Attracting Youngsters to Engineering Education through Simulation Based Teaching
- The French Example

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INTRODUCTION

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Government and industry often point out the increasing demand for engineers. There are many reasons for this:

- The rising complexity of technology, requiring more people in the production process with a high-level understanding of technical concepts
- A renewed focus on research and development in many European countries, as domestic production shifts elsewhere with globalization
- An increased awareness of environmental problems and the part technology plays in creating and solving them
- The aging population of highly experienced engineers in Europe

All of these factors have increased the demand for university-educated engineers and lowered the demand for technology staff with vocational training. To meet this demand, upper secondary school programs must prepare more students for engineering studies at university level. This creates a tough challenge for the upper secondary school, which must:

- attract a larger number of students to the relevant programs
- ensure students obtain the necessary knowledge to be eligible for university
- maintain students' interest in technology throughout their studies

Recently, the French upper secondary education program changed to address these points. Among the changes, simulations took a central role in the learning process in one of the streams that prepare students for university-level engineering education.

The purpose of this paper is to describe the experiences from teachers and students in implementing this new system in order to understand if the teaching methodology can attract students to engineering education.

Section 1 of this paper describes the changes in teaching philosophy in relation to the previous system and alternatives routes. Section 2 discusses the question of how to implement these teaching ideas. Section 3 covers teacher and student feedback from the changes. Section 4 summarizes the conclusions.

1 THE STI2D SIMULATION-BASED TEACHING APPROACH

The upper secondary school Science (S) stream was once the main one that prepared students for higher engineering education in France. It uses a scientific and technological approach in which students first learn fundamental concepts in mathematics, physics, and chemistry, and then apply these concepts in experiments. By contrast, the Science and Technology (STI) stream previously prepared students mainly for short-term practical or manufacturing professions. This stream was redesigned in 2011 to offer an alternative route into engineering. The teaching was actively designed to appeal to a group of students not generally attracted by the theoretical teaching of the S stream.

The new stream, called STI2D (Science, Technology, and Sustainable Development), has the objective of allowing the students to gain the same level of understanding of concepts as the S-stream students; the differences is in the teaching and learning activities to get there. [1]

1.1 STI2D Teaching Approach

The STI2D approach has three principles. The first principle is to use the practical approach in STI to teach concepts from a top-down approach. Students start with experiments and then deduce concepts from their observations. The pedagogic idea is for students to learn scientific and technological concepts by active participation and exploration. Although this pedagogic approach differs from that of the S-stream, the learning outcome in terms of concepts and theory must be the same in order to prepare the students for further studies. [1]

The second principle in STI2D is to position technology and industry in relation to its global environment. Students should see that factors such as environmental and societal impact are integral parts of the design and production process. An important reason for this is that these factors become increasingly critical for modern industry. [1]

The third principle is to divide teaching and learning activities in multidisciplinary themes rather than individual subjects. Classes study the design of a new industrial process or technology so they can understand the need to choose and control materials, transform energy, and monitor the flow of information. These three sides form the basis of systems study in the STI2D education. [1]

- Materials including the composition and structure of different materials. This view also covers concepts from solid and fluid mechanics.
- Energy including transformation and management of energy in all its forms.
- Information including control, interaction, and monitoring of information, both locally and remotely. This view includes concepts from communication technology and describes how systems interact with its environment.

This third principle of STI2D is completely opposite to the principles behind the older STI structure in which teaching and learning activities were divided in specific technological domains in order to more directly prepare students for a professional career.

1.2 STI2D Curriculum

The STI2D is a two-year education. The choice of the specialty is done in the first year. Students can chose from one of the following specializations:

- Information Systems and Numerical analysis
- Innovative Technology and Ecological Concepts
- Architecture and Construction
- Energy and Environment

However, teaching remains general during the two years, so that the students can change the specialty whenever they want to. The objective is for the students to obtain an understanding of a complex technical system as well as to understand how it relates to its global surrounding. The teaching approach is based on generic concepts that could be applied on different practical problems and rely on knowledge from many different fields of science and engineering. The generic and global approach avoids early specialization and allows the students to learn all the basic knowledge to understand complex systems.

The studies focus on concrete applications and real systems. There should be a clear link to reality, observations and practical student activity. The teaching divides in the three topics (energy, information and materials) rather than in individual subjects. [1]

As an example, the students study practical problems in mechatronics, which requires concepts from fields such as mathematics, mechanics, electronics, controls and computer science. Understanding how the different concepts interact and work together and with its environment becomes vital for understanding the whole mechatronic system.

Projects are integrated into the curriculum in order for the students to obtain deeper knowledge in their specialized area and enable them to apply the knowledge in a design process through a professional engineering workflow. Students apply the knowledge gained along the two year through design projects. The process is organized to illustrate the workflow of a professional engineer and is divided in steps. Students start by conceiving, then continue on to designing and finally build a prototype. The whole process is realized through project-based learning. [1]

1.3 Simulation-Based Teaching in STI2D

The predecessor (STI) focused largely on applied technological knowledge in specific specialization areas, whereas STI2D is focused on giving students a more general system based perspective and on guaranteeing that students reach higher education. The STI2D therefore does not require students to get hands-on experience with the tools of the manufacturing process, as did the STI students. This implies a different need for laboratory equipment; the experimental equipment specific to the industry branch is no longer mandatory.

Experiments are still used in STI2D, however the idea is to use modeling and simulations when possible. The simulations prepare and test concepts prior to experiments. Simulations are also used to validate the different steps in the development process and are compared and linked to hardware experiments in order to highlight the link to reality.

There are practical advantages with replacing some experiments with simulations. By working with a simulation, students can discover more freely, exploring wild “what if” scenarios that inspire curiosity. Simulations also offer a safer alternative to using actual electronic or mechanical equipment; simulations eliminate the risk of injury and damage. A final practical point is that simulation software is less expensive to purchase and operate than physical equipment. This is even more so in STI2D teaching where the complex technical systems studied often lead to very expensive experimental equipment.

Research in educational science also shows that working with simulations can improve the learning process and outcome for students. A study on electronics has shown that students who use simulations to prepare for a lab perform better when examined on higher order cognitive skills such as applying their knowledge and analyzing new problems [2]. Similar studies have shown that students became more enthusiastic about the subject when allowed to use simulations [3], [4]. Thomas and Hooper [5] reviewed a larger number of studies on the advantage of using simulations in teaching and concluded that simulations that allow for active interaction by the student have a positive effect on the learning process and enhance the higher order cognitive skills in the Bloom taxonomy.

These findings are often understood in terms of a constructive view of learning, implying that teachers can never transfer knowledge or skills directly to students but that all knowledge must be constructed in the mind of the student. This view emphasizes that students must work actively with the material in order to learn. The increased activity of the students has been proposed as a large factor in explaining the improved learning outcome. Menn [6], in an often cited study, claims that we only remember 20% of what we hear but 90% of what we experience hands on – even as a simulation.

The findings that simulation-based teaching improves higher order cognitive skills rather than basic knowledge has been understood as promoting other learning activities than traditional lectures and exercises [7]. Students explore, hypothesize, and test instead of read and recall which increases the level of abstraction. Simulation not only adds activity, it adds high-level activity.

Many educational scientists now also emphasize the use of interactive simulations or “learning games” as a possibility for creating the next generation of education. [8] Thus, simulations are not only a way to reduce risk and cost; they can also increase student interest and performance when used correctly.

2 IMPLEMENTATION OF SIMULATION-BASED TEACHING IN STI2D

The ambitious philosophy of the STI2D must be implemented in the practical teaching and learning activities at schools in order to have any effect. Section 2.1 describes the practical factors that were considered when choosing simulation tools in STI2D and Section 2.2 describes the implementations in the concrete classroom situation that will be discussed further in Section 3.

2.1 Simulation Tools

The STI2D philosophy sets high demands on the simulation software. First, it sets demands on how it represents models to the students. The complex technological systems studied require advanced mathematical concepts that students have not yet mastered. Furthermore, the emphasis should be on interaction and conversion within a system rather than on the underlying equation. The simulation software must therefore be a graphical tool for physical modeling and simulation rather than an equation solver only.

Tools for physical graphical modeling are often specialized to one area such as mechanics, electronics, or energy transfer. However, the multidisciplinary approach of STI2D where emphasis is often on how energy and information are transferred between these fields, requires that one tool can handle all fields.

Since working with prototypes is an important part of STI2D, and the prototypes are tuned first when the students have investigated the system with simulations, the simulation tool must also be able to communicate with hardware.

2.2 Example of Teaching Controls in STI2D Programs Using Simulation Tools and Low-Cost Hardware

Here, we share our experience in teaching control concepts to STI2D students using MATLAB and Simulink software and LEGO MINDSTORMS NXT robots. The complex system studied is a Segway system (*Fig. 1*), which is a mechatronic system composed of mechanical elements, electrical components, and embedded systems. The teaching covers the multidomain concepts around this system. The example we present in this paper is one taught in all STI2D programs in more than 500 schools in France, and is an integral part of the STI2D course book [9]. It consists of a number of “activities” taught during the first year and a follow-up project during year two.

Fig. 1. Segway [10]

Fig. 2. L RMS NXT

In the first year, pedagogical activities include several lab sessions of two to four hours delivered to a class of 25-35 students who work in teams of two to four individuals. The students study the system from materials, energy transfer, and dynamics perspectives. In this example, we investigate a line of activities centered on the Segway. Students investigate its different components using a full Simulink model of the global system. This allows them to notice important design features such as influence from the dimensions of the wheels and the power of the motors. Students estimate which Segway configuration maximizes its autonomy for a particular usage. In a subsequent lab, students investigate the choice of DC motors that maximizes autonomy, by using a Simulink multidomain model. [11]

The Segway system is also used to illustrate control concepts. The Segway is an instable system that becomes stable via a controlled system inspired by the inverse pendulum problem. The first control activity focuses on the question, “Why it is necessary to correct the position of the Segway via a position feedback control?” The second activity deals with “How do I optimize the performance of the controlled system” Both activities use Simulink models of an inverse pendulum with a 3D animation. The students are asked to: [11]

- Visualize the behavior of the pendulum through the animation
- Identify which of the parameters is responsible for the instability of the system
- Justify the need to control the position of the system

These activities are consolidated in the second year through projects with LEGO MINDSTORMS NXT. Schools use LEGO MINDSTORMS NXT to build a Segway configuration as a prototype (*Fig. 2*). Indeed, in addition to being low cost, the NXT robot offers a robust and open hardware platform equipped with a microprocessor and a set of sensors and actuators that can be configured diversely. This makes the NXT well suited for a variety of projects in mechatronics and robotics.

Students learn how to apply the knowledge acquired in the first year when they conceive and design a controller for the prototype. Thus, after achieving good simulation results using the Simulink model of the controlled system, students implement the controller into the hardware using Simulink with its support for target hardware [12]. After that, they analyze the behavior of the prototype and optimize the values of the control parameters to improve the performance. This is achieved by adjusting the control parameters of the LEGO MINDSTORMS NXT directly from the Simulink model. By changing the parameters of the controller, students can visualize the result interactively using Simulink scopes.

3 EXPERIENCE FROM TEACHERS AND STUDENTS

We gathered results and feedback from our experience teaching the Segway/LEGO MINDSTORMS NXT example to a class of 25 STI2D students at Lycée Polyvalent Gustave Eiffel de Cachan in France. The results are from students who started the first year of the new program in 2011 and are currently on their second academic year (2012-2013). It covers the full integrated STI2D curriculum.

The use of the simulation-based approach with MATLAB and Simulink software offered the following main advantages:

- It eased the learning process with the students. As students experiment on a model, they can repeat the actions as many times as needed to understand how modifying the parameters can influence the behavior of the system. We observe that students find it easier to implement knowledge when they can interact with the system themselves instead of just observing.
- It reduced the preparation time for the teacher and the realization time by the students. A lab session that was previously 3-4 hours can now be managed in 2 hours. Students can finish their activity and document their work faster.
- Class location is more flexible. Because the support material is computer-based, no extra space is needed for hardware equipment. Therefore, activities do not have to be done in small groups; it is now possible to gather the entire class for the same activity.

Analyzing the behavioral system through graphics is an important challenge for students. Therefore, the use of 3D animation together with the simulated graphics helped the students better analyze and interpret the graphics, as it maps the form of the graphics with the natural 3D visualization of the real behavior. This approach gives a physical meaning to the graphics, such as associating the rapidity of the system to the changes in the control parameters.

Since Simulink is a multidomain platform for simulation, teachers can use a single model for different activities and concepts.

Running models on the LEGO MINDSTORMS NXT attracted and excited students because they can see the results of their design immediately and understand how the design influences system behavior.

4 SUMMARY

We described the simulation-based teaching implemented in the new French upper secondary STI2D stream. The stream was designed to attract more students to engineering education.

Students appreciate the “gamification” of engineering concepts and the playfulness of the learning approach. Since they actually do stuff on their own, they build a better relationship to the subject, which has been shown in literature to establish a deeper level of understanding. Thus, the simulation-based teaching used in STI2D prior to theoretical concepts has great potential in getting more students interested in technology and preparing them to pursue engineering in higher education.

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