Why Should I Teach Performance Evaluation to Students in Networking?

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ABSTRACT

In this contribution, we share our view on teaching methodological topics in STEM disciplines and we report our experience on teachning performance evaluation to students in a M.Sc. focused on ICT for Smart Societies. This program aims to equip students with the necessary knowledge and skills in ICT to drive innovation across various engineering fields. The focal point is communication networks, viewed as a collection of enabling technologies fundamental to enhancing engineering through information-driven approaches. Given the multi-disciplinary nature of the program, the students require methodological tools that can help them to understand problems in different contexts. The effort to approach problems from multiple perspectives is addressed by using tools, such as analytical modeling and simulation, in a complementary way. Performance evaluation well fits the need to propose to students general methodologies that can be applied to several fields. These methodologies push them to approach problems from different levels of abstraction, deriving holostic views, practicing creative and critical thinking.

1. INTRODUCTION

"The function of education is to teach one to think intensively and to think critically." This is what Martin Luther King stated in [1] and it is (or should be) the driver and long term purpose of our activities as teachers, independently on the discipline, including the fields of science and technology. The role of university is multi-facet. Without the ambition to exhaustively treat the several aspects of the role of university in society, as sketched in Fig. 1 we can state that university contributes to:

- personal growth
- social responsibility
- cultural development
- innovation
- knowledge sharing

Personal growth is a cornerstone of the university experience. Universities provide an environment where students can explore their interests, develop critical thinking skills, and gain knowledge across diverse disciplines, helping students build confidence and resilience. Through interactions with peers and faculty, students refine their communication skills, learn to tackle challenges, and become well-rounded individuals prepared for professional and personal development. Universities foster *social responsibility* by encouraging students to engage with pressing societal issues. Students learn the importance of empathy and collaboration, which are essential qualities for driving social change. *Cultural development* is significantly enhanced by the diverse and inclusive environments found in universities. Exposure to a variety of cultures, perspectives, and ideas, as well as methodologies and tools, enriches the university experience, promoting mutual understanding and respect. Universities are key to *innovation*, fostering cutting-edge research and development across various fields and providing an environment that encourages creativity and critical thinking, through the collaboration with public institutions and industries they drive technological advancements and economic growth. Universities also serve as centers for education and research dissemination, or, in other terms for *knowledge sharing*. By hosting conferences, seminars, and workshops they bring together experts and students to exchange ideas and findings. Through publications universities share research outcomes with the global community, advancing collective understanding. Through interdisciplinary projects and partnerships with industry and government agencies they promote the distribution of knowledge and expertise.

Also in Science, Technology, Engineering and Math (STEM) disciplines, universities aim at growing new generations of citizens capable of independent and critical thinking. In addition, in STEM disciplines, university teaching can be considered successful only if in the long term it contributes to tackle challenges of the future, like the sustainable development goals [2] proposed by the UN. By developing sustainable technologies and addressing social challenges, universities equip students with the skills and knowledge needed in various industries for the production of goods and services that improve quality of life or translate into economic growth. At the basis of this, innovative approaches are proposed and creative thinking is stimulated.

With this global picture in mind, we consider here how performance evaluation, in particular, can contribute "to teach one to think intensively and to think critically". We report -as a sort of case study- about our experience with teaching performance evaluation in the context of networking and within a M.Sc. in ICT related topics.

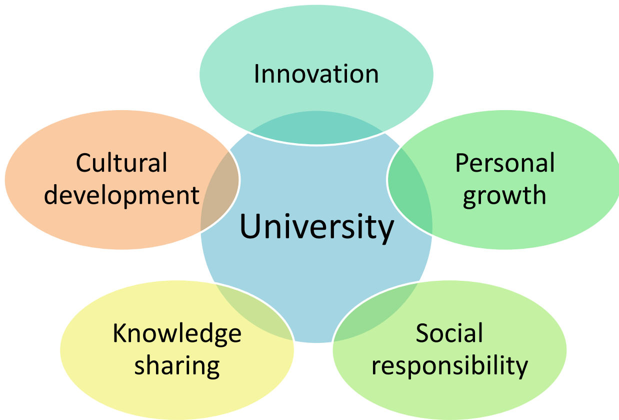

Figure 1: The role of university.

This contribution is organized as follows. In Sec. 2 we discuss the general objectives of teaching STEM disciplines. Our experience is reported in Sec. 4. Finally, Sec. 5 proposes some concluding remarks.

2. TEACHING STEM DISCIPLINES

With respect to the general discussion in Section 1, the objectives of education in STEM disciplines are enriched with additional items. As summarized in Table 1, the expected knowledge goals include acquiring *fundamental concepts in science* as well as the essential *mathematical principles* needed to investigate, understand, and analyze these concepts. Beyond understanding technologies, knowledge includes the capacity to *grasp the impact* of technologies on society and the environment. Education can be considered successful only if it fosters *holistic views* of technologies within the contexts of science, society, and the environment.

The Table lists also some key skills that education in STEM disciplines should target. The ability to use the *scientific method* —formulating hypotheses, designing experiments to confirm or discard these hypotheses, and analyzing experimental outputs and data to extract knowledge— is a key skill fundamental to science. *Critical and creative thinking* are essential for both science and technology, enabling the design of new solutions, exploration of unknown phenomena, and development of new visions and paradigms. Additionally, modern science benefits from continuously improving *tools* that make the work of scientists, engineers, technicians, and mathematicians easier and their studies more effective.

To achieve these goals, teachers should find ways in education that meet also the expectations of students. From our 20 year experience teaching in engineering, these expectations typically include that:

- the topics that are the objective of a course are *useful and interesting*, meaning that what is learnt is instrumental to understanding, designing, investigating, other topics;
- the acquired skills enrich students' CV, turning to be effective in getting good jobs opportunities;
- the learning process exhibits a *short start up time* that allows students to start applying new tools or concepts in a short time so that knowledge can be consolidated by practice, and learning by doing;
- the learning process includes *hands-on experiences* that are very effective to deepen knowledge and skills and to make learning fun.

Table 1: Objectives of education in STEM disciplines in terms of knowledge and skills.

Knowledge	Skills
Fundamental concepts in science	Scientific method
Fundamental mathematical principles	Critical thinking
Grasping impact of technologies	Creative thinking
Holistic views	Using tools
...	...

Considering these objectives of teaching STEM disciplines, the characteristics of performance evaluation as a topic to teach and learn make it perfectly suited to contribute to knowledge and skills as in Table 1 and to meet students' expectation about the learning experience.

Indeed, performance evaluation is a nice way to apply some theorical foundation of math, it requires critical and creative thinking, it can facilitate the development of holistic views. By properly designing teaching methods, performance evaluation can easily meet students' expectations.

3. TEACHING PERFORMANCE EVALUATION

In several fields, performance evaluation tools, intended as tools to model and analyse dynamic discrete systems (whose state is discrete and the behavior consists in the system evolving with time moving from state to state), are very useful to accomplish three categories of tasks: i) assessing the performance of a system, including understanding the inter-relation among its components, ii) sizing of its components, iii) designing new solutions. While apparently far from each other, problems in fields like logistics, transportation, networking, production and manufacturing, share the same need for tools to model the dynamic behavior of systems with time. Performance evaluation tools are a valuable choice for these tasks and they have a wide range of possible applications. For example, in a production system, dimensioning the capacity of a machine, in terms of number of pieces that can be handled in the time unit, is not conceptually different from dimensioning the capacity of a channel in terms of packets per second that can be transmitted. Understanding the stability conditions for the output lines of a router is similar to understanding the uncontrolled formation of a queue at the junction between two streets. The dialog between parties in a communication protocol raises issues that are not that different from the interaction among elements of a logistic supply chain.

Besides being a set of methodologies that are quite general and potentially useful in several fields and for tackling different problems, performance evaluation can be a valuable mean to achieve some of the skills and knowledge reported in Table 1. To try and understand why, consider the sketch of the learning cycle of modeling reported in Fig. 2. The cicle is composed of three steps:

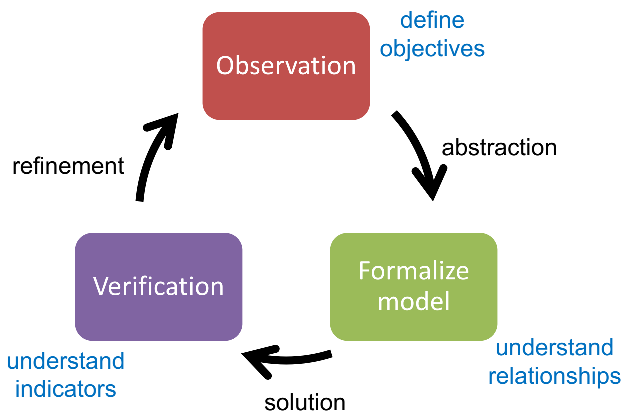

Figure 2: Performance evaluation learning cycle.

1. **Observation:** the objectives of the study are identified, the boundaries of the system are outlined, including the definition of the various components, the state variables that describe in each instant the behavior of the system are specified.

2. **Formalize the model:** From the observation, through *abstraction*, the fundamental relationships among the components of the system are formulated, together with the characterization of the key (random) variables.

3. **Verification:** By computing the *solution* of the model previously formalized, the key performance indicators are derived. The system behavior is analyzed, hints are drawn, unexpected behavior understood, performance is assessed and quantified. If needed, the model can be *refined* and the cycle can iterate to either tune and deepen the system analysis or to investigate new aspects previously neglected.

The learning cycle shows the acquisition of several skills that are the objectives of education in STEM disciplines: creative thinking in formalizing the model, critical thinking and development of holistic views in verification and refinement, use of tools, in solving the models.

Keeping in mind that performance evaluation tools and methodologies have a wide spectrum of possible application fields, it results relatively easy to identify practical problems that can be used as (toy) examples to practice the skills previously mentioned for a hands-on learning experience.

4. OUR TEACHING EXPERIENCE

In this section, we present our experience in teaching performance evaluation. In what follows, we refer to performance evaluation tools as the set of methodologies that includes: Markov chains, queuing theory, simulation.

4.1 Organization of the course

We teach performance evaluation within a M.Sc. degree titled ”ICT for Smart Societies” [3]. The M.Sc. aims at providing to students knowledge and skills on Information and Communication Technologies (ICT) together with some basic domain knowledge on some of the most relevant sectors that are looking at ICT as a set of enabling technologies to propose innovation and improvements. Environments like buildings, cities, transportation systems, health care, electricity distribution are becoming ”smart” through the introduction of digital solutions. On top of ICT related skills and knowledge, the M.Sc. program offers to students also some basic domain knowledge in the sectors listed above.

The solutions that make ”smart” these environments, which are quite different from each other, have in common the following functions:

- collection of data;
- implementation of algorithms that elaborate the data to either extract knowledge or make decisions;
- actuation of control actions.

While the actual way in which each of the function is implemented and deployed is specified by the domain, objectives and environment characteristics, the core of the digital technologies is basically the same. In terms of ICT technologies, the basic functions require two kinds of competence: i) *communication and networking* for data collection, data transportation, architectural organization of the services, and ii) *algorithms*, often ML and AI based, to make decisions and extract knowledge.

For example, in a smart building data about temperature, humidity, presence of people, are collected by sensors and transported to a control unit where they are stored and elaborated to make decisions on how to manage heating and cooling facilities, lightning and surveillance services. Similarly, in a smart transportation system, data about the presence of vehicles and pedestrians, air pollution, lighting conditions, are collected and transported to some computing facility to be elaborated so as to optimize routing, detect critical situations, and design traffic management strategies. In a electricity distribution systems, sensors collect consumption data, information about the conditions of electrical lines, weather and environment; these data are transported to the control room where they are combined with predictions about energy production and consumption and they are translated into requests to be shared with users in a demand-response fashion as well in indications for the operator about operation and maintenance.

While algorithms are covered by other courses, our teaching focuses on data collection and transportation, i.e., on networking. In this context, performance evaluation tools are envisioned as methodologies for the analysis and design of networking solutions that are instrumental to making other environments ”smart” and innovative.

The course on performance evaluation focuses on:

- Markov chains: introduced as a very versatile tool for the design of protocols and to model elementary queuing systems;
- Queuing theory: in particular Markovian queues and queues with general distribution of the service times;
- Queuing networks: with a focus on identification of stability conditions and bottlenecks;
- Discrete-event simulation: used to model some case study.

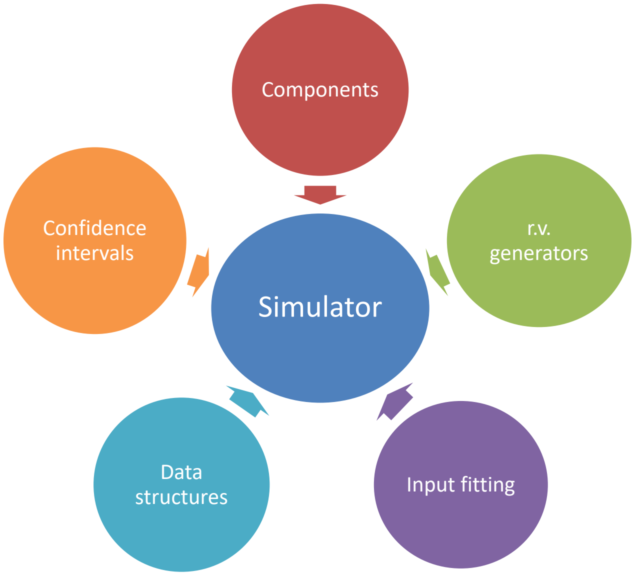

Figure 3: Components of the simulator.

The presentation of a variety of methodologies intends to convey the message that the considered approaches are *complementary* to each other. No approach can, in general, be considered the best one, but it is the joint use of different models that is effective: by leveraging on the peculiar characteristics of each methodology, the combination of them provides a deeper understanding of the problems and facilitate the development of holistic views.

Markov chains are introduced mainly to model queuing systems. During the study of different queueing systems, the effort consists in deriving *general guidelines for networking problems*. This shows that, despite the models being simplistic in some assumptions, they can be extremely useful to get insights into system behavior.

Indeed, general guidelines for networking can be derived from queuing theory in a quite natural way. For example, after discussing the first few simple queuing systems, the comparison of single- and multi-server queues is used to emphasize that segregating traffic or splitting the available bandwidth in portions tends to deteriorate performance, while aggregating customers in a unique waiting line and service capacity in a unique server improves the overall performance. Also, the comparison of single-server queues under different distributions of the service times emphasizes how variance can be harmful for performance, and why traffic shaping and, in general, smoothing service times turn to be useful. Through these guidelines students are rewarded for their effort of deriving analytical models by understanding their practical applications and gaining valuable insights.

The introduction of simulation has the twofold objective to highlight the importance of complementary approaches and to allow, in a short time, a hands-on learning experience. All the main parts of a discrete-event simulator are discussed and, as shown in Fig. 3, these are: the components of the simulator (procedures, event cycle, collection of measurements, ...), generation of random numbers and instances of random variables, fitting of input data, data structures, confidence intervals.

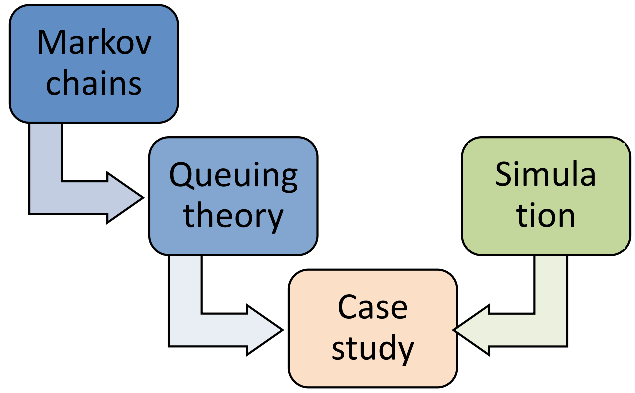

Figure 4: Case study to appreciate the complementarity of approaches.

To allow, in a short time, a hands-on learning experience, instead of using a tool already developed by others, the students build (starting from some simple but complete simulator) their own simulator in a general purpose language. The idea is to increase the sensitivity to the several parts that compose a simulator, to practice with the simulator and with running simulations. The students are first requested to focus on some queuing system. Even considering simple queuing systems, the comparison between queuing theory results and simulation results shows the effectiveness of close-form expressions with respect to numerical results obtained by simulation but also the difficulty in deriving analytical models. Practicing with simulation allows to acquire skills in understanding accuracy of results and the cost of collecting relevant statistical data. The students learn (by doing) that there is not a best way to model a system and to understand its performance. Integrating approaches increases knowledge.

Then, a more complex case study is proposed. The case study is usually inspired by some actual problem we might be interested in during our research activities. As shown in the sketch of Fig. 4, the case study puts together the knowledge already acquire and consolidates the competence and skills. It also contributes to the objectives reported in Table 1 and meets the expectations of students in terms of usefulness of the proposed methodologies and hands-on experiences.

4.2 Discussion from the experience

To get a feeling about the perception of our students on their experience with performance evaluation tools, we recently performed a survey based on a questionnaire to students from last two editions of the course. We are aware that the conclusions are very specific of this situation and it is not possible to generalize to other cases. However, we are satisfied to get that most of the students enjoyed the course. One thing that was particularly appreciated is the impression that the tools they learnt are useful, and this appreciation applied to simulation as well as queuing theory. No significant difference in the appreciation of these two methodologies could be noticed. Students caught that performance evaluation has the potential to be useful for their future professional life.

Another element of appreciation is the comparison of approaches and the possibility to have a hands-on experience by comparing analytical and simulation results.

One aspect emerged as potentially critical for teaching and this is the perception of the topics being too difficult for a portion of students and not at all difficult for another portion. In particular, the students who perceived the course as difficult mentioned their feeling to have a weak and inadequate background. Heterogeneity in the background knowledge and skills, in particular on probability theory and stochastic processes, but also on coding (for simulation), is potentially critical and should be properly managed, for example by providing additional teaching to fill competence gaps to selected students who need it.

5. CONCLUSIONS

In this contribution, we have discussed our view on teaching performance evaluation. Starting from some general considerations on the objectives of courses on STEM disciplines, we have discussed how performance evaluation can very well meet the expectations of students to receive teaching on interesting topics that result to be useful and applicable in several contexts, that are learnt through examples with pleasant hands-on experiences. We report our experience in teaching performance evaluation in the context of a M.Sc. degree related to telecommunication engineering. We enjoyed teaching performance evaluation, students appreciate it. We believe that a few aspects contributed in particular to the success of the course: showing the complementarity of approaches, proposing hands-on activities, deriving general messages from models. However, a careful effort should be put in taking care of students with different background.

Acknowledgement

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6. REFERENCES

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