and can verify that the theory can actually be implemented.
- ***Exams:*** Exams are a fundamental part of the learning methodology. This is probably the most important feedback for the professor about the success of their teaching methods. Though a good indicator, it is probably not best to decide on the success and failure of students solely on the exam results.

2.3 Importance of Laboratories

For a long time, students have had the impression that circuit theory classes were taught like graphical mathematics classes: Typical RLC circuits are explained in a not-so-exciting way and the component values in the circuits are unrealistic, such as 1-F capacitor and 1-H inductor, to simplify the analysis. Students, therefore, lack

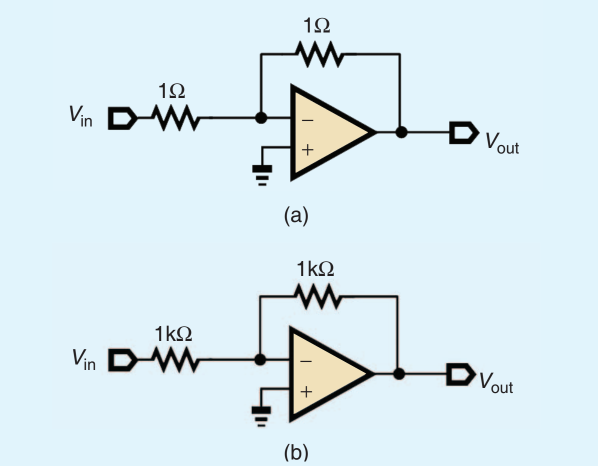

Figure 1. Inverting amplifier that (a) works in simulation, (b) works in reality.

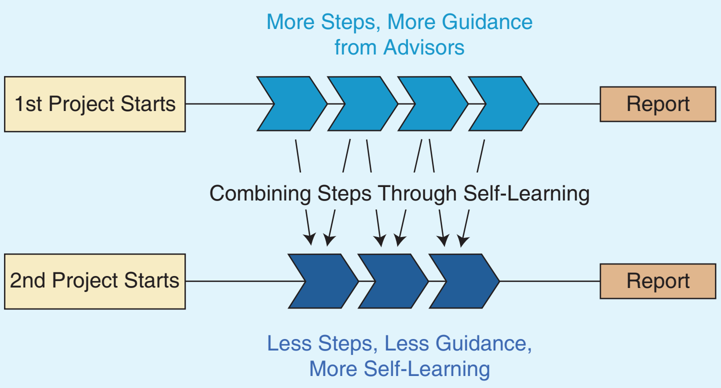

Figure 2. Concept of self-learning through practice.

the ability to link theory and practice and they have less understanding of the limitations of circuit simulators.

For instance, if the circuit configurations shown in Fig. 1(a) and Fig. 1(b) are given to a student who has no hardware experience. If the student is asked to pick the configuration that will work: It is possible that the student will select the one shown in Fig. 1(a), which works perfectly in simulation (assuming an ideal operational amplifier) but fails in reality.

Students should have the opportunity to understand the size and the shape of electronic components. Understanding the circuit physically and intuitively plays a key role in motivating the students and awaking their curiosity. Students of this generation are very active, interested in studying through their hands and head, rather than sitting in the classroom and passively listening and absorbing the lecture. Practice must be built on top of basic theory. With a limited number of classes, instructors always face a tradeoff between teaching more theory vs. practicing more experiments. In fact, many circuit concepts can be self-learned through projects. The idea is shown in Fig. 2.

The first project in the example is completed in several steps and requires more guidance from the instructor. However, the experience gained from the first project helped reducing the number of steps in the second project since self-learning of many theoretical concepts occurred during the first project. In other words, it is possible to self-learn theory through additional practice.

Laboratory practice, on the other hand, also offer a way to improve team work by sharing roles and responsibilities during the experiments, to help students in generating engineering criteria and verify and understand theoretical concepts. It is important that the students can establish a link between what they already know and what they have just practiced. It is known that there are two kinds of laboratories:

Verification laboratories: The students learn the theory and design circuits to prove the theory.

Design laboratories: The students learn how circuits work and they have to design and test their own circuits.

The best way to verify a design is to work on the real circuits. For instance, the best BJT model is the BJT itself. Simulation is also important but nothing is more motivating and exciting than having your own design work. It is obvious that the student's motivation is a decisive factor in the learning process.

2.4 Role of the TAs in the Laboratories

TAs play a key role in the student's learning:

- Take all the time needed to explain the laboratory.
- Pay attention to the motivation of the students.
- Clarify all laboratory safety rules to students.
- Try to get the students involved in their own learning process.
- Orient the students towards the prior discussion of the basic concepts.
- Make students aware of the magnitude of the work they are doing.
- Give students a chance to make their own decisions without the constant intervention of the professor or TA.
- Visit each laboratory group for their questions to increase the students' analysis capacity as well as their critical skills.
- Give feedback to the students so they can learn from their experience.

- Help the students to frame clearly their work inside the scope of the practice to get an idea of their own capacities.
- When the laboratory work is finished, take ten minutes to address all the students' problems and achievements.
- Do not resolve the problems for the student, instead, give the students the tools to resolve them.

2.5 Impact of New Technologies on Educational Reforms

As time passed by, pure electronic products such as computers, TV, cell phones, iPods, etc., lose most of their attractiveness in motivating students to study electrical engineering (EE). Students trusted that the developments of those products were among the hottest in engineering study in the past few decades, but have entered into a mature status already. Re-triggering the modern students' curiosity on circuit theory needs more attractive topics as the motivation. Examples are how green CAS helps improving the environment and energy savings? How biomedical CAS improve the quality of life? Potential students to join EE will be extended to those who interests in science, engineering or both. It is reasonable to say that the multi-disciplinary technologies are creating new many opportunities challenging the modern EE education.

However, multi-disciplinary education has its own challenges; building a hospital laboratory for experimenting biomedical CAS requires a considerably amount of investment for human resources and equipments. For instance, designing an implantable chip for biopotential signals acquisition requires researchers/engineers who have good knowledge and practice of both EE and biomedical. Accounting the fact that many small- or medium-size universities in less developed countries get little to no funding from the government and industry (industry does not like to work with universities that are not well known), the success of future EE education in these countries will largely depend on the available funds available, and on the personal relationship of the professors with the government and industry. The question is, in what way the industry can help.

Equipment donation and special classes given by industry are becoming popular to accelerate research in new directions. Industry can highlight what combination of skills and knowledge will match the jobs they offer. The study plan of their current successful employees can be given out as references. Building an Engineer Skill Menu (Fig. 3) not only can inspire the students in selecting courses, but also the instructors in preparing their teaching materials.

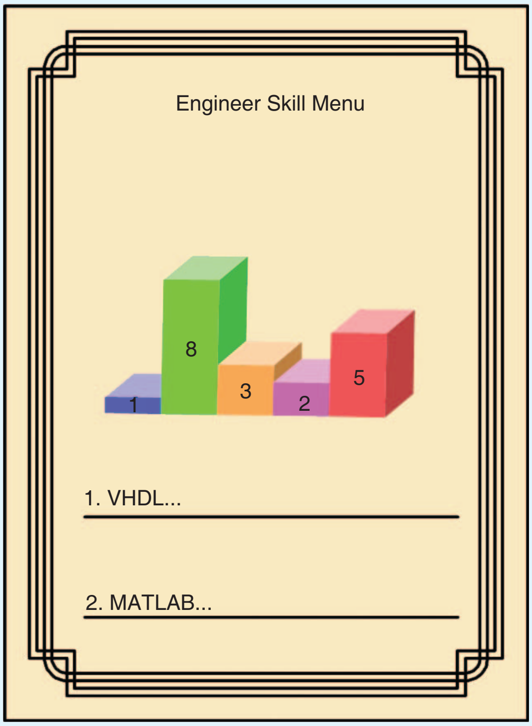

Figure 3: An Engineer Skill menu.

2.6 Impact of Globalization on Less Developed Countries and the Role of IEEE CAS Society

Less developed countries typically lack funds and latest information on industry trends. Informative and updated resources downloadable through the Internet or purchasable in the form of a DVD appear as economical ways in serving our CAS members in both academic and industry. Those resources can come from the conference tutorials, keynotes, distinguished lecturers or workshops. The IEEE CAS Society has been working on parts of them through new initiatives and membership services [3], attempting to network across the regions and to improve the educational levels in less developed countries.

3. An Industry Viewpoint

In the past, when hiring an electrical engineer to a company, the task of the engineer was clearly defined. The engineer would have a specific responsibility and would be interviewed for knowledge in that specific area: Design engineers were responsible for designing circuits, test engineers were testing the chip when it comes back from manufacturing, product engineers were responsible for the product, EDA/methodology engineers were responsible for defining methodologies and flows, system engineers were responsible for designing the system, and so on so forth. All these jobs had their boundaries, and in most cases the engineer's task would be done when they completed their specific task.

Things are quite different today. Engineering no longer means sitting in an office all day, isolated from the rest of the team and working on our own specific tasks. Nowadays, it is ever more important to have broader knowledge in circuits and systems, test, characterization, EDA and methodology instead of focusing on a single topic. It is a must to be a team player and to have good communication skills.

All of this translates to circuits and systems education as "basics", "flexibility" and "broad knowledge".

3.1 Know Your Basics

Companies look for engineers who can handle various tasks because the needs of projects constantly change. It is not reasonable to expect an engineer to know "everything", however, it is reasonable to expect an engineer to know the basics of their discipline and grow their knowledge base as they gain additional experience. The best people that this author has worked with are those who learned their basics well in school. It did not matter what task they were given, they performed very well because they knew what they had to do. Even if they did not know too much about the topic at first, they learned very quickly because they knew how to learn. This is one of the main things CAS education should help with: An education should teach students how to think and how to learn and it should begin with teaching the basics of the discipline. The students should not have to go through graduate school to learn these basic skills.

This author has met many electrical engineering students who knew that they needed to run transient simulations on their circuits and they certainly knew how to run it, however, they did not know why they were supposed to run it. If there is difference between "learning the basics" and "learning enough to graduate", the example above shows it.

How does knowing our basics relate to being flexible and having a broad knowledge?

3.2 Flexibility and Broad Knowledge

As we get better in learning the basics of our discipline, our capability and willingness to be flexible with respect to what task to take on and what project to work on will increase because we see learning new topics as challenging opportunities to be successful as opposed to obstacles because we are not familiar with the topic. We welcome and enjoy the challenges and opportunities that come in the shape of working on new designs or new methodologies because it helps us gain experience and build on our strong foundation. Indeed, the stronger our foundation is, the stronger we can build on it. Imagine a building with a strong foundation: As we build more stories on top of the foundation, we have confidence that it will strongly carry all stories. If, on the other hand, we have a building with a shaky foundation, it is more likely that the building will collapse in a matter of time; maybe not after the first story is built, and maybe not after the second or third, but eventually the building will collapse. This is very similar to our educational foundation.

Broad knowledge is something linked to the basics and flexibility. Imagine that we have one opening to hire a design engineer, and there are two design engineers who practically have the same knowledge on the same topics that we need. They both have the same degree, they have both worked on the same type of circuits, they have the same experience level, and they are both good communicators. What would be the next distinguishing factor? It will be how broad knowledge they have on different topics such as layout, design automation, modeling, manufacturing, and device physics. It is still true that being a good engineer is the starting point to be hired to a job; it is just that the definition of "good engineer" has changed over the years.

Being flexible and learning new topics makes us well rounded engineers with a broad knowledge and gives us the opportunity to understand different aspects of a project. Even today, there are engineers working in industry who believe that their job is done as soon as they complete the design of their circuit. Clearly, these engineers need to change their mode of operation and adapt to industry's changing environment.

3.3 Team Work and Good Communication Skills: Are They Really Important?

Over the years, project cycle times have increased from years to months. Furthermore, most companies now have project teams in various countries worldwide and projects are becoming multi-site. However, the complexity of products has not decreased; to the contrary, products are becoming more complicated and that every person in the project team needs to understand different tasks and even perform those tasks when necessary: The design engineer needs to work with the test engineer, the characterization engineer, and the system engineer every step of the way. The validation engineer needs to work with the design engineer and test engineer. Similarly, many others need to work together during the course of a project.

Engineers know about the importance of "teamwork". This is not only a cliché; teamwork is the key for successful products. As project cycle times get shorter and shorter and project teams become more and more multisite, all team members need to be aligned with regards to the big picture, the end goal of the project, and the project timeline so they could all work in synchronization and complete their tasks on time.

Meeting the project timelines depends on the clear communication between multi-site teams and the common understanding of the goals. This is one place where good communication skills play an important role. This is also the reason why hiring managers' job descriptions include a statement similar to "must be able to work in a team environment".

Many projects have failed to finish on time not because the project team lacked technical knowledge, but simply because they did not know how to communicate within the project team. Many managers rightfully so have a hard time choosing between a candidate with great technical knowledge and poor communication skills, and a candidate with average technical skills and great communications skills.

3.4 CAS Education: Good or Bad?

CAS education should not be only about educating students on technical topics. It is important that our education is aligned with the real world needs (industry and academia) and that the CAS curriculum is up-to-date to prepare the students for their jobs after school.

Most schools in the US offer a reasonable graduate electrical engineering education. However, the undergraduate engineering education is often too generic: it offers too much flexibility to students in terms of what classes to take and does not always require a graduation thesis.

There is a saying that "practice makes it perfect". Laboratory work and hands-on practice are a must in CAS education and it provides an effective way to learn. In that sense, plenty of laboratory work and a graduation thesis would help the students gain practical experience before they start working in industry and without having to go to graduate school.

4. Summary

Students have different learning characteristics and the teaching methods of professors have to be constantly reviewed in order to define which methodology can have a better result for the set of students enrolled in the course. It is also necessary to make the students aware of the importance of learning the basic theory and to help them achieve synergy and the necessary positive internal motivation to learn circuits and systems.

Undoubtedly, CAS education is always evolving and ever challenging. These challenges can be addressed through collaborative research, implementation and shared experiences. Looking ahead, it is believed that the IEEE CAS Society will continue to play the key role in reforming the CAS education in this century and beyond through innovative initiatives and membership services.

From an industry viewpoint, the curriculum of electrical engineering needs to be constantly updated with new classes in new research topics. Academia plays a key role in educating tomorrow's young minds, successful engineers and successful engineering managers, and it is therefore essential that academia always stays up-to-date with the required education to meet industry's needs to design products. Academia and industry need to work together to establish a well defined CAS education. Without academia, industry would not have the resources to research new topics that soon become products. Without industry, academia would have no reason to do research. We need to work together to define a CAS education that meets the needs of both.

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Babak Ayazifar

Can We Make Signals and Systems Intelligible, Interesting, and Relevant?

1. Why This Prolegomenon?

The way we teach signals and systems often leaves our undergraduates bored, bewildered, or battered.

"We need more practice problems."

"This stuff is too abstract!"

"Why do I need to learn about op-amps before I even know what 'frequency response' is? Shouldn't it be the other way around?"

"Somebody, please rescue me from this torturous algebraic grunt work!"

"Where in the world can I apply what you're *trying* to teach me?"

The litany of their grievances is virtually endless, and substantially legitimate.

Most of our lectures and textbooks are short on interesting, relevant, and mind-bending examples. Instead, they're saturated with theoretical minutiae, mathematical pedantries, or rote exercises whose solutions are better suited for a recipe book. Is it *that* essential to harp on Dirichlet's conditions for the convergence of Fourier series, on a first pass? Perhaps we should introduce Fourier series in a context where convergence is ensured—discrete-time periodic signals. More on this point later.

A typical undergraduate curriculum imposes unnecessary prerequisites for an introduction to signals and systems; traditionally, this has been in the form of an electronic circuits course, though there *have* been recent exceptions. The problem sets we assign drown our students in unwieldy mathematical manipulations, which clutter the main concepts and interfere with learning. The exams we design are plagued with formulaic problems that interrogate our students for cookbook solutions based on literal recall, rather than stimulate their creativity, gauge the depth of their understanding, or stretch their knowledge to the brink and beyond. Our focus on applications is narrow and of questionable relevance to the modern, interdisciplinary world. And, alas, we often do not motivate what we teach—and this, perhaps, is our greatest failing. Sometimes, I wonder if we even know what we want our students to learn, much less how to teach it to them.

When I was an undergraduate, we used to describe our state of affairs thus: "The problem sets, lectures, and exams form a set of mutually orthogonal vectors." In retrospect, we should have added discussion sections, labs, and textbooks—the completed basis would

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