Didactical resources for sustainability

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Abstract

In this paper we discuss the use of computer simulations for sustainable systems. Specifically, we propose laboratory practices for Automatic Control subjects where the plants are sustainable systems. The interest is the simulation of this kind of systems to forecast their behaviour in order to control and actuate over them. In this paper, the use of a didactic material for laboratory practices is explained. This pedagogical resource is published in a web (http://model.upc.edu) where the student can find the practice statements, the explanations and the software to develop sustainable models in form of laboratory practices for the subjects related with simulation and modelling in different engineering degrees, because we have the belief that undergraduate students must receive an Education for Sustainability independently of their career without learning the basic and specifically concepts of the own subject.

Introduction

In our modern society, distance education has become a viable solution for students who require more flexible, accessible, and adaptive teaching systems, without spatial and temporal restrictions (Aktan et al., 1996; Poindexter & Heck, 1999). In the past, the interaction methods for distance education were limited to the telephone, postal mail, or fax. Today's new information technologies provide alternative tools for improving teacher-student interaction, two of which can be pointed to as the most capable and reliable for distance education. These tools are hypermedia systems as a new way of arranging information and wide-area communication networks (i.e., the Internet) for information support (Maly et al., 1997)

Although these tools are sufficient for constructing support systems for subjects without a strong practical component, teaching of systems modelling or other subjects with strong experimental content requires a new element. This new element must allow students to apply the knowledge acquired in a way that goes beyond the traditional physical laboratory, which requires the presence of students as well as an instructor or tutor. If the laboratory environment is to be transferred to distance education, the element required to put simulation and modelling concepts into practice is the virtual laboratory (Schmid, 1999; Sanchez et al., 2000).

Today, numerous commercial and university computer tools are available for the analytical study of dynamic systems from a purely graphic or a numerical viewpoint, or a combination of both approaches (Wittenmark, Haglund & Johansson, 1998; see also: http://www.act-control.com/topas.pdf). These quantitative tools require the user to have university-level knowledge of mathematics and a solid background in dynamics and systems analysis.

This article describes the experience in the Automatic Control Dept at the Technical University of Catalonia (UPC) in teaching simulation and modelling of dynamic systems subjects that uses dynamic and interactive simulations in a stand-alone or Web-based environment.

The article focuses on how this new stand-alone experimentation environment maintains a clear separation between the graphical experimentation interface, developed in Java, and the math and simulation engine. By constructing the environment in this fashion, the math engine can be replaced with a different one or with a real plant, or can even be ported to a remote server. A Web-based, multi-user virtual lab is also possible without the necessity of reprogramming the experimentation interface code. Other differences with respect to other tools are the dynamic simulations, the user interactivity, the generation of new experiments as goals change, and the opportunity to practise different models for the same problem. The article also focuses in a new way of understanding the contents of technical subjects, such as modelling and control of dynamic systems, following a strategy well-implanted at the UPC: incorporating the education for the sustainable development (ESD) and social aspects in the curriculum.

The article is organized as follows. First, the inherent relationship between the sustainable systems and the modelling and control of systems in the actual world is explained. Second, the educational MODEL web is briefly introduced. This pedagogical resource leads to implementing virtual laboratory practices of sustainable systems simulation and modelling based on a real case study, and one of these models is described. Easy Java Simulations is the tool that will be used to program the model and the views for the simulation. Finally, the didactic methodology used for the laboratory is explained, analyzing the tasks for the teaching staff as well as for the students.

Modelling and control of systems for the sustainability

In the last few years society has become aware of that the pattern of current development affects our Planet in a noxious way. The wrong and excessive use of natural resources, the group of substantial changes in the environment (deforestation, natural disasters, climatic, pollution...) has generated the environmental problem that all the countries of the world are living, especially the industrialized ones. For this reason the 21st century outlines a new and important challenge in the society: sustainability.

The university plays an important role in transmitting this environmental conscience in its studies traditionally related with the natural environment such as biology, medicine, ecology and zoology, but its interest goes beyond this point and arrives to the merely technological subjects (Weaber et al., 2000): engineering (industrial, civil, chemical, automatic control, telecommunications, etc.) and computer science. Following this path, the Technical University of Catalonia, UPC (http://www.upc.edu/mediambient) among other universities (http://www.odo.tudelft.nl/english/index.html), gives priority to environmental education in its curricula, mainly technological. The reason lies in the belief that many problems in our Planet can be solved, achieving so-called “sustainability” through actions indirectly related with the environment, and using the technological advances not only in an economic and efficient productive manner but also taking into account our natural environment (Chauveaux, 2004).

The application’s domains of biological and ecological systems provide many opportunities and challenges for the technologies of modelling and control Fath et al., 2004; Hashimoto et al., 2004), as well as engineering degrees (Dynm, 2010; Lau, 2010). High schools are places where students and teachers share knowledge, learn skills, and transmit values. Specifically, a Control Engineering degree opens up possibilities to connect the network analysis methodology to traditional control theory, to reintroduce a network-based control parameter using flow analysis and to extend the methodology to network storage analysis (Grau et al., 2005). Model ecosystems are constructed and used to investigate these properties. For this purpose we propose to introduce terms of sustainability in the subject Simulation and Modelling of Dynamic Systems of this degree, mainly by the presentation of environmental case-studies systems. Normally, the main objectives of environmental modelling are the following: 1) prediction and estimation of important environmental variables using a composite model to explore efficient environmental strategies and management schemes; 2) prevention of environmental risk, an area that involves work on accident prevention in industry, through accident modelling and evaluation of the possible effects; 3) the challenge of environmental control issues for industry (chemical industry, iron and steel industry, etc.). Over the past decade, industry in general has made efforts to save energy, improve efficiency of energy use, reduce CO_2 emission, and promote recycling and life cycle assessment.

Model web pedagogical resources

Despite the fact that students use a virtual laboratory, this does not suppose that the laboratory practices have to be invented. The idea is just the opposite: we propose the use of practices based on real cases. This can stimulate students in their practices and increment their interest in environmental applications in order to make them aware that environment and engineering are closely related. The role of these students in the professional world will be decisive for the preservation of the natural resources.

The STEP project (Sustainability, Technology and Excellence Program at UPC) has as its principal objective to assure the existence of ‘the sustainability and the social commitment’ competence in the curricula of all the engineers.

The faculty of the Automatic Control Department has developed an innovative didactic resource: the MODEL web (http://model.upc.edu). This web, Fig.1, is a compilation of sustainable modelling education resources, specifically a virtual laboratory. In this page a collection of pedagogical resources in Dynamic Systems (System Theory) are presented. These resources are intended to analyze and predict some events in our World in order to understand them in their whole complexity. The resources are multidisciplinary and they will give us a systemic vision. The modelling and simulation of different systems that can be found in this page will help us to understand the behaviour and evolution of our society: ecology, human behaviour, health, economy, biology, engineering, chemistry, history, politics, journalism, sociology, psychology, among others. By these applications, faculty can teach the basic concepts and fundamentals of the simulation and modelling integrating the sustainability in a transversal way. We are immersed in a myriad of systems that describe the World complexity and the systemic reality of the life. Therefore, the parts and the components of things must be analyzed in depth but it is also necessary to assemble these parts to understand how they interact to make up a single entity. This is what we understand as a system.

Figure 1: Website main page of MODEL.

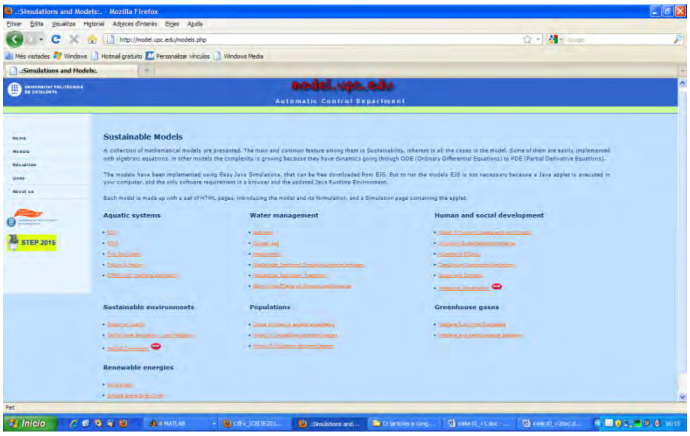

Figure 2: Models list.

The models are oriented for use in education (at university level) as well as in research. We have focused our attention on an issue that must be taken into account transversally in all the disciplines: ‘Sustainability’. This website is continuously updated and new models are added, accepting external proposals.

The virtual laboratory is composed of models in the following typology (Figure 2): 1) Aquatic systems; 2) Water management; 3) Human and social development; 4) Sustainable environments; Populations; 5) Greenhouse gases; 6) Renewable energies.

Next, as an example we describe one of the models published in the web: “Wastewater Secondary” (Davis & Cornwell, 2007). The practice describes the functioning of a wastewater treatment plant, and specifically, the secondary process where the water is cleaned, removing solid particles in suspension, generating sludge. The representation of the system is done by the following ordinary differential equations:

$$
\begin{aligned}
\frac{dS_a}{dt} &= \frac{Q_i}{V_a}(S_i - S_a) + \frac{Q_r}{V_a}(S_r - S_a) - \frac{\mu_M}{Y}\cdot\frac{S_a}{S_a + K_S}\cdot X_a + (1 - f_P)\cdot K_d \cdot X_a \\
\frac{dX_a}{dt} &= \frac{Q_i}{V_a}(X_i - X_a) + \frac{Q_r}{V_a}(X_r - X_a) + \frac{\mu_M \cdot S_a}{S_a + K_S}\cdot X_a - K_d \cdot X_a \\
\frac{dS_e}{dt} &= \frac{Q_i - Q_d}{V_c}\left(S_a(t-c) - S_e\right) \\
\frac{dX_e}{dt} &= \frac{Q_i - Q_d}{V_c}\left(Z(t-c)\cdot X_a(t-c) - X_e\right) - \frac{X_e}{V_c}\cdot\frac{dV_C}{dt} \\
\frac{dS_r}{dt} &= \frac{Q_r + Q_d}{V_s}\left(S_a(t-s) - S_r\right) \\
\frac{dX_r}{dt} &= \frac{Q_r + Q_d}{V_s}\cdot\Big(\frac{Q_i(t-s) + Q_r(t-s) - Z(t-s)\cdot\left(Q_i(t-s) - Q_d(t-s)\right)}{Q_r(t-s) + Q_d(t-s)}\cdot \\
&\qquad \cdot X_a(t-s) - X_r\Big) - \frac{X_r}{V_s}\cdot\frac{dV_s}{dt}
\end{aligned}
$$

The description of the wastewater treatment plant and the statement practice is published in the web, see Figure 3.

The sample activated sludge unit considered works as any other typical sludge unit. The block diagram with the space-state/input/output variables are shown in Fig. 4. The wastewater flow (that has already received both pre-treatment and primary treatment), with a volume of Q, containing concentrations of Xi for biomass, and Si for substrate, enters the unit. Before entering into the aeration tank, the flow is "seeded" with the returned sludge flow Qr. This returned sludge contains the microorganism that will degrade the organic matter. Next, this "mixed liquor" enters the aeration tank, where atmospheric air or pure O_2 is introduced. For the sake of simplicity it is assumed that air injection is correctly adjusted at any moment, existing the optimal oxygen conditions for microorganism growing. Thus, after being treated by these microorganisms, concentrations Xi and Si will become Xa and Sa as the wastewater progresses through the unit. At some point the wastewater mixed with sludge will pass to the secondary clarifier. The flow rate from aeration tank to secondary clarified equals a delayed value of Qi+Qr, with concentration of Xa for organic matter and Sa for substrate.

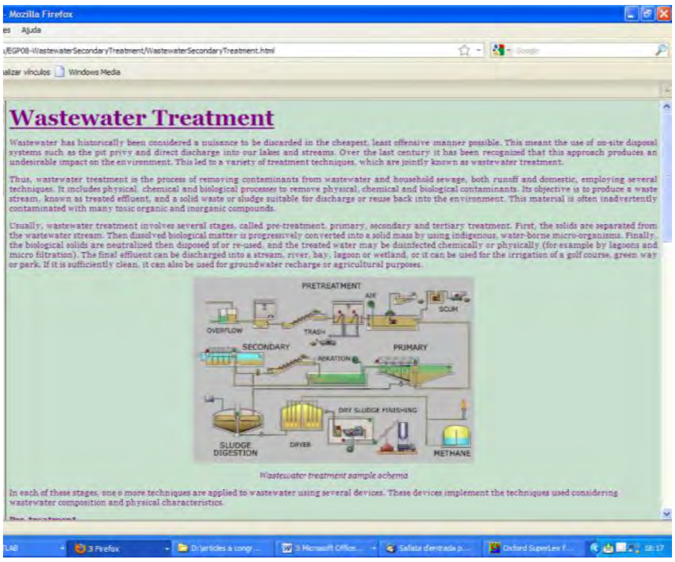

Figure 3a: Wastewater treatment process

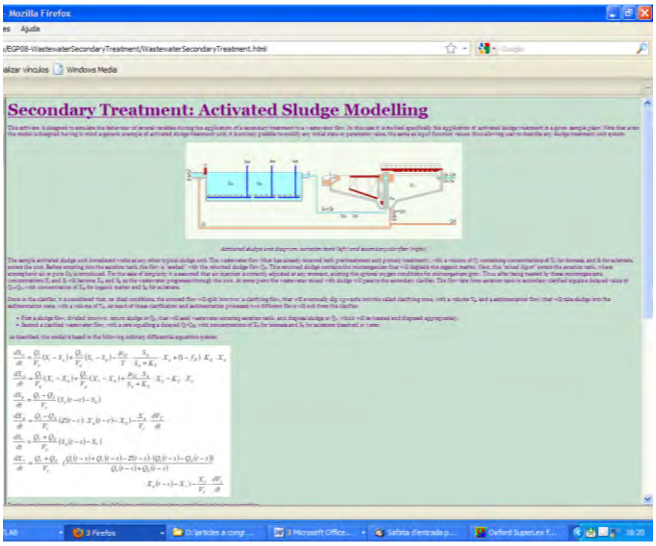

Figure 3b: Practice statement.

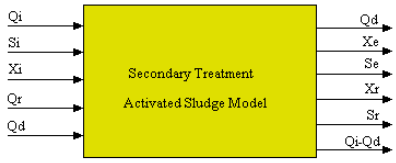

Figure 4: Block diagram of the activated sludge model in the secondary treatment.

Once in the clarifier, flow will split into a clarifying flow and a sedimentation flow. As result of these clarification and sedimentation processes, two different flows will exit from the clarifier: a sludge flow, which will be treated and disposed appropriately, and a clarified wastewater flow.

The results of the simulation are showed in the Figure 5 (Bottom), model parameters can be changed during simulation using sliders, see Figure 5 (Top). The different parameters used in the model are described in Table I.

Table 1: Parameters used in the wastewater secondary model

Name of parameter	Description	Value	Unities
A	Clarifier section	200	[m2]
H	Clarifier height	2	[m]
K	Separation constant	7·10-13	[dimensionless]
N	Speed ratio exponent	6	[dimensionless]
be	Sludge age exponent	2.2	[days]
fp	Biomass inert fraction	0.08	[ratio]
Va	Volume of aeration tank	600	
Ks	Half-saturation constant	150	[dimensionless]
Kd	Sludge degradation constant	0.015	[SSI·hours-1]
µ	Maximal growth rate	0.15	[dimensionless]
Y	Sludge production performance	0.5	[SSI/DBO5]
R	Return sludge ratio (Qr = Qi · R),	0.75	[ratio]
P	Disposal sludge ratio (Qd = Qi · R)	0.0156	[ratio]

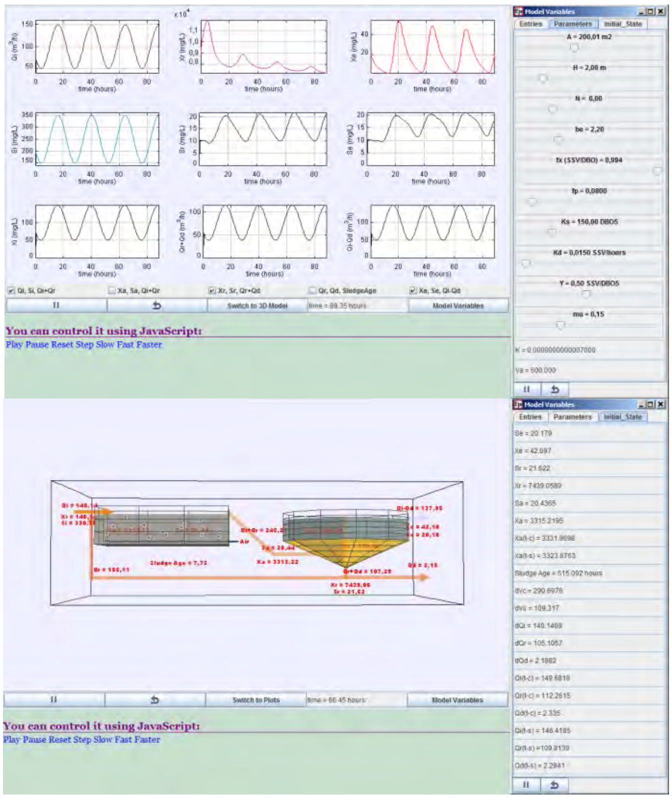

Figure 5: (Top) Simulation page with adjustable parameters.

(Bottom) Simulation according to the ODE of the activated sludge model.

Easy Java simulations

Easy Java Simulations is a freeware, open-source tool developed in Java, specifically designed to create interactive dynamic simulations (Esquembre, 2004). Ejs was originally designed to be used by students for interactive learning under the supervision of educators with a low programming level. However, the user needs to know in detail the analytical model of the process and the design of the graphical view. Ejs guides the user in the process of creating interactive simulations, in a simple and practical way.

The architecture of Ejs derives from the model-view control paradigm, whose philosophy is that interactive simulations must be composed of three parts: the model, the view, and the control. According to that, the steps to build an application in Ejs are the following: (1) to define the model is necessary to specify the variables that describe the system and the mathematical equations interrelating them; (2) to define the view in order to represent the states of the process; and (3) to define the control in order to describe the actions that the modeller can execute above the simulation. In Fig.6, the Ordinary Differential Equations (ODE) editor is shown and view definitions, in the case of the advertisement model that belongs to the collection of sustainable educational models Zill, 2005).

These three parts are interconnected because the model affects the view and the control actions affect the behaviour of the model. Finally, the view affects to the model and the control because the graphical interface can contain information about them. Ejs simulations are created through specifying a model to be run by the Ejs's simulation engine and by building a view to visualize the model state and that readily responds to user interactions. So, to define the model in Ejs, it is necessary to identify the variables that describe the process, to initialize them, and also to describe the mathematical equations that generate the model.

The view is now the user-to-model interface of Ejs interactive simulations. It is intended to provide a visual representation of the model's relevant properties and dynamic behaviour and also to facilitate the user's interactive actions. Ejs includes a set of ready-to-use visual elements. With them, the modeller can compose a sophisticated view in a simple, drag and drop way. The properties of the view elements can be linked to the model variables, producing a bi-directional flow of information between the view and the model. Any change of a model variable is automatically displayed by the view. Reciprocally, any user interaction with the view automatically modifies the value of the corresponding model variable. To summarize, the model is the scientific part of the simulation; yet the creation of the necessary graphical user interface (the view) is the part of the simulation that demands more knowledge of advanced programming techniques.

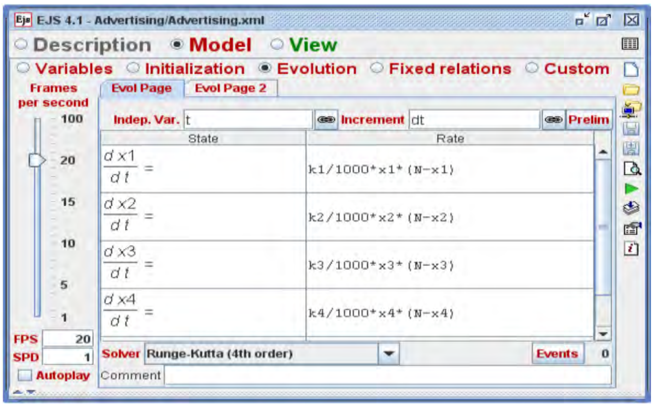

Figure 6a: Ejs ODE editor.

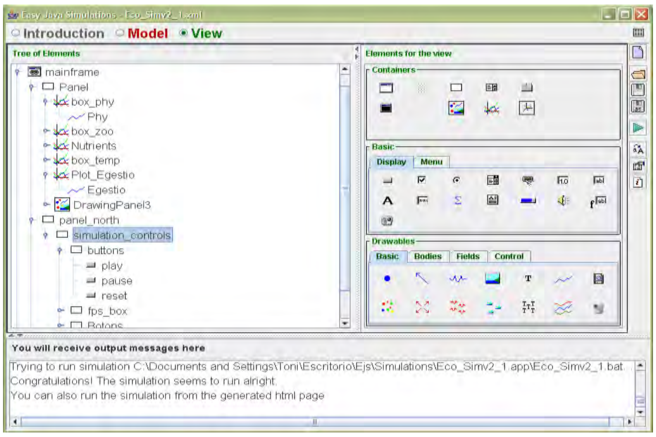

Figure 6b: Ejs view definitions.

Once the modeller has defined the model and the view of the interactive simulation, Ejs generates the Java source code of the simulation program, compiles the program, packs the resulting object files into a compressed file, and generates HTML pages containing the narrative and the simulation as an applet. The user can readily run the simulation and/or publish it on the Internet. Easy Java Simulations, the software tool, and a complete English manual for it, can be downloaded for free from Ejs' web server at http://fem.um.es/Ejs.

Developers can then insert Matlab code in an Ejs application to make calculations in the Matlab workspace. But also, the model of a system can be completely or partially developed using just Simulink block diagrams. In this last situation, Ejs can just be the tool that will help create the view of the simulation, i.e., the visualization and user interface for the Simulink model. This process has been made as simple as possible. Once a Simulink simulation has been selected in Ejs as part of the model, all the Simulink variables can be accessed from Ejs and be associated to regular variables. So, developers can link them to the graphical elements like regular Ejs variables. When running the simulation, Ejs will automatically take care of running the Simulink model and of the two-way exchange of information between the model and the view (on the side of Ejs) and the Matlab workspace.

The virtual laboratory

The laboratory practices proposed in the Simulation and Modelling of Dynamic Systems subject consist on the use of a virtual laboratory based on the Easy Java Simulations tool. The objective of this laboratory is to implement and test models related with Sustainability.

Teaching staff have an initial task of preparing the contents of the practice, and it consists on the following steps: 1) to develop the model of the real system by physical or empirical equations. 2) to implement the model with the Ejs in order to verify the equations, and 3) to propose a specific view. When the above steps are perfectly done and the view is attractive enough, it is necessary to create a web page with the output of Ejs. This web page will contain descriptive information about the practice, the objective, the methodology, the deadline and other academic information as well as the simulation results. These results hold great interest for the student because he/she can check which the expected results for the proposed practice are.

Once the practice is on the web, students can begin to carry out the practice in a local way. This aspect is very important because Ejs can be easily installed in their own PC and it is not necessary to be connected to Internet to do the job. Ejs can be installed for the most common operating systems. Then, the steps the student must follow are:

- Read attentively the practice. Previously, Ejs is introduced in the classroom and some exercises have been realized. Fig. 7 shows the practice formulation of advertisement model Zill, 2005). Due to the Ejs interactivity, students are asked to show the more significant variables of the model (in this case the variable xi, i = {1,2,3,4}, represents the number of people informed about the awareness campaign through the respective medium, (i=1 press, i=2 radio, i=3 TV, i=4 Internet) as well as to allow the modification of the most significant parameters of the model (such as the total number of population, the proportionality coefficient representing the impact of advertising, the number of people who already knows the existence of the campaign, among others). With a set of sliders these values can be easily modified, causing a sudden change in the simulation.
- Implement the model with Ejs, following the ODE system proposed for the practices' instructor. Implement a view for the simulation results. Students have, as example, the results that instructor has posted in Internet. It is not necessary for the Ejs installation to see the simulation execution because this is just a Java applet.

When the student finishes the implementation and the results are similar to the solution, he/she has to send the file where Ejs stores all the model equations, views and description. This information is stored in a XML file, and its size is relatively small. This is another feature of Ejs, the information is not in binary format nor codified in any way. The instructor can easily evaluate the task of the student just compiling the XML file and checking the simulation results.

Using this method, two of the current problems in distance teaching are solved: temporary availability and the training aspect. Students/operators can practise anywhere at any time, without the need to go to a training centre or keep to a timetable (the teaching/training system will be available 24 hours a day via their computers).

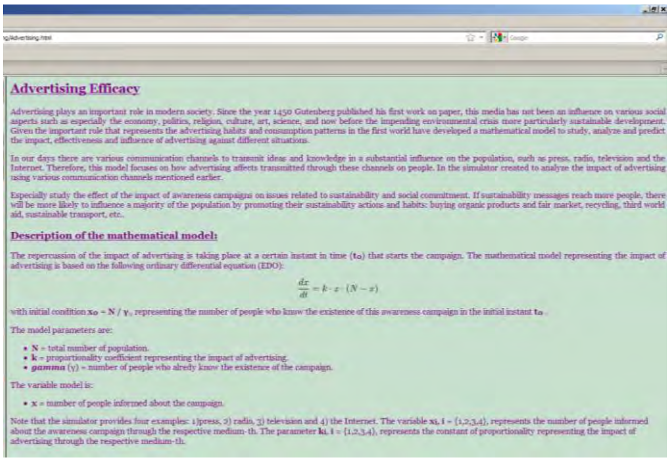

Figure 7: Web page: model formulation for students.

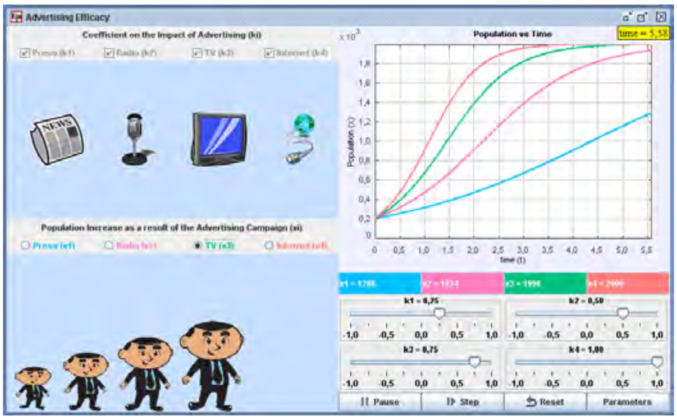

Figure 8: Web page: simulation results.

From a faculty point of view, this method allows the addition of new practices on the Internet, as well as new simulations results that students have to achieve. Apart from these practices, it is proposed that students (as extra work) change the simulation engine from Ejs to Simulink, using the views with Ejs. This shift can be easily (but also carefully) done and it has some academic interest, because it demonstrates how to link different applications. Ejs accepts also to use the Matlab workspace to share variables, using it as math engine.

Conclusion

The introduction of sustainability and social commitment competence is a challenge and a duty for the most advanced universities. The UPC with the project STEP wants to achieve the stimulation of comprehension of the engineering, to recognize the social role of engineers and to emphasize the more human aspect of engineering. The assessment of these skills is not easy because they have been transmitted as experiences and as attitudes. The real effect we hope that it will be achieved in a long -erm period. Besides, the modelling of control systems teacher is an expert in his/her subject but not in programming techniques. The development of interactive didactic applications is not so easy with the typical tools that a modeller teacher uses to explain concepts, as for example, Matlab/Simulink. At the same time, there are many commercial tools designed to create animations and multimedia but, in general, scientific simulations cannot be created with them because they make a poor or nonexistent use of mathematical language to define the system to model.

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