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Statistical analysis of undergraduate chemical engineering curricula of United States of America universities: Trends and observations

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ABSTRACT

Chemical engineering (ChE) is a historically-relevant degree that is experiencing an emergence of diverse research and industrial trends. However, adapting to them is a challenge, because the overloaded nature of the ChE curriculum makes adding new courses, without removing older ones, difficult. The problem is further exacerbated by the need to justify any modifications to various university committees while satisfying accreditation organizations' criteria. With the ultimate goal of guiding and/or justifying potential curricular changes, this manuscript presents a thorough statistical analysis of the current state of the ChE curricula in the United States of America (USA). Specifically, publically-available undergraduate degree sheets are aggregated from the majority of established ChE departments in the USA, and subject-specific descriptive statistics are reported for core ChE courses. Among the significant findings are two different approaches to teaching *Transport Phenomena*, the rise of *Bio*, and the scarcity of traditional *Statics and Strength of Materials* and *Process Safety* courses. Ultimately, the results of this study are intended to be used by the other departments interested in improving their curriculum.

1. Introduction

Chemical engineering (ChE) education is becoming increasingly relevant among the other engineering disciplines in the United States of America (USA), according to Fig. 1. As the world around us continues to evolve more rapidly than ever, the ChE profession gets exposed to an emergence of evermore diverse and vibrant sub-specialization trends (Varma and Grossmann, 2014): several examples include the growing demands for energy (including biomass-based fuels), environment, sustainability, entrepreneurship and the integration of the traditional chemical processes with biotechnology (Gavrilescu and Chisti, 2005; Erickson et al., 2012; Kiss et al., 2015). While some of these trends are driven by industry, the shift in ChE from commodities in the 1970s to products in the 1990s being a prominent example (Cussler, 1999); the others may originate within academia, as is the case with the emergence of biologically-oriented ChE that began roughly in the second half of the 20th century, and was inspired by the pioneering works in the fields of pharmaceuticals and bioengineering (Varma and Grossmann, 2014).

Yet, despite the numerous proposed curriculum renovations (Armstrong, 2006; McCarthy et al., 2006, 2005), most of the *core* ChE course-sequence has remained static (Armstrong, 2006) since its initial inception and consequent development between 1905 and 1965. Likewise, the industrial employment of the ChE professionals has remained largely traditional also. For instance, the USA biotech sector revenue is esti-

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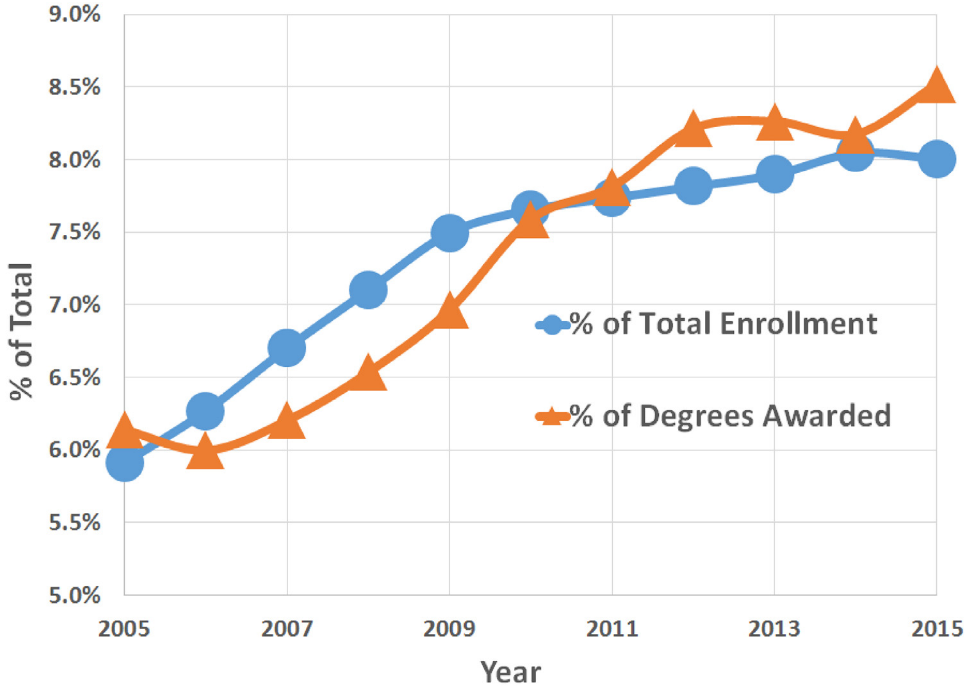

Fig. 1 – Chemical engineering as percent of USA total undergraduate engineering enrollment (circles) and of total undergraduate engineering degrees awarded (triangles). Data from Ref.# Yoder (2014).

mated to have grown on average >10% each year over the past decade—much faster than the rest of the economy (Carlson, 2016). Yet, the relative number of ChEs working in this sector, versus those in the traditional industries, has remained steadily below 10% over the past decade (Bryner and McCreight, 2015). So, the stagnation of the curriculum may be limiting the options of ChE graduates arriving into the work-field.

Therefore, it is apparent that maintaining the degree up-to-date with the current industrial and research trends is critical to providing its students with the necessary technical skills for being competitive in the future work-force. However, as history has shown, proposing a complete overhaul is not effective. This is likely because justifying such major changes to Accreditation Board for Engineering and Technology (ABET—a non-governmental organization, which accredits post-secondary education programs in "applied science, computing, engineering, and engineering technology" in the USA and 30 countries worldwide; similar to IChemE accreditation for non-USA countries) reviewers, and various university committees, is unrealistic. The curriculum refinement is further complicated by the fact that even a task as simple as adding new courses is challenging due to the overloaded nature (i.e., very little room for additional courses) of the degree.

Alternatively, a better strategy is to "surgically" swap some outdated courses for more modern topics, like biology and energy. However, even removing the formers also requires substantial justification, because maintaining consistency with the rest of the universities is considered imperative. Yet, there is a lack of data sources available for guiding the curriculum committees' decisions and facilitating their justifications. After an extensive literature search, only a guide for a core curriculum content based on surveys of 21 European chemical engineering schools has been found (Gillett, 2001); while for the USA, only a survey over half a century old was found (Committee AICEEP, 1962), as well as a survey of ChE electives (Vigeant, 2014) based on responses from 96 departments, and a survey of safety courses from 26 departments was found (Dee et al., 2015). Unfortunately, none of these studies performed a comprehensive and robust comparison of the core chemical engineering with the objective of identifying general trends. Thus, without easily accessible reference sources, it is not apparent which courses can be convincingly classified as "outdated".

To that end, this manuscript attempts to provide a snapshot of the current state of the ChE curriculum in the USA by answering the following questions: "What does a representative curriculum look like currently? Are there general trends, similarities, or differences among the USA ChE curricula?" In order to address these questions, the daunting task of aggregating and reviewing the *majority* of the publicly-available curricula of established undergraduate programs in the USA was undertaken. Subsequently, a comprehensive analysis was performed, and subject-specific descriptive statistics were calculated for core ChE courses. In addition to the core courses, data concerning biology- and computation/modeling-related courses was also incorporated into the analysis due to the growing popularity of these subjects. Thus, the manuscript highlights the main findings of the performed survey, as well as observed trends/differences for various ChE courses in 148 curricula across the U.S.

2. Methods

The following is a brief introduction for the international readers to the USA college credit system, and to the related terminology used in this section:

In the USA, a "credits" system is used as an administrative indicator of a student's progress toward their degree completion: in order to graduate a student must satisfy a specified number of *total* credits. Each course that the students take is worth a certain number of credits, which is based on the amount of contact and preparation hours spent per week in