Circuits and Systems Education: Viewpoint of Industry and GOLD

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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-the-theory 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 that are passionate about education, and 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, and 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 in the following fashion: Section 2 and Section 3 are the viewpoints of the IEEE CAS Region 9 and Region 10 GOLD members, respectively. 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 Region 9 GOLD member

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 can not work on their own. These students need a lot more assistance from their professors and teaching assistants. Another class of students know just enough to get by in classes, and they never get into the details to understand the basics. Since these students have no proper understanding of the basics, they face a lot of problems dealing with more advanced courses, and this is a serious problem that needs to be addressed.

2.1. 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. 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 listed below:

- ***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 student 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 of the 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 most important of all, awakening the interest and curiosity of the students.
- ***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 which 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, but 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 and this 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.

2.2. Importance of laboratories

Laboratory practice is one of the best learning strategies in engineering. Laboratory practice is when the students acquire and develop the necessary skills to generate engineering criteria, 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 learned and laboratory work can help establish this link.

Laboratory practice is a way to improve team work by sharing roles and responsibilities during the experiments. The laboratory experience allows the students to increase continuous improving and learning. There are two kinds of laboratories:

- Verification laboratories are where students learn the theory and design a circuit to prove the theory.
- Design laboratories are where students learn how the circuits function and they have to design and test their own designs.

It is important to note that the best way to verify a design is to work on the real thing. 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 working, and it is obvious that the student's motivation is a decisive factor in the learning process.

2.3. Role of the teacher assistance in the laboratories

The TAs play a very important 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.

3. Viewpoint of Region 10 GOLD member

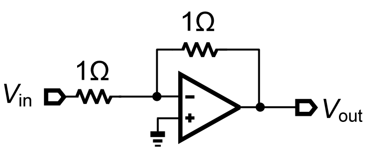
This section discusses the undergraduate circuits and systems (CAS) education from a recently-graduated educator's viewpoint, highlighting the importance of hardware experiments, and active education methods such as self-learning the theory through practice. The impact of new emerging technologies on educational reforms is discussed, and suggestions to get industry involved in the formulation of a new multi-discipline education curriculum are given. This section also discusses the impact of globalization on Circuits and Systems (CAS) education in less developed countries and the role of the IEEE CAS Society, on the subject matter.

3.1. Current practices

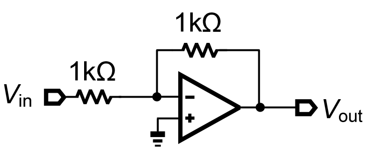
3.1.1. Theory, simulation and experiment

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 1F capacitors and 1H inductors, to simplify the analysis. Students, therefore, lack the ability to link theory and practice and they have less understanding of the limitations of circuit simulators.

Even though students like to use circuit simulators, such as Spice, to quickly analyze their large circuits, hardware experiments in the laboratory should simply not be replaced by simulations. Imagine that the circuit configurations in Fig. 1(a) and Fig. 1(b) are given to a student who has no hardware experience, and 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.



(a)



(b)

Figure 1: Inverting amplifier (a) Works in simulation, b) Works in reality.

Students should have the opportunity to feel 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. The GOLD member who is authoring this section of the paper has observed that students of the new 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. On the other hand, 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. This GOLD member has also experienced that many circuit concepts can be self-learned through projects. The idea is shown in Fig. 2.

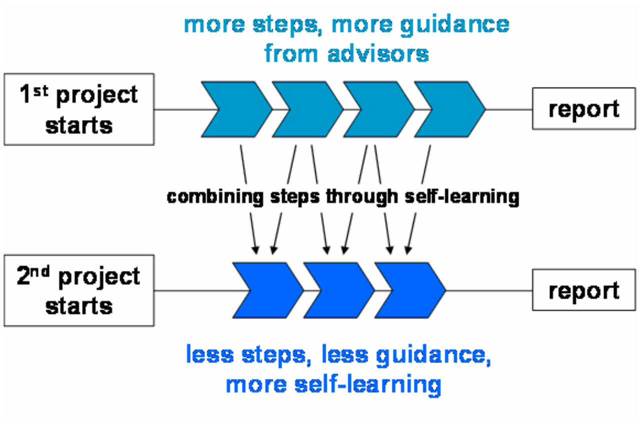


Figure 2: Concept of self-learning through practice.

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

3.1.2. Teaching materials and methods

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 to the course. Books that can offer supplementary websites [1, 2] are even better for self-learning, where students can easily find the Spice netlists discussed in the book.

In teaching undergraduate courses, this author's experience is that the traditional blackboard is still very effective. 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 figures from a computer program and highlight the key points [1].

3.2. Impact of new technologies on educational reforms

Multi-disciplinary education in Electrical Engineering (EE) is the trend of the century, nanoelectronics, biomedical, and organic electronics being just a few of the multi-disciplinary emerging technologies. Multi-disciplinary education has its own challenges; for instance, building up a hospital laboratory for adopting biomedical circuits and systems requires a significant amount of investment on equipment and human resources, and a significant effort to build a research team which has members of different professional background. Taking into account the fact that many small or medium size universities in less developed countries get little to no funding from 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 funds available, and on the personal relationship of the professors with government and industry. The question is, what can industry do to help?

Industry should invest on education to stay competitive. Equipment donation and special classes supported by industry are becoming more and more common to accelerate the research in new directions. Industry can highlight what combination of skills and knowledge are most suitable to be successful in the jobs they offer, and the training plan of their current successful employees. 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 (a win-win situation).

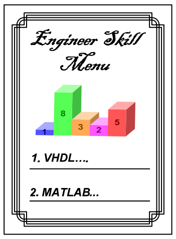


Figure 3: An "Engineer Skill" menu.

3.3. Impact of globalization on less developed countries and the role of IEEE CAS Society

Less developed countries typically lack latest information on industry trends and technologies. Offering international courses is a way to alleviate this. These courses should be localized to reduce the travel cost so that students and professors can afford to attend. Another option is to make the course and conference material available through videos, which can then be shipped with low cost or downloaded through the Internet. The IEEE CAS Society has been working on the latter through new initiatives and membership services [3] attempting to network the regions and bring up the educational levels in less developed countries.

4. An industry viewpoint

In the old days, when hiring an electrical engineer into 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 would be responsible for designing circuits, test engineers would test the chip when it comes back from manufacturing, product engineers would be responsible for the product, EDA/methodology engineers would be responsible for defining methodologies and flows, system engineers were responsible for designing the system, and so on so forth. All of these jobs had its boundaries, and in most cases the engineer's task would be done when they completed their specific task.

Things are quite different these days. Engineering is no longer sitting in an office all day long, 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.

How does all of this translate to circuits and systems education? It all boils down to the "basics", "flexibility" and "broad knowledge".

In this section, we will go through these one at a time.

4.1. Know your basics

Companies look for engineers who can handle various different tasks because the needs of projects constantly change. It is not reasonable to expect an engineer to know "everything", but it's reasonable to expect an engineer to know the basics of their discipline and grow their knowledge base as they gain more and more experience. The best people that this author has worked with are the ones 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, and 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 start with teaching the basics of the discipline. The students should not have to go through graduate school to learn these.

This author has come across many electrical engineering students who knew that they needed to run transient simulations on their circuits and they certainly knew how to run it, but 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 clearly.

How does knowing our basics relate to being flexible and having a broad knowledge? Let's go to the next section to read more about this.

4.2. 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, 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 will have confidence that it will carry all stories strongly. 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.

Let us now review the third requirement: Broad knowledge is something linked to the basics and flexibility. Imagine 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 are trying to hire for. 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 of a knowledge they have on different topics other than design, such as layout, design automation, modeling, manufacturing, device physics, and others. 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 think 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.

4.3. Team work and good communication skills: Are they really important?

Over the years, project cycle times have gone from years to months. In addition to this, most companies now have project teams in various countries all over the world and projects are becoming multi-site. On the other hand, the complexity of products has not decreased; on the contrary, products are becoming more and more complicated such that every person in the project team needs to understand the 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 hear about the importance of "teamwork". This is not just a cliché; teamwork really is the key for successful products. As project cycle times get shorter and shorter and project teams become more and more multi-site, 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 can 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 will have a hard time choosing between a candidate with great technical knowledge and poor communication skills, and average technical skills and great communications skills, and rightfully so.

4.4. CAS education: Good or bad?

CAS education should not be only about educating students on technical topics. It's 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 to their jobs after school.

Most schools in the US offer a reasonable graduate Electrical Engineering education, however, the undergraduate engineering education is generally 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". Our CAS GOLD members have repeated in their sections of this article that laboratory work and hands-on practice are a must in CAS education, and that it is an effective way to learn. In that sense, a lot 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.

4.4. Summary

The GOLD member from Region 9 highlighted that students have different learning characteristics and the teaching methods of professors must be constantly reviewed in order to use the best methodology for the set of students at that time. Also it is necessary to emphasize that it is important 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, as mentioned by the GOLD member from Region 10. These challenges, however, can be addressed through collaborative research and implementation, and shared experiences. Looking ahead, the author believes that the IEEE CAS Society will continuously play the key role in reforming 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 very important 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 will soon become products, and without industry academia would have no reason to do any research. We are in this together and we need to work together to define a CAS education that meets the needs of both.

References:

[1] B. Razavi, *Fundamentals of Microelectronics*, John Wiley & Sons, Inc., 2008

[2] R. J. Baker, H. W. Li and D. E. Boyce, *CMOS Circuit Design, Layout, and Simulation*, IEEE Press, 1998.

[3] IEEE CAS Society President's Message, http://ewh.ieee.org/soc/icss/pres-msg.