A Problem-Based Learning Approach for Green Control & IT in a Master Program

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Abstract. Students' interest for science and technology studies has been decreasing during the last decade, to the profit of careers with more social impact or economic benefit. While the economic aspect is related to industrial policies and out of reach for university curriculum designers, problem-based learning (PBL) can be a solution to renew the students' interest for science. This work presents an example of curriculum design at the master level where the theoretical classes of systems, control and information technologies (SCIT) are illustrated with PBL-oriented labs and projects related to a topic with high social impact: environmental sustainability. The focus of the paper is on practice and experience sharing; the general approach to motivate the need for SCIT in sustainable and green development is presented, along with some specific projects carried in the master program. The perspective of relying on Web 2.0 tools to improve communication and collaboration in the PBL framework is also discussed.

1 Introduction

Young people's drive for scientific studies has decreased in the recent years, leading to a shortage of engineers before the financial crisis that is expected to propagate in the forthcoming years (cf. [4] and references therein). The conclusions proposed in [4] highlight the importance of raising the view of technology from a daily commodity to a mean for fascinating scientific advances. Becker also encourages university education to motivate less-gifted students with hands-on applications rather than focusing on the extremely challenging nature of science.

It is interesting to note that, according to the European report [10], the young people's attraction for science is still relatively high. Indeed, the presented study shows that the news on science and technology raise 67% interest and that most young people have a positive view about science (one third strongly agree that science brings more benefits than harm). Furthermore, one-third strongly thinks that profit motives have too much importance on the potential science benefits. Such results reflect the potential involvement of young people into s cientific curricula with clearly identified social and/or environmental benefits.

The inter-disciplinary approach provided by curricula in systems, control and information technologies (SCIT) allows for a large range of applications. The approach described in this work is focused on combining the SCIT analytical framework with green (or sustainable) development applications. This is achieved with a problem-based learning (PBL) approach to the theoretical SCIT topics, where the problems considered are the green applications. The Master program in SCIT[1] has been proposed at University Joseph Fourier (UJF, Grenoble, France) since 2008. International issues and the expected learning outcomes for this program are described in [23]. Several labs and projects have been set according to the green SCIT objectives. The motivation for the selected topics, the specific contributions of SCIT and the objectives given to the students are reported in this paper. An experience to motivate high-school students for such higher education is also described.

The paper is organized as follows: first, some theoretical aspects regarding problem-based learning are introduced in Sec. 2. Next, the practical application of PBL in the context of SCIT master courses is illustrated in Sec. 3; the PBL outcomes obtained by the master students serve also as motivational material to attract high school students toward the SCIT field, as described in Sec. 4. Finally, Sec. 5 summarizes the lessons learned from the implementation of PBL in the master curriculum, outlining both the achievements and the difficulties encountered; the perspective of introducing Web 2.0 tools to improve communication and collaboration in the PBL framework is also envisioned.

2 Theoretical Background - Problem Based Learning

According to [3], PBL represents "the learning that results from the process of working towards the understanding of a resolution of a problem". So the emphasis is not on the solution, as in the case of conventional problem solving strategies, but on the process leading to it [15]. The approach was first introduced in medical education at McMaster University in Canada about four decades ago and its use was extended to many other areas in the meantime [2]. PBL is an instructional model rooted in constructivist principles [18]: i) understanding is an individual construction and comes from our interactions with the environment; ii) learning is driven by cognitive conflict or puzzlement; iii) knowledge evolves through social negotiation. Accordingly, in PBL all learning activities are anchored to a larger task or problem, which must be authentic and reflect the complexity of the real-world environment in which students will eventually apply that knowledge. The teacher assumes the role of facilitator, supporting the learner in developing the metacognitive skills associated with the problem solving process, encouraging them to think both critically and creatively. The problem solving takes place

[1] http://physique-eea.ujf-grenoble.fr/intra/Formations/M2/EEATS/PSPI/

in collaborative groups, in which students' knowledge is tested and enriched with peer's alternative views [18].

According to [22], students follow several steps during the PBL: i) identify the problem; ii) explore pre-existing knowledge; iii) generate hypotheses and possible mechanisms; iv) identify learning issues; v) self study; vi) re-evaluation and application of new knowledge to the problem; vii) assessment and reflection on learning [15].

The efficiency of PBL was reported in various papers, in different areas of study [9, 11, 19]. This can be explained by the fact that PBL is based on four modern insights into learning: constructive, self-directed, collaborative, and contextual [11]. Nevertheless, there are also some researchers who take a more critical stand towards PBL [1, 8], outlining various disadvantages: i) students may have gaps in their cognitive knowledge base and not demonstrate expert reasoning patterns; ii) PBL can be very costly; iii) PBL may have a robust positive effect on skills but a negative effect on knowledge [11]. Therefore, in our master program we decided to apply a blended approach, combining traditional lectures with PBL scenarios, thus aiming to take the best of both worlds.

The next section describes the practical application of PBL for Green SCIT, outlining the key topics and the actual problems that are proposed to the students. The objectives of the course were divided into milestones, which were transformed in self-contained problems [20]; each problem raises concepts and principles relevant to the content domain and at the same time is highly motivating to the students.

3 Problem-Based Learning for Green SCIT

3.1 Green IT, Systems and Control

The rising importance of IT and pervasive computing on everyday life renders the IT sector contribution to greenhouse gases a topic of major interest. Indeed, the emissions due to IT are projected to increase from 3 % of total global emissions (CO_2 equivalent) in 2009 to 6% by 2020. This figure shall be balanced by the potential use of IT to create a low carbon society, as this sector could lead to emissions reductions five times larger than its own contribution [21].

The analysis of systems and global control strategies typically provide a framework to monitor and optimize large-scale plants for a reduced consumption based on IT solutions. A significant contribution to sustainable development can thus be brought by educating systems and control engineers with a specific sensitivity for Green IT applications. While this field is particularly broad, specific topics can be selected to illustrate some key applications. They can be classified as: i) sustainable power generation; ii) efficient use of energy at the industrial level; iii) efficient use of energy at the domestic level; iv) anthropogenic impact on the environment.

Each of these topics is illustrated by an application where SCIT plays a major role and which motivates the students' involvement in the next subsections.

3.2 Sustainable Power Generation: Tokamaks Modeling and Control

Controlled thermonuclear fusion is a topic of prime interest as a source of sustainable energy, which could possibly compete with classical fission reactors in terms of efficiency and as a key process to produce energy. In the forthcoming years, the main challenge for the fusion community will be to develop experimental scenarios for the tokamak ITER[2] (International Thermonuclear Experimental Reactor, the largest fusion process ever built and with a first run planned for 2018). From the SCIT point of view, a tokamak is a complex process with multiple interconnected dynamics, several (possibly conflicting) control objectives, a large number of sensor signals to handle and challenging objectives in terms of real-time control.

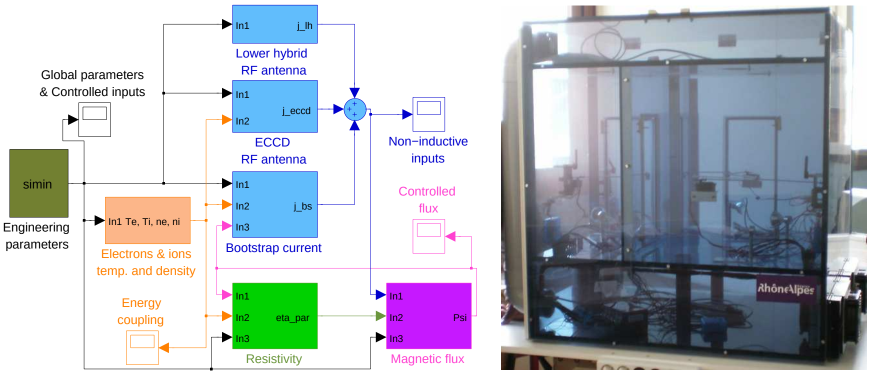
While implementing the students' controller on a real tokamak would not be feasible, two PBL topics are proposed in the master program: the real-time modeling of a complex system and the optimization of a feedback source. For each lab, a technical document describing the main physical processes is provided to the students, along with an experimental data set[3]. As numerous concepts in this document relate to specific knowledge in fusion engineering, students have to complement their understanding with web resources or questions to the professor. The requested outcome is to provide an input/output description of each subsystem, identify the interconnections and the specific challenges addressed in an integrated approach. Once each student gained a sufficient level of understanding of the process, the class is divided in groups of two to work on specific topics. Collaborative work is emphasized in one lab, where each group has to design a *Simulink*® model for a specific subsystem. The groups have to interact in order to get the appropriate specification and format for the interconnection variables, the ultimate goal being to assemble the blocks designed by each team in a global *Simulink*® tokamak model, presented in Fig. 1(a).

3.3 Green Buildings and Networked Intelligent Systems

The concept of green (or sustainable) buildings implies the efficient use of energy and water resources to reduce the impact of the built environment on humans' health and natural environment. To fulfill this goal, intelligent buildings control is seen as a key solution that raises several research problems of immediate actuality, such as wireless automation and control of complex interconnected system. An interesting case study is provided by [7], where the potential energy savings obtained by a connected workspace product (fully relying on IT solutions) are estimated to be up to 44 %. Another case is related to the ventilation system, with potential significant improvements both in terms of user's comfort and energy savings.

[2] `http://www.iter.org`

[3] A collaboration with Tore Supra tokamak, operated by the Commissariat à l'Énergie Atomique - Institut de Recherche sur la Fusion Magnétique (CEA/IRFM at Saint Paul lez Durance, France), provides some real data set for teaching purposes.



(a) Tokamak Simulator (b) UFAD experiment

Fig. 1: Examples of PBL applications for green SCIT: sustainable power generation (tokamak) and intelligent buildings (UFAD).

The topics related to SCIT include protocol design for large-scale networking, wireless sensing and actuation capabilities, networks security, embedded control design and centralized energy optimization. More specific problems (e.g. associated with the ventilation problem) also necessitate control-oriented models and robust multiple-input multiple-output regulation strategies. A reduced-scale experiment, presented in Fig. 1(b), has been built at UJF to illustrate the main associated automation problems. Three different PBL projects are set along these lines.

The first project is focused on under floor air distribution (UFAD), which was highlighted as a particularly efficient solution in comparison with traditional ceiling-based ventilation systems [6]. Successive projects contributed to the design of the UJF experiment. The general tasks for the students are to propose simplified physical models for this system, identify the model parameters from the measurements and design some feedback regulation schemes.

The second project considers wireless sensor networks, with the real-time tuning and application protocol synthesis for a wireless controller PAN (Personal Area Network) based on the IEEE 802.15.4 MAC (Medium Access Control) layer. These protocols are set on ZigBee motes that contribute to the UFAD experiment by providing temperature measurements and actuating the fans.

The third project aims at producing green resources using the building architecture. People environment in cities is then improved thanks to an appropriate exploitation of the available space and resources to grow different kind of plants in an energy-efficient way. Within this framework, a specific solution has been proposed by the *vegetalworkshop* team[4] to grow up plants on Grenoble library.

[4] `http://www.vegetalworkshop.com`

3.4 Domestic Energy Savings: the Heat Pump Automation

The heat pump extracts energy from the outside air to provide it for domestic heating. This process allows for significant energy savings and is thus a key issue for the development of sustainable energies at the domestic level. This topic motivated specific scientific research. Modeling concerns can be tracked back to the beginning of the 1980's, following the energy crisis of the 1970's. More actual concerns are focused on simulation and control issues [13].

The aim of the related PBL task proposed to the students is to investigate new automation solutions for the minimization of heat pumps energy consumption thanks to real-time feedback operation. This automation is based on distributed sensing capabilities, networked sensors, physical modeling for the process automation design and real-time feedback control.

3.5 Anthropogenic Impact and the Ozone Depletion Problem

Among other trace gases, CH_3CCl_3 (1,1,1-Trichloroethane, used as a solvent for organic materials and as an aerosol propellant, for example) has been identified as responsible for the ozone layer depletion effect. Many applications have been identified as harmful for health in 1970 and CH_3CCl_3 was completely banned in 1996 by the Montreal protocol (when its ozone depleting effect was identified). Trace gas (small concentration in the atmosphere) measurements in interstitial air from polar firn (permeable snow in the top 50-100 m of the polar cores) allow to reconstruct their atmospheric concentration time trends over the last 50 to 100 years. This provides a unique way to reconstruct the recent anthropogenic impact on atmospheric composition (see e.g. [24] and references therein).

The PBL task proposed on this topic illustrates the importance of SCIT for the reconstruction of CH_3CCl_3 history based on a gas transport model, atmospheric scenario and firn measurements. The data set and a transport model are given to the students[5]. The conclusions of this lab illustrate the need of SCIT analysis tools to provide reliable information out of sparse measurements.

4 Motivating High School Students to Join Science

A one day visit for a class of high school students from Lycée Barthélemy-de-Laffemas (Valence, France) was proposed at UJF. Several activities were organized, such as doing a physics lab and visiting the experimental areas of research and education labs. A connection with the PBL projects presented above was done with short presentations from the master students to the high school visitors. Each group of master students was asked to prepare a twenty minutes talk with an experimental demonstration (when applicable), intended for a large audience.

[5] provided by the Laboratoire de Glaciologie et Géophysique de l'Environnement (LGGE, Grenoble, France) and by GIPSA-lab, respectively.

The high school students were very enthusiastic about this experience, both for being included in a multi-cultural class (nine nationalities were composing the class, with non French-speaking students) and for the topics that were presented. This experience gave them a refined idea of the university life and of the possible achievements at the end of the curriculum. They were impressed by the possible realizations of the master students and it increased their interest for long scientific studies. The master students also gave a positive feedback, as they felt directly involved in the science transmission task. They got into numerous informal discussions with the high school students concerning their PBL topics, personal curriculum and life as a student.

While the proposed framework cannot be extended to a large number of students, it allowed for specific interactions beyond the classical teacher/student relationships. The interest for scientific studies of the involved group of young people was clearly raised and such experience ought to be repeated in the forthcoming years.

5 Discussions and Conclusions

5.1 Lessons Learned

The green orientation of SCIT brought with the PBL approach was very successful to motivate the students to get involved into the class and to compensate for their natural hesitation to address complex and not necessarily well-defined problems. This was especially true for specific students with low to middle interest in the theoretical aspects who could thus compensate with outstanding reports. The diversity of the lab topics led to the success of different students on different topics, which was valuable both for the class motivation and for providing future references to potential employers. Indeed, a well structured report on an innovative topic was particularly efficient to trigger an employer's interest for some students.

While the students were able to get substantial results on the projects (running on one semester), the labs on advanced green topics (such as tokamaks) were difficult to adjust to the allocated time (two times three hours per lab on the average). Support from corrected homework and mid-lab reports helped to overcome this difficulty. On the other hand, team-working aspects and project management appeared as the major difficulties in the projects.

The choice of several specific topics in the green-SCIT field (especially with the building-related projects) generated stimulating discussions between the groups that did not necessarily occur with groups on different topics (a project on robotics was also proposed). The interest for green applications extended to other classes, where some students chose related topics on their own (such as the talk for the speech class). The presentation from master to high school students was a particularly rich experience to motivate master students to convey their findings and understanding to non-specialists in the field.

A difficulty observed with the proposed PBL approach was to channel the intra and inter groups communication, and to carry out the information over the years (the goal being that the students of each year build on the work achieved during the previous years). Hence, the need for providing improved communication and collaboration support, as envisioned in the following subsection.

5.2 Perspectives: Introducing Web 2.0 Support Tools

Since PBL relies on group work and collaborative generation of content (e.g., the deliverables teams have to hand in at various stages of the problem solving process), Web 2.0 tools may be seen as an appropriate support framework for communication and collaboration.

Web 2.0 is a term promoted by Tim O'Reilly [14], which designates a set of interactive and collaborative aspects of the Web seen as a platform (i.e., the applications are built on and for the Web, not for desktop). Web 2.0 brings a user-centered approach - designing applications whose content is generated by the users and therefore depend heavily on their contribution (e.g., YouTube, Flickr, Delicious). Consequently, Web 2.0 is also known as "participative Web": the user is not just content consumer but also content generator (often in a collaborative manner). Furthermore, Web 2.0 is also called "social Web": with the advent of social networks, it started offering support for users to interact, communicate and collaborate (e.g., Facebook, MySpace, Twitter). Recently, Web 2.0 tools (e.g., blog, wiki, social bookmarking systems, media sharing tools) have been introduced in educational contexts, with encouraging results with respect to student satisfaction, knowledge gain and/or learning efficiency [16]. This is motivated by the fact that the principles Web 2.0 is based on (user-centered, participative architecture, openness, interaction, social networks, collaboration) are in line with modern educational theories such as socio-constructivism.

In this context, it is only natural to rely on Web 2.0 tools for providing the collaborative framework for PBL. Indeed, several authors have emphasized the inherent alignment between PBL and Web 2.0 technologies and reported successful experimental results in Health Science education ([12], [5]), but also in Telematic Engineering education ([15]). We believe that the approach will prove successful also in Green SCIT studies and we aim to introduce it in our master program.

More specifically, the collaborative learning scenario that we envision involves the following Web 2.0 tools:

- A blog for communicating between team members, for discussing and analyzing the problem, for planning actions and sharing experiences. This could be supplemented by a microblogging tool (e.g., Twitter) for the exchange of shorter messages (with wider and immediate availability, as they can be sent and received also by SMS).
- A social bookmarking tool for finding online resources relevant for the problem at hand and sharing them with the team
- A wiki for gathering and organizing learning resources, for collaboratively constructing the solution as well as for co-writing the team deliverables.

Thus, the face-to-face lab sessions will be supplemented by asynchronous collaboration; students will be able to contribute from remote locations, at the time and the pace they choose. This flexibility is particularly important in case of master students, who often hold part-time jobs. Students' activities and progress will be recorded in the blog and wiki - thus the instructor will be able to continuously monitor students' problem solving steps, observe group dynamics and provide feedback and guidance when needed. Furthermore, the teacher has the opportunity to see not just the final deliverable, the end product of the collaboration, but the whole process of tackling the problem, enriching the assessment potential [5].

As far as the technical solution is concerned, there are several possible approaches: i) use stand-alone Web 2.0 tools on top of the course framework (as in [5]); ii) use a learning management system (LMS) with integrated Web 2.0 applications (e.g., Moodle as in [12] or .LRN as in [15]); iii) use a dedicated social learning environment, which integrates all the required Web 2.0 tools, together with additional support for both learners and teachers (e.g., eMUSE [17]). We are currently investigating the integration of the latter solution within the master program framework.

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