

# A Network for Learning about Networks: A Model and Innovative Approach to Teaching Network Engineering

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**Abstract:** We propose a model for design of courses in which students need to develop understanding not just of theory, but also of what happens in complex, distributed real world environments. Advances in network technologies (e.g., Grid technologies, and “the Cloud”) provide opportunities to simulate complex models and to use real, large-scale data sets in learning activities. We apply our model to design of Network Engineering courses in a way that provides different sequences of study for students from different backgrounds, interests, and learning styles, but which enables all students to complete a course of study that balances understanding of theory of how networks work with what happens when a network is implemented in a real operational context. We consider how such a model might be implemented by a network of learning institutions, organizations, educators and learners.

## Introduction

Grid computing is mainly considered as a way to share power computing resources required for modeling and simulation activities (Schroeder 2008). Typical users with such needs include research areas like high energy physics, genetics, earthquake studies (Foster & Kesselman 2003; Hine 2006; Wang, Jie, & Chen 2009). Increased usability of Grid computing platforms has attracted more communities of scientists fostering new applications (Wouters and Beaulieu 2006). Recent Grid projects include integrated cycles of shared research activities from data collection (through remote instrumentation sharing), access to shared data archives, use of networked computing resources, visualization of results and extensions to the social sciences (Dutton 2007; Eccles 2009; Sonnenwald, Lassi, Olson, Ponti, & Axelsson 2009). Nevertheless, even if the Grid is considered as e-infrastructure that permits collaboration and sharing in e-science (Olson, Zimmerman, & Bos 2008), very little attention has been paid to projects devoted to e-collaboration among scientist for teaching and learning purposes using shared resources (e.g., virtual computing laboratories, remote instrumentation sharing, and shared data archives). E-infrastructure-enabled innovation in education is, however, both possible and necessary.

The European network market is under pressure from international competition. The Internet is changing rapidly. In addition to scientific developments, the availability of new devices for consumers, increasing use by consumers and organizational users, and the explosion of wireless and mobile users are stressing the current infrastructure. Internet providers and companies that own network infrastructures are forced to offer new services and they have to define new ways to optimize their networks. At the same time, the big players making network

devices are pushed to offer more powerful and sophisticated devices. In this panorama, network engineers are a scarce resource which is required by Internet providers to optimize network topologies and configurations and by network device makers to re-design both hardware and firmware. In a competitive, globalized market, education of a new generation of network engineers is a strategic issue, and a shared effort is required to deal with this emergency.

In this paper, we consider how large-scale distributed computing of the kind supported by the Grid can underpin innovative ways of learning and teaching in fields where students need to develop understanding not just of theory, but also of what happens in complex, distributed real world environments, and how to resolve increasingly complex problems under conditions of rapid change. We propose a generic model of the elements to be learned by the students of such fields, before applying it to Network Engineering. We conclude by considering how such a model can be implemented in practice, and propose that, given the high levels of network infrastructure and expertise required and the relatively small number of high level students in the field that can be supported at any University, lessons can be learned from e-science. We focus on how communities of scientists, experts, teachers, and learners could share knowledge, virtual computing laboratories, and remote instrumentation in the Networking Engineering field using an e-infrastructure such as the Grid.

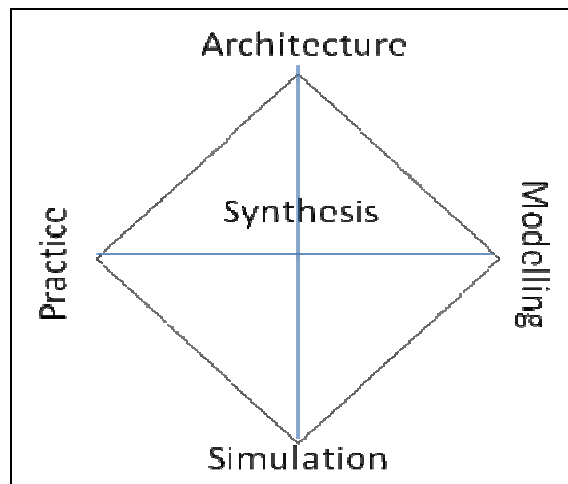
## The Proposed Model

Our model, illustrated in Figure 1, is based on four pieces of knowledge necessary for mastery of a field of study which requires understanding of theory and application in a complex, real-world environment:

- Architecture
- Modeling
- Simulation
- Practice/Emulation/Mastering

These pieces of knowledge need to be interconnected, by a fifth element,

- Synthesis



**Figure 1:** A model for learning with technology about complex real-world environments

The goal for design of courses based on this model is to permit a student to begin their learning journey with any one of the basic elements, but always completing it with synthesis. In order to achieve this, each element needs to be connected to the others. Flexibility in entry point is obtained by permitting each element to be separate, but the principle of integrating application with learning about abstraction (Klobas, Renzi, Giordano & Sementina, 2004; Laurillard, 2002) is upheld through synthesis.

We assume that courses that adopt this model involve distributed collaborative learning at a fundamental level, and that participating learners (and others involved in their learning) share knowledge, resources and methods

across time and distance using common and advanced ICT infrastructure. In this paper, we assume that readers are familiar with current knowledge about computer-supported collaborative learning (e.g., as reviewed by Resta and Laferrière 2007) and the importance of building an effective learning community (Palloff & Pratt 2007).

### **The Model applied to Network Engineering**

Applying the model to Network Engineering, we can define the four basic elements in detail:

- Architecture: knowledge about how networks work (standards, protocols, services, etc)
- Modeling: theoretical background in mathematical modeling, queuing theory, network calculus, large deviation theory, etc)
- Simulation: ability to simulate complex networks in order to evaluate and measure performance, reliability, and security
- Practice/Emulation/Mastering: awareness of network devices available on the market, what configuration and tuning functions and parameters are available and their impact on network performance.

An educational technology design that connects these elements would require:

- Understanding of the pieces of knowledge required to learn the subject and how to connect them for effective learning;
- An overall [meta-]instructional design to define learning outcomes, teaching blocks, teaching & learning strategies, the role of technology, integrate all the above components, and to measure learning efficacy;
- Virtual computing laboratories (e.g., remote power computing for simulation, emulation, measure, performance analysis);
- The remote laboratories to interact with real network devices;
- A knowledge network formed by learners, educators, researchers, experts, and companies and the need to nurture and sustain the learning community they belong with online interaction for collaborative learning and scientific collaboration;
- The Grid as e-infrastructure to connect social nodes, support collaboration, and share virtual computing laboratories and remote laboratories.

### **Implementing the Model**

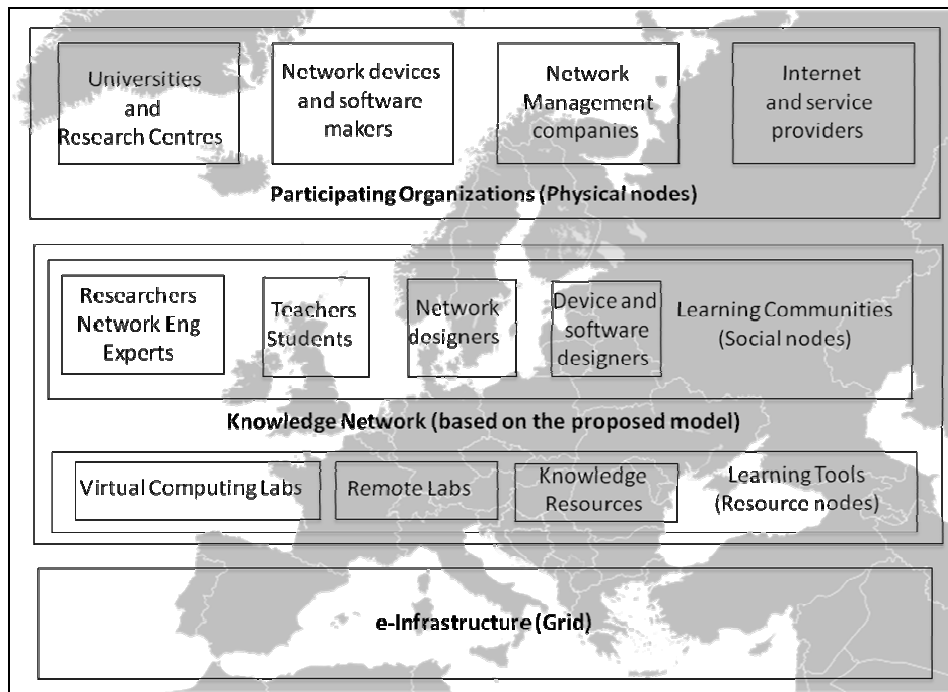
Implementation of the model rests on a knowledge network that consists of both social nodes (educators, learners, researchers, experts in the field of study) and physical nodes (Virtual Computing Laboratories, Remote Laboratories), interconnected through network infrastructure. An overview of the network is provided in Figure 2 (over the page), while each component is explained in more detail below.

### **Connecting the social nodes of the knowledge network**

While Network Engineers can obtain a high level of applied knowledge through company programs, a high level of theoretical knowledge and thinking can only be obtained through Masters degrees and PhD programs, yet there are relatively few universities with high level specialized degrees in Network Engineering and each university can educate only a few students in such degrees. Furthermore, each university has its own fields of excellence and there is the need for frequent exchanges of students, teachers, and experts to increase the knowledge and the ability to innovate by individuals and organizations. Companies, makers of network devices, are also a fundamental part of this knowledge network.

The knowledge network formed by students, teachers, experts, and companies is therefore widely spread, so much value can be obtained from nurturing and sustaining the learning community they belong to. This can be done by making available a network infrastructure that allows online social interaction and resource sharing (i.e., virtual laboratories, computing power, etc) for collaborative learning and scientific and technical collaboration at a distance. One example of a successful collaboration of this kind is Global Cyberbridges. Global CyberBridges is the “implementation of multinational effort to improve the technology training for a new generation of scientists, and to

increase the rate of discovery for all domains” with the participation of the Chinese Academy of Sciences, the City University of Hong Kong, and Universities of Sao Paulo, Brazil (Alvarez et al. 2007).



Note. Background graphic courtesy of [http://en.wikipedia.org/wiki/File:Blank\\_map\\_of\\_Europe.svg](http://en.wikipedia.org/wiki/File:Blank_map_of_Europe.svg)

**Figure 1:** The physical and social nodes of the knowledge network supported by e-infrastructure

### The virtual computing laboratories (VCL)

In Network Engineering teaching, research, and business software such as NS-2 (<http://www.isi.edu/nsnam/ns/>) and GNS3 (<http://www.gns3.net/>) are the everyday tools for network (and related devices) simulation and emulation. Advanced organizations in the field of Network Engineering often integrate such systems with software to enrich functions or to add more simulated or connected devices. Systems for network simulation and emulation are the main, but not the only, resources that universities, research centers, and companies make available in computing laboratories for teachers, students, scientists, and experts.

The availability of suitable computing laboratories is a critical element for learning and teaching. Other university systems have adopted Virtual Computing Laboratories (VCL) to share power computing and software resources (e.g., North Carolina State University, NCSU) among their scientist community. Our model includes VCL as a fundamental shared resource among the social nodes of the knowledge network

### The remote laboratories

Among the knowledge pillars defined in our model, “Practice/Emulation/Mastering” is the required piece of knowledge to connect learners to the real world. In Network Engineering education, the knowledge of what network devices are available on the market and the ability to “pilot” them in order to match the network design with the physical network implementation is part of the educational path. Laboratories with real network devices that aim to test in the field configurations and parameters are another resource that universities, research centers, and companies make available to their teachers, students, scientists, and experts

Universities and organizations participating in a knowledge network for learning about Network Engineering are assumed in our model to contribute, allowing remote access through ad hoc interfaces. Such access

to “federated” remote laboratories by the social nodes of the knowledge network is another fundamental piece of our model.

### **The Grid as e-infrastructure**

The Grid is the e-infrastructure component of the network. It connects social nodes, support e-collaboration, and shared virtual computing laboratories and remote laboratories. In Figure 2, we emphasize European connections through Grid nodes on the European Academic & Research Network, but our approach is not limited to European or academic nodes. In learning about Network Engineering, the Grid could itself be a laboratory for educational and research activities. Much work is needed to develop this e-infrastructure. While the experience gained and the work developed by Grid-based projects related to e-science, remote instrumentation, virtual laboratories and other applications provides valuable guidance, additional scientific study will be required to develop specialized interfaces and functions to satisfy the educational and research needs in the field of Network Engineering.

### **The overall instructional design**

While the Grid is the glue that connects the social and physical nodes of the knowledge network, the instructional design that ensures learning is achieved provides the detail how the pieces of the model work together. As in any course, the instructional design will define learning outcomes, teaching blocks, teaching & learning strategies, the role of technology, and how to measure the learning efficacy. As this is specific to the subject of study, we do not go into detail here, but our earlier work on the CALEIDONET project provides some indication of how the model outlined in Figure 1 can be applied. In CALEIDONET, a high level PC-based learning object (an animated case study) enabled entry into learning about introductory notions of network history, structure and trouble shooting from different points of view and different disciplinary perspectives (Klobas, 2005; Klobas et al., 2004).

### **Conclusion**

We have defined a Technology Enhanced Learning model for teaching and researching Network Engineering at higher education level. The model defines in detail how to structure teaching Network Engineering in order to grow up a new generation of European Network Engineers able to compete on the global market. The model takes into account the need to connect in a knowledge network both social nodes (teachers, students, researchers, experts in the Network Engineering field) and physical nodes (Virtual Computing Laboratories, Remote Laboratories). Participating organizations might be universities, research centers, and companies with the collaboration of infrastructure providers and high level organizations. The social and physical nodes interact through the Grid which acts as a unified interface. The Grid nodes are themselves connected via international backbone.

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