LEARNING THROUGH INTERACTION AND CREATIVITY IN ONLINE LABORATORIES

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My Thoughts about the Future of Teaching and Learning

Education and pedagogy are thousands of years old. In fact, education is as old as the human race itself, as our species is characterized by its ability to learn, and learning is key in our evolutionary process. However, it is important to consider that humankind has never faced such a rapidly changing and dynamic global environment that requires so much of engineers as we are witnessing today.

And as our environment changes, it is imperative we better learn to adapt, which requires us to question and, when necessary, be open to changes in our educational systems, our pedagogies and all our methods and processes in teaching.

Never before have the challenges in education been as challenging as today. Never has so much been demanded of engineers.

Peter F. Drucker, the well-known Professor of Politics and Philosophy and author of the book *Management Challenges for the 21st Century* has identified the most important 21st century challenge:

> The most important contribution management needs to make in the 21st Century is similarly to increase the productivity of KNOWLEDGE WORK and of the KNOWLEDGE WORKER.

If we replace *knowledge work* and *knowledge worker* with *education* and *educator* (or teacher), we have a more exact dimension of the challenges we face, especially in engineering education.

Let me summarize my thoughts about the challenges in adapting the educational system to these new conditions by the following theses:

First of all. The future of learning will require the conceptualization and implementation of a new learning model. We need to be focusing more on 21st century competencies and expertise such as:

- Critical thinking
- Complex problem solving
- Reflection
- Interactive collaboration
- Multimedia communication

- Teambuilding and leadership
- And much more

Moreover, all this should be seamlessly woven into the tapestry of all content and domain areas.

However, let me also say the following:

> *Learning is primarily an individual process and therefore it needs personal efforts!*

We should not forget this. Nothing (no technology, no Web, no other tools) can replace the human teacher.

Therefore --

Second challenge. The future of learning will be a balanced approach between:

- E-Learning and face-to-face learning
- Formal and informal learning

A modern approach of teaching and learning is a blended one -- a combination of Technology Enhanced Learning (TEL) and the face-to-face contact between teacher and learner and the learners with each other. This is my deep belief.

> *We have to better exploit synergies from traditional (face-to-face) and non-traditional (online) education.*

Third challenge. The future of learning will revolve more around context than content.

Our age is the Information Age. We live in the Knowledge Society where data, information, knowledge are easy to access 24/7. We need a radical change from teaching facts and knowledge to convey skills and creativity (to find necessary data, facts, and knowledge) in a global context!!!

Education has to move from Instruction to Construction!

Nevertheless, there is also a paradigm shift from the amount of knowledge to the structure of knowledge!

For a long time the benchmark for successful learning was how much knowledge a student had acquired. Knowledge is multi-faceted and not only knowledge of facts:

- Knowledge about how to get facts
- Knowledge about abstract concepts (how efficiently to solve routine problems)
- Knowledge about how to master complex and dynamic problems
- Knowledge about learning strategies

Pure knowledge of facts occurs in the background.

Fourth challenge. The future of learning will be characterized by

- Open content
- Open knowledge
- Open technology

For all!

The start of MIT's Open CourseWare initiative in 2002 marked a major shift in the paradigm of restricted access to academic materials.

Several other projects had adapted and further developed the Open CourseWare approach and now readily share course contents with outside users. Meanwhile we can observe also a shift to scientific Open Access Journals. There are nearly 10.000 journals already available in the Directory of Open Access Journals.

Fifth challenge. Learning today is a global project!

The Internet and other modern communication channels do not know borderlines. In education, we actually find global expertise, as we presently are witness to:

- A global market for content, skills and competences
- Expertise which can be exported anywhere whenever it is in demand
- Recruitment of experts from anywhere

Global education is the next online-learning leap.

Sixth challenge. Learning today is characterized by:

- Mobile and ubiquitous learning
- Learning on the job or workplace integrated learning
- Embedded learning

Because we observe decreasing innovation cycles of products, technologies and many other things in society.

Therefore, people of all ages have to renew their knowledge in decreasing cycles. This is what we understand as *lifelong learning.* Or in short: *pervasive learning!*

Seventh challenge. The future of learning will be inseparably connected with ICT and especially with upcoming Web 3.0.

The transition from Web 2.0 to Web 3.0 represents a transition:

- From receiver to producer of information
- From static to dynamic contents,
- From control of the few to the wisdom of the crowds

The main characteristic of Web 3.0 is the use and combination of:

- Cloud Computing and Cloud Environments
- Semantic Technologies
- Social Web Services
- 3D interactive technologies

Up to this point, you could not hear in my talk the buzzword *MOOC.* Now it is the moment to tell you my opinion about MOOCs. I did not include this topic in the seven challenges, because it could be mentioned as an example in all of them.

Coined in 2008 at MIT by Stephen Downes and George Siemens, the term *massively open online courses*, or MOOCs, refers to online courses, that are offered free of charge or at very low fees and that people can take from anywhere across the world.

Now, most MOOCs are courses that primarily deliver content through short video lectures and problem sets. MOOCs are typically unaccredited courses with no transferable credits or recognized degree. Those who complete the course successfully will receive a grade with a statement of accomplishment or completion certificate.

MOOCs have an enormous dropout rate, in some cases as high as nine out of 10 students. For example: a free artificial-intelligence course offered by Stanford University attracted 160,000 students from around the world — 23,000 of whom finished it.

MOOCs have a simple pedagogical approach: Knowledge is transferred from an expert to a newcomer, rather than something that is constructed by the learners by their engagement.

(*From Debbie Chachra*)

Exactly the opposite of what we try to establish with project based learning, problem based learning, lab work (especially in Engineering Education), learning by doing, etc.

I would like to highlight here:

Learning is collaborative! Effective Learning is not a purely solo activity but essentially a distributed one, involving the individual student, other students and teachers in the learning environment and the resources, technologies and tools that are available.

(*Salomon, already 1993*).

However, what makes MOOCs so appealing?

There are about 180 million students enrolled worldwide in about 20,000 tertiary institutions. The demand for tertiary education is growing and enrolments are projected to reach 260 million by 2025.

With the cost of education going up and more students aspiring for quality education, there is growing interest in online courses offered by world-class universities. Teachers at these institutions are often involved in the generation of cutting-edge knowledge.

Accessibility of low- or no-cost knowledge and skills from the world's best is appealing to many aspirants and working professionals who wish to upgrade their skills while working and without losing income.

MOOCs are also helpful to pre-university students who are yet to make up their minds on which disciplines to pursue.

They are also a boon to keen learners who come from families with limited financial resources.

(*Seeram Ramakrishna*)

Yet, there are many unanswered questions regarding this new emerging model. Among them:

- How will students develop the skill (not the knowledge) necessary for the job they will undertake?
- How will the home institution accredit these courses?
- How will student learning be assessed?
- Can all courses be offered this way?
- Can whole degrees be completed with MOOCs?
- What will the role of faculty be?
- How will industry value the new learning models and its outcomes?

(*From a discussion with Lueny Morell*)

However, investors in open courseware are seeing potential commercial opportunities in MOOCs, and their format is still evolving with the participation of more faculty members and world-class universities.

EdX currently offers already courses from six universities and has 700,000 registered students. Partners are, for example, Australian National University, Delft University of Technology, Ecole Polytechnique Federale de Lausanne, Rice University, the University of Toronto, etc.

I think there is room for both MOOCS and other types of learning experience.

Maybe a *blended model* combining online lectures with a teacher-led classroom experience could be a success story.

Students will continue to see the value of a live interaction versus one through a screen.

My Thoughts about the New Aspects in Engineering Education

Moreover, there are some additional new aspects in engineering education.

The question is: *What is engineering?*

We can find many different definitions of engineering. A short definition of engineering might be:

> Exploiting basic principles of science to develop useful tools and objects for society.

This means that engineering is the link between science and society, which can include almost anything that people come into contact or experience in real life. The concept of engineering has existed long before recorded history and has evolved from fundamental inventions such as the lever, wheel and pulley to the complex examples of engineering today.

The history of engineering shows different periods and evolutionary as well as revolutionary developments. Contemporary and future engineering will have an evolutionary part that is characterized by a further development in areas like telephony, computers, energy, and so on.

But on the other hand there are some revolutionary elements; and we are starting now in a new phase of engineering!

The new paradigm of engineering is to offer:

- Services for society and
- Circular solutions for a circular economy

For a long time science and the daily life of the people happened more or less in parallel. Today we have a close interweaving.

By its very nature, engineering is bound up with society and human behavior. More or less every product or construction used by modern society will have been influenced by engineering design.

Up to now, engineering and industry processed resources, designed and produced goods.

Engineers have to re-think and re-organize the production of goods. Already at the beginning of an engineering development task, we have to ask: How can we recycle or renew it after its life cycle.

Re-thinking progress explores how through a change in perspective we can redesign the way our economy works - designing products that can be 'made to be made again' and powering the system with renewable energy.

It questions whether with creativity and innovation we can build a restorative economy. In the course of this, one of the biggest challenges is to reduce the necessary energy.

What does that all mean for engineering education? What are some of the new aspects of today's and future engineering education?

First. We can observe an enormous (and accelerated) growth of the area of engineering. Besides the traditional fields of civil engineering, construction engineering, electrical engineering, etc., new engineering disciplines occur:

- Bioengineering
- Software engineering
- Information engineering
- Data engineering
- Medical engineering
- Neuro engineering
- Gene engineering
- Social requirement engineering (!)
- Systems engineering as integrating discipline
- …

And new tasks requiring new competencies **within** traditional engineering disciplines have grown in number and complexity:

- Online engineering
- Remote engineering
- Virtual engineering
- Reverse engineering
- Sustainable engineering

The field of engineering now covers nearly all areas of society.

Second. We can observe a terrific acceleration of the life cycles of technical (or engineering) products.

The field of engineering has never seen such growth and suffered such reduced times to bring their innovations from concept to market. Competition in the field of technology is now measured in month and weeks.

Third. The focus of the engineering disciplines is shifting from pure technical subjects to subjects directed to Information Technologies and the daily life of humankind.

Fourth. There are serious changes in the social position of learning.

- According to some estimates, more than 80% of all learning occurs on or during the job rather than in tertiary and post-tertiary education!

Learning in the future has to be an integrated part of the job! People of all ages have to renew their knowledge in decreasing cycles. This is what we understand as *lifelong learning.*

- Engineering students have to learn to work in teams. Data from Australian and Portuguese surveys show engineers tend to spend the majority of their working week (around 60%) engaged in activities that involve interaction with others (meetings, supervision, writing reports, etc.), and only around 40% is devoted to technical engineering activity.
- This shows up also in the NACE's Job Outlook survey. Survey participants rated "ability to work in a team structure" and "ability to verbally communicate with persons inside and outside the organization" as the two most important candidate qualities, followed by candidates' "ability to make decisions and solve problems," "ability to obtain and process information," and "ability to plan, organize, and prioritize work."

Fifth. There are also new organizational aspects in engineering education.

On the one hand, engineering issues, either in industrial products or in engineering projects, are quickly becoming increasingly complicated, and most of these issues cross-disciplinary lines.

On the other hand, the working environment is becoming more and more internationalized due to the globalization of the world economy. Products are fabricated by worldwide cooperation, and manufacturing resources are linked by international supply chains. Nowadays, engineers have to know how to work in multi-cultural environments with people from different countries.

This means the next generation of engineers will need to possess the ability to work seamlessly across cultures, have outstanding communication skills and be familiar with the principles of project management, logistics, and systems integration.

Sixth. The size of the systems designed and developed by engineers grows continually. A good example for this is the concept of the *Smart City*, which includes two aspects – the social and the environmental capital.

The smart cities concept is based on regional competitiveness, transport and ICT, economics, natural resources, human and social capital, quality of life, and participation of citizens in the governance of cities.

And the vision is the global village!

Seventh. To face current real-world challenges, higher engineering education has to find innovative ways to quickly respond to the new needs of engineering education, and at low costs.

This means it is necessary to improve the agility of engineering education in the future. One of the approaches in this direction is the creation of virtual educational units, which can be flexible adapted to new requirements in engineering education.

Another conclusion is that engineering education has to focus more on basic knowledge and skills and in this way to prepare for lifelong learning.

Seventh. All these trends result in new questions and the resulting need to evolve educational practices, especially in *engineering pedagogy*. Some of these important questions to consider include:

- What learning approaches have to be used to effectively respond to these changes?
- What are the pedagogies that provide the most effective learning experiences for engineering students of the 21st Century?
- What learning skills in engineering education need to be developed, and how can engineering teachers succeed in guiding their students to achieve them?
- What pedagogical approaches have been found to support the different phases of the present lifelong learning continuum, or is there more research necessary?
- What are the approaches that enable competence in leadership skills in a multi-cultural working environment, and what is the best way for these competencies to be delivered?
- Ambient technology is becoming a reality. What does ambient learning in engineering education look like? How can it be designed, delivered and assessed?

These are some of the reasons why the relevance and importance of engineering pedagogy is growing so enormously.

My Thoughts About the Role of Online Laboratories

Online laboratories are necessary for distance or mobile learning for the same reason laboratory practices are important in traditional educational scenarios. Learners can acquire theoretical knowledge and experience by manipulating or viewing the behavior of real world phenomena.

Online engineering laboratory practice can be delivered by means of online laboratories that permit workers to access knowledge and experience from remote colleagues or institutions who share similar problems. In this way, an individual problem can become a shared problem to be resolved with the experience of homologues for different places. Among other things, remote laboratories are important because they provide real-world results, not simply knowledge or resources. Persons using remote lab resources can view how objects actually behave under a certain set of circumstances, providing them with a better insight as to what needs to be done. Online engineering in the workplace is becoming increasingly important because of the growing complexity of engineering tasks, the need to share resources among different companies (equipment, simulators, etc.), especially for short-term trouble shooting that does not warrant the purchase of equipment, the potential collaboration among workers in different companies who share the same problems and can contribute to collaborative solutions, the increased linkage among SMEs and larger enterprises, etc.

In addition, importantly, online laboratories offer the additional advantage of not being subject to the limitations imposed by time and location, as persons can synchronously collaborate, experience, and obtain results in a collaborative synchronous manner. This, along with expanded access to broadband internet, is transforming the way e-learning is carried out, allowing increased levels of interactivity and providing virtual environments closer to real ones. Virtual environments provide the opportunity for students to freely practice various scenarios in quick succession without the fear of actually damaging resources, which often hinders real-life practice. This 'safe' way of gaining practice also encourages initiative, experimentation and creativity, as students do not have to face real-world practical restraints.

Synchronous active interaction with experiments and problem solving helps individual or collaborative learners directly acquire applicable knowledge that can be used in practical situations, which is why pedagogical theory and practice considers laboratory experimentation an essential part of the educational process, particularly in the sciences and engineering.

Synchronous interaction is also important because it provides immediate feedback so that students can interact with experiments in real-time, thus obtaining numerous potential results, instead of running one experiment and waiting for the results later.

Online laboratories make all this shared use available via the Internet and are becoming increasingly important applications in the new domain of *online engineering.* Online engineering can be defined as an interdisciplinary field utilizing the areas of engineering, computing and telematics, where specific engineering activities like programming, design, control, observation, measuring, sensing, and maintenance are provided to both remote and local users in a live interactive setting over a distributed, physically-dispersed network (for example: an Intranet or the Internet).

The availability of high bandwidth Internet connections worldwide and other derivative capabilities in the areas of real-time communication, control, teleconferencing, video streaming and others have made multi-site collaborative work, utilizing state-of-the art equipment in remote laboratories across the globe a current reality.

Learning situations in laboratories can be highly complex, although they have the advantage of usually being well structured. Particular experiments and learning strategies of specific practices provided in laboratories must be tailored to the knowledge students possess in the theoretical realm and in function of the abilities and competences that are explicitly stated in educational objectives of each individual practice.

Although self-directed learning is the most common learning strategy used, a mix of self-directed and collaborative learning is also very common. This mix in learning strategies is important as it favors both field independent and field dependent learning styles respectively.

It is still difficult to share instrumentation and experiments among laboratories. Each one has its own security policy and adopts its own technology for accessing and controlling real devices. A common integrated framework, offering indexing facilities, unique logins, file sharing and the seamless access and run of experiments, is the main challenge in order to create a network of online laboratories. Grid technologies can be used to set up an effective network of remote laboratories for education purposes by sharing instrumentation and resources. However, the evolution of remote laboratories from the current client/server architecture to grid-based architecture requires well-defined tools for location, security, and integration of resources, and further research is currently being conducted to examine this issue.

As universities and other institutions are likely to develop their own solutions and standards to deliver online laboratories to their users, no trend to a unique standard is observed, creating an obstacle against sharing these online labs. Considering the current scenario, a migration towards standardized solutions for delivering online labs becomes necessary to ensure software reusability and therefore facilitate online labs development and sharing.

At this point, the ISA (iLabs Shared Architecture) comes into play. ISA is a software architecture developed at MIT (Massachusetts Institute of Technology) (see Figure 1), which facilitates a cross institution sharing and management of online labs. ISA provides a framework for the maintenance of a lab session, lab users' management and experiment data storage. It establishes clear rules governing the communication between clients and their respective online lab servers by means of an API (Application programming Interface) based on Web services SOAP calls.

ISA proposes a classification for online experiments. On one side there are the batched experiments and on the other the interactive experiments. Batched experiments are those in which all parameters necessary to run it are specified before execution. On interactive experiments, the user can change the course of the execution at any time.

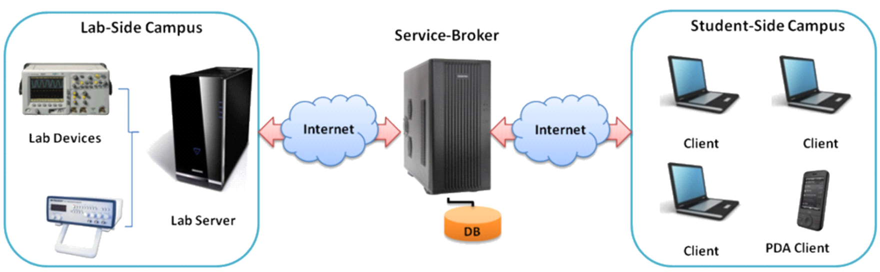

Figure 1. The iLab Shared Architecture.

In this architecture the communication between clients and laboratory is mediated by a middleware server (service broker), a Web application that manages users' accounts and data storage that can provide different clients with access to several different lab servers in a *many to several* mode, and that delegates to the experiment server only the experiment execution.

The interface that provides the communication between clients with service broker and service broker with lab servers is implemented with Web services and is therefore platform independent. That means that clients and lab servers can be developed in any platform supporting Web services.

The iLab Europe started as an initiative from Carinthia University of Applied Sciences in Austria and now includes six partners throughout Europe who agreed to share their online experiments within the network.

The software architecture used to maintain the lab sessions as well as scheduling service and experiment data storage is the iLab Shared Architecture (ISA) described above. ISA has an important characteristic namely its distributed topology, what made it the ideal solution for the implementation of such a network of interconnected online experiment.

ISA has already built in mechanisms that allow set up of trusted connections between its autonomous network nodes (service brokers) so that online laboratories can be seamlessly shared between them. This means that the institutions are free to manage their own online laboratories and their own user accounts and deliver these labs via their own server. In this way, access for their users to their own labs does not depend on the status of other service brokers. On the other hand, in order to be able to use labs from other universities a user has to authenticate himself/herself in the main service broker as depicted in Figure 2. Each institution member of the network is expected to set up one service broker and deliver at least one experiment via this server. This means that for a pool of labs available at one institution it is up to them to decide which labs will be available to the other members of the network.

This topology was chosen because, in this first stage of implementation, it seemed to be the most suitable one from the network management point of view. It is a general consensus that online laboratory providers should manage their own labs and their own users. Users can access the online laboratories available at their institutions either by authenticating themselves in the main service broker or in their institution's service broker. In this way, each service broker from an institution can be considered a subset of the whole iLab-Europe experiment poll.

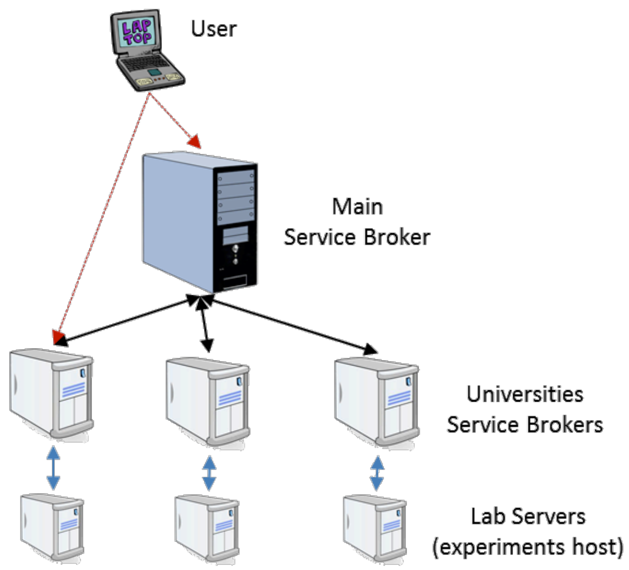

Figure 2. iLab Europe network topology.

In spite of all the efforts and the technology available, the idea of sharing remote or online laboratories has still to mature. If on one hand it is very appealing, on the other it might be complicated to set up all the policies to share these online labs. These constraints are not related to the technical aspects associated to the practice of sharing labs as a number of software architecture focus in providing services for online lab users already addresses these issues. The constraints lie in the lack of an economy of online laboratories and a business model to govern the practice of a cross institution sharing of labs considering implementation and equipment maintenance costs.

The iLab-Europe network is, in this context, a step towards a broader usage and dissemination of online laboratories and helped to raise the issues that must be addressed for the implementation of a more efficient model to govern the practice of sharing labs on a cross institution basis. It has shown that the administrative efforts are high, and it assumes the adoption of a specific technology by the different online lab providers.

The efforts for the future will be to implement a network with such autonomous nodes as a peer-to-peer architecture. However, to some extent, Administrators of each node should be able to decide which resources will be available for others and at which costs, if an agreed business model exists. The client-server model should still be maintained for users to carry out experiments and for any other communication between the lab servers and laboratory client (user). In the proposed architecture, each node should manage its own users. This means that the user database will be maintained as a distributed one. Authentication is necessary only once in one of the network nodes, but available are all resources and services from the whole cloud. Another advantage is if any node of the proposed network happens to be offline, this would have no consequences for the remaining nodes.

Beyond the technical aspects, sharing experiments can offer several advantages, such as providing access to potential expensive laboratory hardware to students from universities with scarce financial resources by means of a cooperative network of remote systems. Furthermore, online controlled systems can be very useful when applied to situations involving the often substantial costs of transporting people or equipment. Different institutes and schools could share experiments and knowledge in a collaborative manner that parallels real-life working conditions. Importantly, online labs can be also used in workplace settings where there is a pressing need to apply these systems to continually provide learning opportunities for workers who must adapt to rapidly changing conditions.