Work In Progress: Pillars of Chemical Engineering

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Abstract – Here, we discuss the development as well as the early assessment and implementation of a novel integrated curriculum in chemical engineering. This curriculum, based on block scheduling, consists of 6 main or “pillar” courses, augmented by a number of concurrent laboratory classes. The goal of this new curriculum is to foster integrated thinking beginning as early as the sophomore year, while at the same time enabling instructors to have the flexibility to utilize modern pedagogical tools. At present, the curriculum is in its pilot phase with 4 of 6 courses ongoing and corresponding assessment results being available for a subset of these. By using a world-class suite of assessment techniques including concept maps, concept inventories, and surveys, we hope to produce a truly validated success story that can serve as a model that is applicable for all engineering disciplines.

Introduction

The National Science Foundation (NSF) has funded a number of engineering coalitions[1] to study “best practices” in engineering education. Overwhelmingly, these coalitions have favored active-learning activities and integration of complementary subject materials - often combining mathematics, physics, and chemistry in freshman engineering programs[2], for example.

In our project, we expand the recommendation of the coalitions and develop an integrated curriculum that spans the upperclass years, from sophomore to senior. Our fully integrated chemical engineering curriculum is unique for its use of block scheduling[3] – a technique with a strong literature base and proven track record in K-12 education – for the first time in a traditional higher education engineering curriculum. Block scheduling, in its simplest form, is transforming multi-semester courses into a single-semester course via extended, concentrated contact time.

Adapting these two proven educational methodologies has resulted in the 6 Pillars of Chemical Engineering[4]. These courses have considerably longer contact hours than a traditional university course so that: (1) students may gain systems insight through integration[5] of their core knowledge across traditional course and discipline boundaries; (2) the instructors have the time to include truly multi-scale (from molecular to continuum to macroscopic) descriptions of chemical engineering content; and (3) the instructors have the flexibility to accommodate diverse learning styles and incorporate active learning more effectively[6].

Pillars

Current engineering instruction is often compartmentalized within a traditional 3-4 credit per course schedule, so that knowledge is disconnected and well-defined relationships are established across a curriculum only during the senior year, if at all [7]. By moving to a block-scheduled curriculum, we have integrated complementary subject-matter along with experiments and open-ended problems, so that students see connections across the discipline during each course.

The Foundations of ChE pillar course combines elements of mass and energy balances, thermodynamics, separations, and product design. This course introduces chemical engineering problem solving techniques from both a (traditional) process-centric viewpoint as well as a product-centric viewpoint. The course spans from theoretical (basic thermodynamics) to applied (separations) allowing a simple route to problem-based learning of difficult theoretical concepts.

Pillar students

The Thermodynamics pillar course combines ideas from both pure and multi-component thermodynamics. It introduces molecular insight and the tools (including commercial software) for solving both simple and complex problems in phase and chemical equilibria. The course has a strong focus on multi-scale analysis, for example, covering intermolecular potentials (molecular-scale) to aid students in choosing equations of state for novel materials (macro-scale).

The Reactive Processes pillar course integrates reactor
design, reaction kinetics, and advanced separation processes to allow the comprehensive study of systems ranging from polymerization reactors to enzyme-catalyzed metabolism to (bio-)artificial organs.

The Dynamics and Modeling class is the first of a two-part Systems Engineering pillar sequence. This course covers dynamical analysis of process systems, process control fundamentals, feedback, basic process modeling, and optimization. The second course in this sequence is the Design course which formally combines topics from all other pillars to allow both product and process design.

Assessments and Preliminary Results

Our assessment strategy differs from our traditional course assessments due to the inclusion of two new methodologies: concept inventories[8] and concept maps[9]. These techniques are aimed at evaluating, respectively, the level of gains in the core areas as well as the level of integration of knowledge attained by the students — a new goal with the revised curriculum. At present, there are no results available from the concept map measurements.

In order to assess the level of expertise attained in the core areas, and any gains that may be achieved, we are administering concept inventories (CI) [8]. Preliminary results for two of our pillar courses are available using existing CIs developed at the Colorado School of Mines (CSM)[8] in thermodynamics (See Figure 1), heat transfer (see Figure 2), and fluid mechanics (see Figure 3). Due to the current (small) size of the sampled data, percentage differences smaller than 10 are ignored.

Scaling the average percentage of questions correct by dividing by the average grade point average of the participating students – a new goal with the revised curriculum. At present, there are no results available from the concept map measurements.

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Scaling the average percentage of questions correct by dividing by the maximum possible GPA), it can be seen in Figure 1 that there was a significant improvement in over 63% of the thermodynamics concepts with an accompanying decrease in performance in only 18% of concepts when comparing one traditional class to a corresponding pillar class. Similarly, Figure 2 shows a comparison of a transport phenomena pillar to two traditional heat transfer classes. It can be seen that there was an improvement in nearly 67% of the concepts with a decrease in proficiency in only 22% of the concepts. In Figure 3, we can see that there was almost no change in ability for fluid mechanics concepts when we compare one traditional class to the transport phenomena pillar with an increase of proficiency in 31.3% of concepts and a corresponding decrease in 37.5%.

Additional concept inventories are under development for the remaining pillar courses following the procedure used by CSM[8]. These new CIs will be discussed in detail in a future communication.

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References