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Programming skills in the industry 4.0: are chemical engineering students able to face new problems?

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ABSTRACT

A reflection on teaching programming at undergraduate level using advanced tools is presented. Advanced digital tools and computational evolution have shaped different areas, such as industrial process, communications, education and innovation. New technologies, such as the Internet of Things-IoT, cloud computing and artificial intelligence, have boosted software development and computational skills in different areas. The chemical engineering knowledge acquired by senior students and programming skills can be integrated to develop computational tools, favoring chemical engineers to take advantage of new opportunities in digital area. Normally, programming courses are offered at the beginning of chemical engineering program, with examples not related to chemical engineering problems. To fill this gap, an elective discipline was created for final year undergraduate students in the Department of Chemical Engineering at University of São Paulo (Brazil). This paper discusses the main motivations for a new programming course, presents the structure of the course and shows some outcomes from a students' survey about what they have learned.

1. Introduction

According to the Institution of Chemical Engineers (IChemE) blog, computing skill is among the top ten skills chemical engineers should be talking about (Maitland, 2014). Indeed, in the current information society, new computational technologies such as cloud computing, artificial intelligence, development of advanced materials, advanced analytics, big data and robotics, have largely impacted the job market, industrial production, social relationships, health, security, commerce, research and development and education. The so-called "Internet of Things-IoT", the connecting of sensors, devices and equipment to the network, is a major trend with significant implications for the global economy, including manufacturing, mining, agriculture and oil & gas (Daugherty et al., 2015). Advanced levels of digital tools are one of the core features of the so-called Industry 4.0, known as the next phase in the digitization of the manufacturing sector. Manufacturers have frequently prioritized digital performance management, real-time supply chain optimization, digital quality management, remote monitoring and control, predictive maintenance, and smart energy consumption (McKinsey Digital, 2016). These issues concern the chemical industry and in this context, the role of teaching programming and the opportunities for chemical engineers are discussed.

2. Background

From the pioneering initiatives to teach programming to children (LOGO: http://el.media.mit.edu/logo-foundation/index.html and Scratch: scratch.mit.edu in MIT) up to the recent initiatives like Code Club, Codeacademy and Code.org, supported by companies such as Google, Microsoft and Amazon, non-profit campaigns have encouraged people to get coding and have expanded access to computer science (codeclub.org.uk, codeacademy.com, code.org). In the UK, a programming curriculum in all primary and secondary schools is now mandatory (https://www.gov.uk/government/publications/national-curriculum-in-england-computing-programmes-of-study).

Thus, if children aged 5-16 years old are getting used to code, why not to re-think teaching programming and programming skills for chemical engineering students? Indeed, the main argument against the popularization of teaching programming used by IT experts and followed by the LINUX creator (Linus Torvalds) is that coding requires high-level logical reasoning and ability to solve complex problems, skills that are not inherent to everyone (Geraldes, 2014). However, as chemical engineering students are

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expected to cover both skills, programming should be encouraged in chemical engineering curriculum.

Important discussions about teaching programming for chemical engineering students have already been made. Kassim and Cadbury (1996) concluded that while the value of teaching programming in an engineering degree may fairly be questioned, it does have a place, promoting a logical and disciplined approach to design in general. More than ten years ago, Coronell (2005) argued that three-quarters of entry-level chemical engineers were not expected by their employers to be competent in any programming language. Rather, they were expected to use commercial software solutions supplied by vendors (Coronell, 2005). Integrating chemical engineering knowledge with advanced programming skills can open opportunities in the current digital era. We also think that chemical engineering education can transform market rather than simply respond to market demands.

It is sometimes believed that it is best to teach Microsoft Excel and Visual Basic for Application (VBA) programming to chemical engineering students, rather than an object based programming language. Favoring Excel environment to learn programming skills is due to student's existing familiarity with Excel and its common use in industry (Wong and Barford, 2010). However, the role of education is to widen student's skills rather than limit them to what they are already familiar. Indeed, they are not familiar with thermodynamics or transport phenomena when they begin the course. We believe that presenting modern and advanced programming tools to students can open opportunities for those who have, or want to have, programming skills. Also, among the skills normally associated with learning programming, there are: autonomy to solve problems, collaboration, systematic reasoning, planning and creativity. Thus, programming has an important role in the chemical engineering formation, not only by allowing coping with technical problems but also stimulating those competences that are required in the young professional.

The present work describes the first experiences and reflections about the creation of an elective course called "Advanced Programming for Chemical Process" for senior undergraduate students in the Department of Chemical Engineering at University of São Paulo (Brazil). In the first offering, nineteen students attended the course.

3. Learn to program. Program to learn

Although teaching programming is common in the early periods of many engineering courses, there is a great difference between teaching programming in the first periods and at the end of the undergraduate level. In the early periods, they have not yet been in contact with the disciplines of their specialization. In the chemical engineering case, these disciplines concern mainly transport phenomena, thermodynamics, reactors engineering and unit operations (TTRU).

In the chemical engineering undergraduate course at USP, the first (and probably the only) contact with programming was in the first semester using Python language. This course is offered by the Department of Computer Science within the Institute of Mathematics and Statistics. Thus, the students have contact with programming in a period in which they have not been introduced to the basic problems in TTRU. A similar issue was also discussed by Wong and Barford (2010). These authors observe that programming courses delivered to all engineering disciplines have examples that are disciplinary neutral and not related to chemical engineering problems. The creation of the programming discipline at USP aims to fill this gap.

The program to learn approach, *i.e.* the development of educational tools to teach TTRU is more common in the chemical engineering education literature. Cartaxo et al. (2014) show the development of an educational software for the transient analyses of shell-and-tube heat exchangers using Delphi language. Granjo et al. (2012) describe the development of a virtual platform to teach separation processes (Distillation, Extraction, Absorption and Adsorption) using mainly Matlab®, FORTRAN, Octave and Java™. The work of Cartaxo et al. (2014) is independent of proprietary tools and the work of Granjo et al. (2012) has web interface. Other examples are software to teach heat exchanger network design (Martin and Mato, 2008), thermodynamics (Castier and Amer, 2011; Martin et al., 2011) and process control (Rahman et al., 2013; Ospino et al., 2017). Also, numerous works use Excel/VBA spreadsheets approach (Coronell, 2005; Wong and Barford, 2010; Castier and Amer, 2011). In these works, programming is a means of teaching.

Concerning the teaching of programming, two questions arise: a) Are the students getting computational skills to solve Chemical Engineering problems or they are just getting used to the syntax of a particular programming language in the early stages of the chemical engineering curriculum? b) Once the students have studied TTRU, do they have the opportunity to face TTRU problems with advanced programming skills? In order to fill the gaps revealed by these questions, the "Advanced Programming for Chemical Process" course was implemented with two basic characteristics: at the end of the undergraduate course and as elective course. Fig. 1 illustrates how programming courses can appear in the students' chemical engineering undergraduate course: as a basic programming course in first year, with the use of educational softwares and as a senior elective course. This last one is indicated as a course that offers to the student the opportunity to develop their own programmes to deal with TTRU problems in the professional cycle. Q2

The "Advanced Programming for Chemical Process" course was created in 2015 and its structure, evaluation methodology and students' perception are detailed in the next sections. It must be noted that the first year course remains fundamental to introduce students to basic algorithms concepts. The proposed Advanced Programming course do not to intend to replace the first year course, but rather to serve as an (optional) opportunity to students with computational interests.

Also, a first course on programming has the advantage of teach students with basic concepts that will be useful to several applications throughout their studies of separations, reactions, and thermodynamics and so on.

4. Course structure

The course is offered as an elective discipline in the last year of the chemical engineering undergraduate program and it comprises a total of 60 h (four months long). It comprises lectures and practical classes in the informatics laboratory (50%/50%). Students' final grades are composed of exercises and three computational problems given as exams. These exams have one week as a deadline to be finished. The course is divided in Fortran and Structured Programming (45%), Object-Oriented Programming (45%) and exercises in the EMSO software (10%). These percentages correspond to the total of lectures and practical classes.

4.1. FORTRAN

4.1.1. Why FORTRAN is still important

The Fortran (FORmula TRANslation) language has held and it still holds a dominant position in high-performance computing software (Haveraaen et al., 2015). FORTRAN was developed in the 50 s for numerical tasks. The first version to be used in engineering was FORTRAN 4, but it was the 70 s version (FORTRAN 77) that was largely used. Several commercial software were developed in FORTRAN, such as Phoenics, Aspen Plus and CFX. Although many people