Keynote address: Cyber education for the cyber generation

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Nano-electronics is the technology underlying the Cyber Space. The cyber generation, the kids that are raised on and with the internet use it as their natural information environment. And natural it is! Electronics has come a long a way to become this natural, it had to ride many detours to get where we are now, and much naturalness still has to be conquered. We are witnessing shifting paradigms all the time, lately towards Peer-2-Peer, Community Endeavors and Ambient Intelligence (a 'paradigm' describes new ways of doing things). They have upset almost any component of the cyberspace, computers, mobile phones, cameras, displays, CD's, DVD's, WLAN's, encyclopedias, world maps, name it. Many developments that looked promising at first are de facto obsolete before they hit the market. This is the world our new generation of students is growing up with and which they will have to steer once they have become adults. What does that mean for their education?

In this keynote address, I do not want to talk about education in general, but let me nonetheless make a general educational comment that might be relevant for engineering education as well. Kids from age 7 on become internet experts, almost nothing that is there can be hidden to them, much to the distress of their parents and grandparents. The internet covers indeed the bad big world, which is now there on their innocent fingertips. Luckily, most kids are good people with good parents and have a well developed sense of values and ethics. Although they are easily able to visit any site they want, you discover that they usually and naturally go for sites in which they find stuff that matches their age and interests. Education plays a major role here. Parents have to be interested in what their kids go for, talk openly to them, convey values, not in a ponderous way but trying to reinforce what is already living in them, listening carefully and getting involved in the formation of their minds, using the internet as medium.

Besides presenting the big bad virtual world, the internet is of course the inexhaustible source of information. Almost any course on any topic can be found on it, not to speak of lots of graphical information, accounts, guidelines and recipes to set experiments up oneself. You find almost whatever you can think of. Meet the great minds on the internet - maybe not 'meet' in a human sense although YouTube goes some ways already towards that goal, but certainly get acquainted first source of their ideas. Many years ago we who were teaching undergraduate or even graduate courses had lots of trouble getting our students to visit libraries and to search into the literature on their own. Although the library was just around the corner, there was considerable reluctance from both students and teachers to use the available information creatively. The students wanted to restrict their studying effort as much as possible, forcing teachers to be specific about exactly what they had to know, and some teachers either did not know much about what was in the literature or were unwilling to expose their students to other ideas than their own.

Which brings me to the core of my keynote message. Because of the new cyberspace and the cyber generation, engineering education has to change its techniques thoroughly while staying fundamentally the same in its foundations. We have to do things in a different way, based on the cyber space, while remaining the same kind of human learners and teachers. My central thesis is then: the modern educational cyber space requires a more intelligent approach to education with deeper human involvement than before. Just as parents have to guide their kids through the internet information space, we who teach engineering have to focus on guiding our students coherently through the much more wieldy and advanced content that forms the basis for engineering and technology.

What is this mysterious ability teachers need to bring their students up to par with modern cyber technology? A distinctive characteristic of human intelligence is that it only finds what it is looking for. This anticipative property is based on associative thinking, certainly, but also and most decisively on the direction giving ability of our teachers. Education in engineering is about generating the emergence of the technological mind in our students. We teach them what they should be looking for. We are directing their minds towards the possibilities of technology, we are teaching them to ask, to observe and to see. Opening up the mind cannot be obtained from the internet or the library, it precedes the ability to discover and understand, most of us need a teacher for that.

It would be incredibly ironical if cyber teachers would not be able to use the full potentiality of the cyber space to teach their subject. This, however, is a considerable challenge, even we, cybernauts, have to relearn how to teach. It is a bit like the emergence of a new musical instrument. Making good use of electronics in music generation has proven not to be that simple and has not been achieved yet. In the simpler times of the emergence of the piano it took great minds and a slew of pedagogues to incorporate that new instrument in the musical tradition, which, by the way, it thoroughly changed.

The purpose of this conference is for us, teachers, to discover adequate ways to handle the new information medium of our students. Good examples of how that can be done will be presented during the conference, but let me focus on a few basic principles that need to be taken care of, let's say: ground ethics for this situation. Technology is a form of science, it is the science of craft. What makes it science is the systematic development of a coherent, deductive, verifiable and adequate theory. A lot of teaching is devoted to bringing presumably the best theory we have in what we consider the most important fields of technological knowledge - in our case in nanoelectronics.

We fight with each other in numerous university committees about which topics should be included when in the curriculum, and once we have acquired a course and a time slot, we hasten to produce a syllabus, precise directives to the students, course material and if we are open minded enough, discussion topics, laboratory material or even a personal project. But are we conveying the 'creation of technology'?

Students certainly need sufficient background material if only to get familiar with the landscape of their new field of endeavor. The nanoelectronic landscape is indeed very rich and varied. It consists of many features in many dimensions. We design electronic systems top-down traversing several 'layers of abstraction' and verify bottom-up, checking wether subsequent layers correspond to the same objects viewed from different perspectives. To each layer of abstraction there corresponds a mode of thinking and experimentation. We distinguish e.g. process technology, devices, circuits, architectures, systems, middleware, software. At each level we could talk about 'emerging behavior', each level has its own vocabulary, axioms and content, although each borrows from the level below and delivers objects to the level above. So far so good, but things get out of control when levels are not compatible with each other, the abstractions of one level are not anymore supported by the objects the level below is producing or its language cannot be understood by the level above. In modern nano-electronics examples of level incompatibilities abound. The modern 10 nm nano-transistor does not behave in the Mead and Conway fashion, its circuit model does not fit the VLSI paradigm anymore, the nano-electronic world is shaking on its foundations. As to another example, interconnects do not connect any more, they behave more like complex, chaotic transmission environments for which a telecommunication paradigm is more suitable than circuit theory.

The consequence is clear: nothing is stable in nano-electronics! It means that we have to teach students *how to build a theory* given basic scientific abilities. We can use existing theories (e.g. classical electronics) as examples, but we cannot expect that the objects our students will encounter later in their professional career will behave indeed as we taught them. Building new theories used to be the realm of research, it has to become the main goal of education... It is rare to find textbooks that are made in this way, but in quite a few fields they do exist. I already mentioned Mead and Conway's book on VLSI design, that was a good example. I am very fond of MacKay's approach to Information Theory as another. From them we learned to make adequate abstractions to construct a new level of 'emerging behavior'.

To use cyber space effectively, students must be able to construct a new theory and to assemble the information needed in the construction from what they have understood as basic principles and the information they can find and understand. They have to experiment with their new concepts and test them in practical constructs. The role of education then becomes clear: we as teachers have to provide the means and the guidance in that quest. A difficult point in this way of viewing the educational world is a perceived shift towards self-work and self-improvement, with the role of the teacher reduced to internet guru. No more class rooms, even laboratory rooms become obsolete, students all have a laptop which they operate from their dormitory room or the gym cafeteria while having instantaneous internet access to a 'teacher' whose job it seems to be to help them out if something goes wrong. Maybe the teacher can still require them to submit a paper regularly detailing what they have found, but from a human point of view little interaction remains...

Experience with this mode of learning is very negative. Students end up with no knowledge or abilities at all, except a vague idea of the location of websites where information can be found. Although we easily shrug off such a doom scenario as not happening at the Engineering faculties, take the example of Matlab (or Spice!). Wonderful tools for quick experimentation and surely very well suited to evaluate circuit or system behavior, but very few users have any notion of what happens numerically within the toolbox. Most also believe they do not have to know, an answer is an answer... The essence of knowledge, however, is the able to judge and evaluate. Let us not confound means and ends. The end should be understanding, the means is a result obtained effectively, it will only contribute to understanding if the experimenter is able to interpret. It is sad to realize that often teaching has been replaced by search mechanics, destroying its very purpose.

There does not yet exist an artificial mind that is capable to teach students how to think - and most likely there will never be. In my view, thinking or the ability to construct new theories is the same thing. It requires concentration and application - concentration on the object under consideration and application to relate it to others and place it in the knowledge continuum that constitutes the theory. Technology students must be clever, but that is not enough. They must be able to concentrate their attention and focus it on the topic within the context of its relations and the goal of the development. I doubt that this process comes naturally to most people, it has to be learned. There are ways to do that and discussions on what is most effective. Some say: you must make a lot of exercises, get familiar with the mechanics and then sublimate that to a higher level of knowledge. This is certainly a trick that works. The teacher assigns the exercises and, when done, forces the abstraction. Needless to say, that essential latter part is often lacking. That is the way most of us learned integral and differential calculus, just get used to the computational mechanics and after a while you are convinced that you understand. We can teach electronics that way also, it certainly has the advantage that we are able to design at least some useful circuits, but that's about it then, it will not turn us into creative designers!

A better way goes in the opposite direction. Focus on asking the right questions and building the theory, and test your acquired insight on well designed examples, exploring both the potentiality and the limitations of your theory. This approach should not preclude getting familiar with routine exercising and experimentation - often very necessary indeed - but it gives meaning to it not only as the ability to generate new objects but as the ability to construct new generic (and well tested) knowledge. Let me relate an example taken from a recent discussion in the Dutch media. The question under discussion was: 'should the long division be taught and exercised in the primary school?' Long division as a technique is fun, of course, and can be taught as being fun - certainly not worse than playing chess or Monopoly. But there is much more - it is the basis for a great deal of Mathematics (rings, modules), or at least, our ability to solve important Mathematical problems. To put it differently: we know from experience that it is one of the most important algorithms of Mathematics, and it is so important because of its many ramifications, not only in Mathematics itself, but also in the many fields of Engineering that apply Mathematics such as System and Circuit Theory, the basis of our understanding of electronic circuits and systems! If little kids understand the long division, at their level, they have understood a central tenet of Mathematics and Engineering and hence a major component of our culture. The difference between these kids and others is that the former will produce the new technology that may save the world (this seems like an exaggeration, but it is not).

As a major field in technology, Electronics belongs to the world cultural heritage. Not as fossilized legacy but as a living and dramatically quickly evolving endeavor. It is firmly rooted in science, in particular Mathematics, Physics and Chemistry - and more recently even in Biology. How to teach all that to future engineers? Given time and resource limitations, we necessarily have to focus on those aspects that have a generic constitutive value. To be effective, we must provide for the environment in which ample guidance and experimentation is possible - all the information is on cyber space but not yet in an aesthetic shape just like the sculpture that is sitting in an unchiseled marble block (MichelAngelo's stated humbly that his David was already there in the Carrara block, his only contribution was to take away the superfluous marble!). There will be unavoidable discussions on the 'value' of a piece of knowledge, but its being a 'constitutive' component provides already a strong discriminating factor. Starting from the demands of modern Electronics (whether 'More Moore' or 'More than Moore') and its major applications, we can fairly easily derive the constitutive elements that allow us to understand how and why Electronics works, and organize that knowledge in the necessary levels of abstraction that allow us to design and experiment. This is an 'end justifies the means' approach, but doing so with an open scientific mind we encounter many if not most constitutive components of the impressive cultural edifice of modern science.

But let us concentrate our teaching on how to create new (technological) knowledge, using enlightening guidance from the best possible past examples. Building thought in our pupils should be our ultimate goal, not the acquisition of yet another piece of ephemeral technical know how.