MODELLING AND CONTROL OF REFRIGERATION SYSTEMS: AN ACCOUNT OF A PEDAGOGIC EXPERIMENT IN A POST-SECONDARY TECHNICAL COURSE

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Abstract *Traditional post-secondary technical training focuses on laboratory work, on hands-on experience, rather than on conveying theoretical knowledge. However, theoretical knowledge is and will remain an important asset for technical professionals working in the refrigeration industry. This paper presents an account of a pedagogic experiment in which advanced analytical methods and scientific computational tools were used in a post-secondary technical course to study the modelling and control of refrigeration systems. Targeted learning outcomes, topics taught, computational tools used, and the way topics and tools were aligned to meet the learning outcomes are described. Results gathered between 2012 and 2015 showed that the use of advanced topics to model simple thermal systems and simple control systems is possible in a post-secondary technical course. It is argued that levelling up the contents in post-secondary education to match those presented in higher education contributes to a better understanding of the challenges of higher education, and, for students that ponder enrolling in higher education, contributes to better informed decision making. If the growth in refrigeration industry is taken into account and considering future needs for skilled refrigeration professionals, introducing students of post-secondary technical courses to analytical methods and computational tools used in higher education could, for some students, trigger the decision to enrol in higher education, leveraging the number graduates in refrigeration/ engineering bachelor programmes.*

Keywords: Post-secondary education, higher education, refrigeration, modelling, control.

1. INTRODUCTION

The refrigeration industry is “healthy” and, according to market research studies [1], increasing sales are foreseen for most markets. Factors determining increasing sales forecasts are diverse, but The Montreal Protocol on Substances that Deplete the Ozone Layer, stringent standards of hygiene and food safety, socio-economic and cultural changes leading to larger food sales and the proliferation of refrigerated vending machines and display cases, are certainly fuelling progress in the refrigeration industry. The success of the Montreal Protocol and the phase-out of ozone-depleting substances worldwide contributes to the conversion of existing equipments and often to replace obsolete systems, pushing demand for repair services and for new equipments. Stringent standards of hygiene and food safety also push demand for better, more effective and more energy efficient refrigeration systems, again, supporting conversions or replacements. Socio-economic and cultural changes that increase food sales and promote eating everywhere and at all times [2] is also possible because of refrigeration technology. The number of refrigerated vending machines and display cases will continue to grow and, to support increasing food sales, the whole refrigeration network — from domestic appliances to logistic warehouses, and including transportation — will need to grow too.

Considering the expansion of the refrigeration industry worldwide, it is obvious that training needs in refrigeration will increase. Careful planning is required from national education agencies to assure not only that the appropriate number of professionals is trained, but also that the appropriate balance between professionals with post-secondary and higher education is achieved.

In Portugal, with the turn of the century, the need to increase human capital justified several changes in education policy. One of these changes was the investment in post-secondary technical courses targeted at students completing secondary education. These courses were designed to deliver advanced knowledge and skills, allowing increased autonomy, the ability to design, supervise or manage in different technological areas [3]. To promote a smoother transition between post-secondary technical education and higher education, higher education institutions from the Portuguese polytechnic subsystem were asked to include post-secondary technical courses in their portfolio, along with the traditional bachelor and master degrees.

At the Polytechnic Institute of Setubal (IPS), in Portugal, several post-secondary professional courses were taught, including one course dedicated to refrigeration and air conditioning systems, named EPSRC (Portuguese acronym for *Estudo e Projeto de Sistemas de Refrigeração e Climatização*). Traditionally, the pedagogic strategy used in post-secondary technical courses emphasises practical learning with plenty of hands-on experience and plenty of laboratory work; this strategy was used in the EPSRC course. However, since the course was taught in a higher education institution, it was decided to include, within the Refrigeration unit, a 30 hours module on modelling and control of refrigeration systems. This module introduced advanced analytical methods and scientific computational tools such as state space representation and Matlab/ Simulink, allowing a better understanding of the dynamic behaviour of simple thermal systems and control systems.

The objective of this paper is to report the pedagogic experiment associated with the Modelling & Control module included in the Refrigeration unit of the EPSRC course. The paper starts with a generic characterization of the EPSRC course and of the Refrigeration unit, followed by the detailed description of the Modelling & Control module. Results gathered during three academic years and for more than 60 enrolled students are then presented and discussed. Finally, conclusions about the feasibility and advantage of including advanced topics in postsecondary technical courses are drawn.

2. THE EPSRC COURSE AND THE REFRIGERATION UNIT

The EPSRC course is a 60 ECTS [4] course targeted at high school students that wish to take technical training in Refrigeration and Air Conditioning. The course is divided in generic and scientific units, such as English, Business Management or Mathematics; in technological units, which include Thermodynamics and Refrigeration; and an internship worth 40% of the total course workload is mandatory. Table 1 details the structure of the EPSRC course. For all units of the EPSRC course only a small amount of the workload is performed autonomously; students spent most of their studying/ working time either in face-to-face expository lessons (50%) or performing supervised laboratory work (50%).

Table 1: EPSRC course units, corresponding ECTS credits and estimated workload.

Unit name	ECTS	Workload [h]
Mechanical Drawing	3	81
Technical Drawing	3	81
English	1	27
Organisational Behaviour	1.5	40.5
Business Management	1	27
Mathematics	1	27
Mechanics	1	27
Shop Floor Operations Management	2	54
Materials	3	81
Thermodynamics	5	135
Fluid Mechanics	4.5	121.5
Heating and Air Conditioning	5	135
Refrigeration	5	135
Internship	24	648
Σ =	60	1620

Regarding the Refrigeration unit, core topics included, first, the presentation of main components of refrigeration systems, refrigerants, control equipment and, secondly, the presentation of different types of refrigerated appliances and systems for domestic, retail, transport and industrial use. Core laboratory activities included: disassembling and reassembling different types of compressors, brazing of refrigerant lines, monitoring and analysing a refrigerated chamber and a dairy products display case. The photograph in Figure 1 depicts students of the EPSRC course during a Refrigeration laboratory.

3. THE MODELLING & CONTROL MODULE

Since core topics of the Refrigeration unit included control equipment it was recognised that promoting students contact with an advanced computational tool such as Matlab/ Simulink would allow a better understanding of the dynamic behaviour of simple thermal systems and of control systems. It was therefore decided to develop within the Refrigeration unit a 30 hours module (22% of the total unit workload) dedicated to modelling and control of refrigeration systems. The fact that the Refrigeration unit was taught in the latter stage of the EPSRC course, prior to students' internship, also meant that skills from previous course units could be used in the Modelling & Control module.

Figure 1: Students working in a Refrigeration laboratory.

The Modelling & Control module represented a challenge to many students; because it implied that students would have to level up to match analytical requirements of higher education. However, from the first instant it was also recognised that students would benefit from the opportunity to use and integrate topics presented previously (for example, linear algebra, mass and energy balances), and also from learning new analytical methods and powerful computational tools. The final goal of the module was to model and study the dynamic behaviour of a didactic refrigerated chamber used by students in refrigeration laboratories. To achieve this goal five sequential learning outcomes were established:

1. Represent simple thermal systems using electrical analogues and linear graphs [5];
2. Derive the constitutive and (energy) balance equations that describe the dynamic behaviour of thermal systems [6];
3. Derive the state space representation of thermal systems [7];
4. Use Matlab/ Simulink to obtain the dynamic output of thermal systems [8];
5. Use Matlab/ Simulink to model a control system and obtain the dynamic output of controlled thermal systems.

To achieve these learning outcomes, along with topics presented in previous course units, new topics had to be introduced. Table 2 presents an alignment chart relating learning outcomes with topics introduced in the Modelling & Control module and with topics recovered from previous course units.

4. RESULTS

The pedagogic solution described in the previous section was used in three consecutive editions of the EPSRC course, from academic year 2012-13 to academic year 2014-15. In total 66 students enrolled in the course during this period, approximately 22 students per academic year.

Of the total 66 students that enrolled some dropped out (failing in several course units), some had to resit course units in 2015-16 and haven't yet completed the course, but the majority has successfully completed the course. A significant number of those that completed the course made the decision to enrol in an engineering bachelor (BSc; 180 ECTS) programme at IPS.

Table 2: Alignment chart relating topics taught to learning outcomes of the Modelling & Control module.

	Learning outcome				
Topics included in the Modelling & Control module	**1**	**2**	**3**	**4**	**5**
Capacitance; elements that store energy	X				
Electrical analogues of thermal systems	X				
Linear graphs of thermal systems	X				
Deriving constitutive and (energy) balance equations from linear graphs		X			
Obtaining state space representation from constitutive and balance equations			X		
Using the state space representation and Matlab/ Simulink to model thermal systems' dynamics				X	
Using Matlab/ Simulink to model controlled thermal systems' dynamics					X
Contributions from other EPSRC course units					
Mathematics (linear algebra)			X		
Thermodynamics (mass and energy conservation)		X			
Fluid mechanics (continuity equation; (extended) Bernoulli equation)		X			
Heating and Air Conditioning (thermal resistance; electrical analogues)	X	X			
Core topics of Refrigeration unit (refrigeration systems and control equipment)				X	X

Learning outcome 1: Represent simple thermal systems using electrical analogues and linear graphs.
Learning outcome 2: Derive the constitutive and (energy) balance equations that describe the dynamic behaviour of thermal systems.
Learning outcome 3: Derive the state space representation of thermal systems.
Learning outcome 4: Use Matlab/ Simulink to obtain the dynamic output of thermal systems.
Learning outcome 5: Use Matlab/ Simulink to model a control system and obtain the dynamic output of controlled thermal systems.

Figure 2 presents a visual snapshot of the status of the EPSRC students at the end of the 2014-15 academic year.

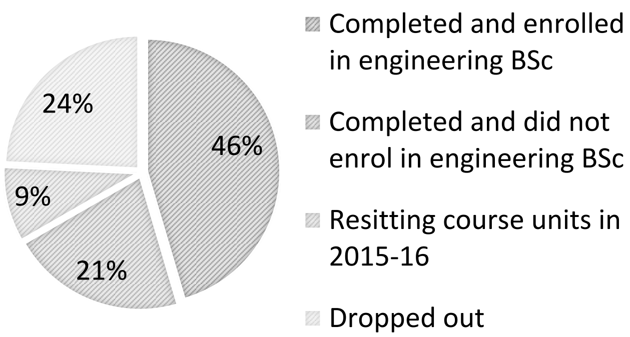

Figure 2: Percentages of students per status (completed the course and enrolled in an engineering BSc, completed the course and did not enrol in an engineering BSc, resitting course units in 2015-16, dropped out) at the end of the 2014-15 academic year.

Figure 2 shows that two thirds (46+21=67%) of the students successfully completed the course. This number could still increase to 76% by the end of 2015-16 academic year, if the students resitting course units are successful. Figure 2 also shows that almost half of the students (46%) enrolled in a BSc programme at IPS, typically Mechanical Engineering (90%), but also Electrotechnic Engineering (10%).

When it comes to students' grades, Figure 3 compares each student grade at the Modelling & Control module with the grade obtained for core topics of the Refrigeration unit.

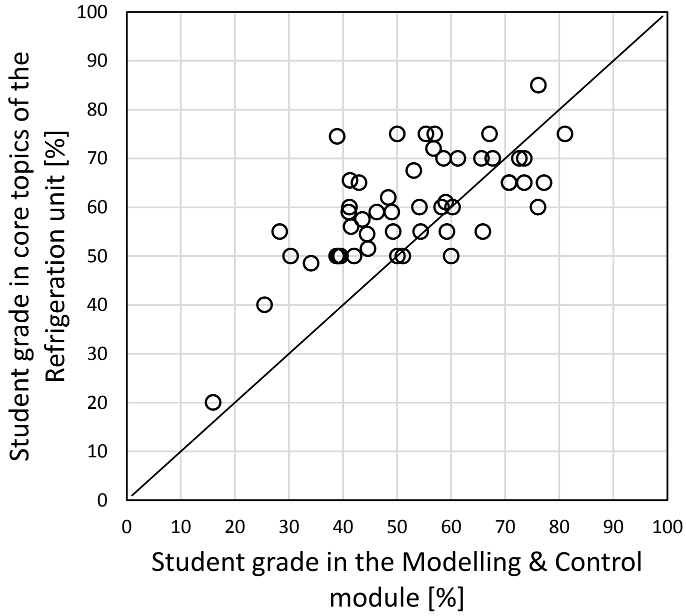

Figure 3: Students' grades at the Modelling & Control module versus students' grades for core topics of the Refrigeration unit.

From Figure 3 it is concluded that for modelling and control the majority of the grades are higher than 50%, however, the number of grades between 40 and 50% is also significant. On the contrary, grades for the core topics of refrigeration are seldom below 50%. In spite of lower grades in modelling and control, Figure 3 shows that a moderate correlation (R^2 approximately 0.5) exists between grades; this proves that most students that had difficulties with the Modelling & Control module also had difficulties with the core refrigeration topics.

5. DISCUSSION

The introduction of advanced topics in the Refrigeration unit of the EPSRC post-secondary technical course picked up and expanded topics presented in different course units and allowed the use of advanced analytical methods and the Matlab/ Simulink computational tool. Based on results from three academic years, the pedagogic solution used was considered appropriate. The majority of the students was successful in the Modelling & Control module (with grades above 50%) and, although grades were generally lower than those for the core topics of the Refrigeration unit, major unbalances weren't found. Moreover, since the Modelling & Control module represented only 22% of the total ECTS of the Refrigeration unit, many students were able to use their skills in core refrigeration topics to make up for difficulties in modelling and control, and passed the Refrigeration unit.

Results also show that almost half of the students that completed the EPSRC course enrolled in a BSc programme in IPS (mostly mechanical engineering). Upon completion of their studies, these students will become engineers skilled in topics of refrigeration.

It is not possible to quantify the contribution of the Modelling & Control module to students' decision to enrol or not to enrol in higher education. Many factors influence this decision [9], including factors external to the academic environment (e.g., financial), however, it is possible to say that the Modelling & Control module was successful in allowing students to better understand the methods and tools used in higher education and, contributed to more informed decision making. It is also fair to conclude that for students that completed the course but chose not to enrol in higher education, the modelling experience and the use of Matlab/ Simulink will probably prove useful in their future professional career.

6. CONCLUSION

Traditionally, post-secondary technical education emphasises hands on experience; more advanced theory and computational tools are frequently missing in the syllabus of course units. At IPS, and in the Refrigeration unit of the EPSRC course, it was recognised that students of post-secondary technical education should be given the opportunity to understand some of the challenges facing students enrolled in undergraduate engineering courses. More advanced modelling and control topics were included in the syllabus of the Refrigeration unit and advanced analytical methods and computational tools were taught.

From the results presented it is concluded that with careful integration of topics taught in different units, with a more in depth study of electric analogues, linear algebra and with the introduction of the Matlab/ Simulink tool, it is possible to successfully model the dynamics of simple thermal systems and control systems in post-secondary technical courses.

Considering future needs for skilled refrigeration professionals, the introduction of advanced analytical methods and computational tool in post-secondary education could, for some students, trigger the decision to enrol in higher education, leveraging the number graduates in refrigeration/ engineering bachelor programmes.

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