**The Pillars of ChE: An Integrated Curriculum at Pittsburgh**

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**Abstract**

In this paper, we discuss the development, implementation, and assessment 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. By using a world-class suite of assessment techniques including concept maps and concept inventories, we hope to produce a truly validated success story that can serve as a model that is applicable for all engineering disciplines.

# 1 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. While these integrated curricula have been used successfully at a number of institutions [3], this approach has only rarely been used outside of the first year, and, to our knowledge, had never been adapted to a full engineering curriculum. In our project, we 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 [4] – 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* [5]. These courses have considerably longer contact hours than a traditional university course so that: (1) students may gain systems insight through integration [6] 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 [7].

This new curriculum has been in use, and under active assessment, in the Department of Chemical and Petroleum Engineering at the University of Pittsburgh since 2002. In this paper, we first outline the concept and implementation of the Pillars curriculum. We follow this discussion by describing our assessment strategies and quote several interesting results. We complete the paper with an outlook to the future for this curriculum and others like it.

# 2 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 [8]. 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*. From a logistical standpoint, the pillar courses are 5-6 credits each with an associated 1 credit lab for each, so that contact time is roughly 2 hours per day, 5 days per week. The goal of each pillar is to be a microcosm of chemical engineering, so that each course serves to enhance a student's understanding of the discipline as whole: in many cases attacking both theory and practical application in the same course. In this way, students build their concept of the discipline gradually rather than as an "epiphany moment" in their senior year, once they have all the

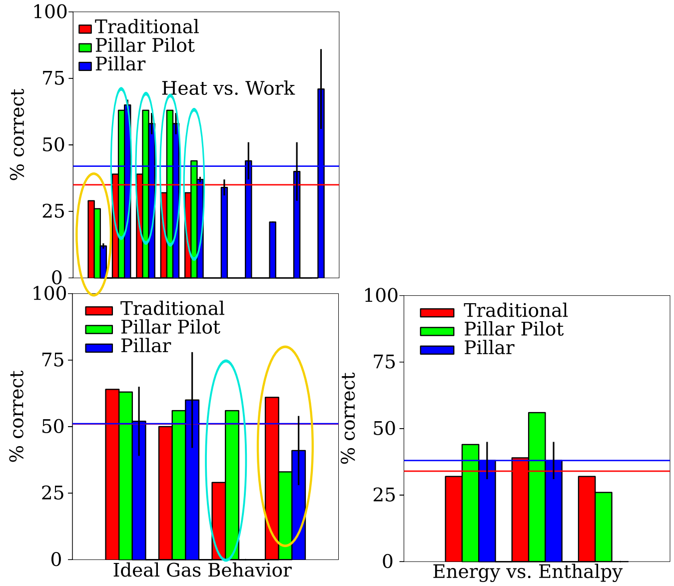


FIGURE 1: *Concept inventory results comparing both traditional and pillar cohorts on thermodynamics concepts. Circled are direct comparisons of concepts that had "significantly" differing scores between cohort groups. As may be noted the pillar cohorts perfomed better on 5 versus 2 concepts.*

relevant pieces of the puzzle. Whenever possible pillars exploit analogies between differing aspects of the discipline both to enhance internalization as well as to decrease instruction time.

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.

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 *Transport Phenomena* pillar course stresses analogies between momentum, mass, and heat transport. Content spans from the molecular origins of transport up through continuum descriptions, as well as macroscopic balances.

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.

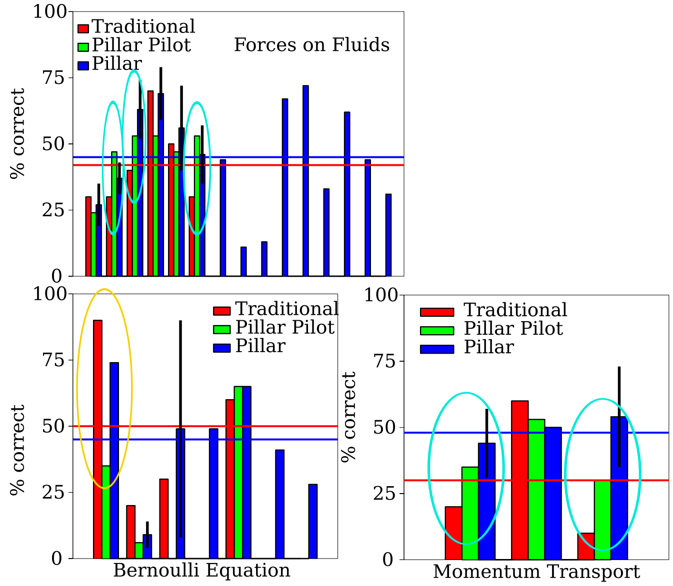


FIGURE 2: *Concept inventory results comparing both traditional and pillar cohorts on transport (fluids) concepts. Circled are direct comparisons of concepts that had "significantly" differing scores between cohort groups. As may be noted the pillar cohorts perfomed better on 5 versus 1 concepts.*

# 3 Assessment Methodologies and (Some) Results

Our assessment strategy differs from our traditional course assessments due to the inclusion of two new methodologies: concept inventories [9, 10] and concept maps [11–13]. 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.

## 3.1 Concept Inventories

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) [9, 10]. Results for two of our pillar courses are available using existing CIs developed at the Colorado School of Mines (CSM) [9] in thermodynamics (See Figure 1), heat transfer (see Figure 3), and fluid mechanics (see Figure 2). At present, development of additional concept inventories to assess attainment levels in the other four pillar course is the subject of ongoing work, and only the Transport and Thermodynamics pillar course will be discussed here.

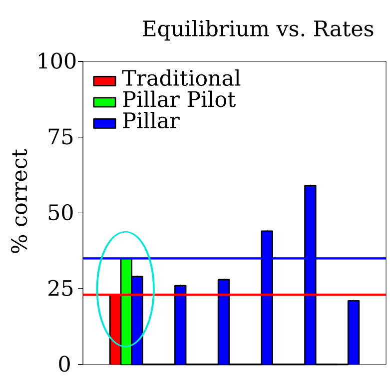


FIGURE 3: *Concept inventory results comparing both traditional and pillar cohorts on transport (heat) concepts. Circled are direct comparisons of concepts that had "significantly" differing scores between cohort groups. As may be noted the pillar cohorts perfomed better on 1 versus 0 concepts.*

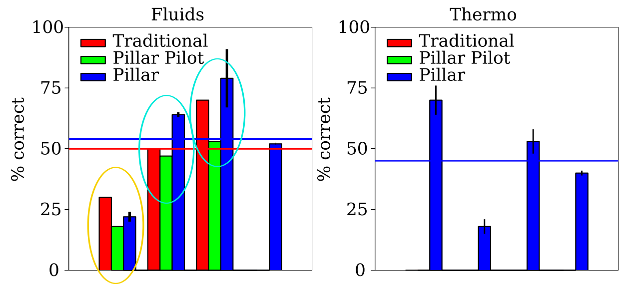


FIGURE 4: *Concept inventory results comparing both traditional and pillar cohorts on cross-cutting (mass vs. energy) concepts. Circled are direct comparisons of concepts that had "significantly" differing scores between cohort groups. As may be noted the pillar cohorts perfomed better on 2 versus 1 concepts.*

Our results are reported in four separate groups – thermodynamics, transport (fluids),transport (heat), and cross-cutting – where the cross-cutting is further subdivided among concepts relating to mass vs. energy and those relating temperature vs. energy. Due to the experimental and evolving nature of the concept inventories used (and the fact that our traditional curriculum cohort group was only available for the earliest versions of the CI's) our results show the raw scores of all related concepts and highlight only significant differences in persistent questions. Furthermore, as an aid to comparison, lines are drawn representing the average (raw) score on the entire suite of related concepts for each cohort group.

As can be seen from the differing classes of concept results reported, we have ample evidence that our change in curriculum has not resulted in a decreased level of mastery of basic (yet challenging) concepts within the discipline. While our results are likely not statistically sound enough to conclude that we have indeed enhanced the learning of our students in these key areas, that was not the aim of the work and we are heartened by the fact that we have "done no harm".

## 3.2 Concept Maps

In order to assess a student's "systems thinking" or their overall understanding of the topology of the discipline, concept mapping exercises are performed [11–13]. In concept mapping, a student is asked to develop a schematic representation of their understanding of what the discipline of chemical engineering entails. In practice, the students draw a diagram showing a hierarchy of ideas or concepts linked through branches between the sub-concepts, with further links showing interrelationships between inter-branch ideas/concepts, when necessary (i.e., cross-links). A schematic of a concept map is shown in Figure 6.

These maps are "scored" by a (consistent) panel of experts that use a rubric to quantitatively describe the map based on its organization, comprehensiveness, and correctness (see Figure 7). These mapping exercises are performed

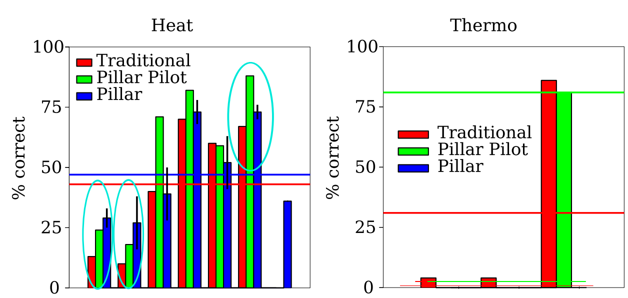


FIGURE 5: *Concept inventory results comparing both traditional and pillar cohorts on cross-cutting (temperature vs. energy) concepts. Circled are direct comparisons of concepts that had "significantly" differing scores between cohort groups. As may be noted the pillar cohorts perfomed better on 3 versus 0 concepts.*

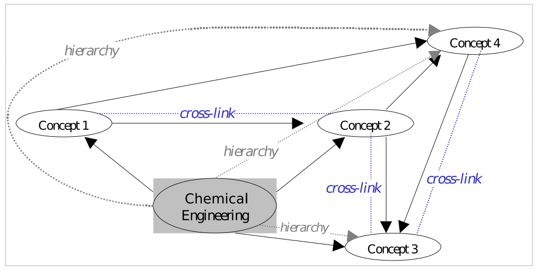


Figure 6: *Schematic of a Concept Map. Shown is an example concept map displaying links, branches and cross-links.*

| | **1** | **2** | **3** |
|---|---|---|---|
| **Comprehensiveness** – covering completely/broadly | The map lacks subject definition; the knowledge is very simple and/or limited. Limited breadth of concepts (i.e. minimal coverage of coursework, little or no mention of employment, and/or lifelong learning). The map barely covers some of the qualities of the subject area. | The map has adequate subject definition but knowledge is limited in some areas (i.e., much of the coursework is mentioned but one or two of the main aspects are missing). Map suggests a somewhat narrow understanding of the subject matter. | The map completely defines the subject area. The content lacks no more than one extension area (i.e., most of the relevant extension areas including lifelong learning, employment, people, etc. are mentioned). |
| **Organization** – to arrange by systematic planning and united effort | The map is arranged with concepts only linearly connected. There are few (or no) connections within/between the branches. Concepts are not well integrated. | The map has adequate organization with some within/between branch connections. Some, but not complete, integration of branches is apparent. A few feedback loops may exist. | The map is well organized with concept integration and the use of feedback loops. Sophisticated branch structure and connectivity. |
| **Correctness** - conforming to or agreeing with fact, logic, or known truth | The map is naïve and contains misconceptions about the subject area; inappropriate words or terms are used. The map documents an inaccurate understanding of certain subject matter. | The map has few subject matter inaccuracies; most links are correct. There may be a few spelling and grammatical errors. | The map integrates concepts properly and reflects an accurate understanding of subject matter meaning little or no misconceptions, spelling/grammatical errors. |

Figure 7: *Concept Map Scoring Rubric*

for each group of students in the Design Pillar (and preceding transitional capstone design class) and, occasionally, by spring-semester students in earlier levels of the curriculum. In this way we can assess the students' "knowledge integration" not only as a function of curriculum followed, but also temporally within the Pillars curriculum.

Our concept map scores to date are reported in Figure 8 where traditional, transitional, and pillar cohorts are compared (and pillar cohorts include results from sophomores and juniors as well as seniors). The scatter in concept map scores, when reported as means with error bars given as one standard deviation of the scores, makes our assessment inconclusive. Nevertheless, when comparing the median values there is an encouraging trend that not only do pillars students (seniors: 5.83 total score; transitional: 5.50) have a higher score on each measure versus the traditional cohort group (seniors: 4.83), but they are achieving comparable scores to the traditional cohorts earlier in their careers (sophomores: 4.83; juniors: 5.50).

# 4 Outlook

The Pillars curriculum at the University of Pittsburgh has been lauded by ABET as "a unique integrated approach" that is "in the forefront of ... education". We have no data that our change in curriculum is harmful, in fact, with limited cohort data student performance has seemingly improved on concept inventory tests thus far. Moreover, the median values of the concept map scores show the encouraging trend that our students understand the "big picture" not only better, but also considerably earlier. At the same time, student attitudes have been quite favorable with an across-the-board increase in teaching effectiveness survey scores (not shown) and anecdotal comments such as, "(an) improvement to old style ..." and "... love the pillar system!". Most faculty have embraced the format as it is

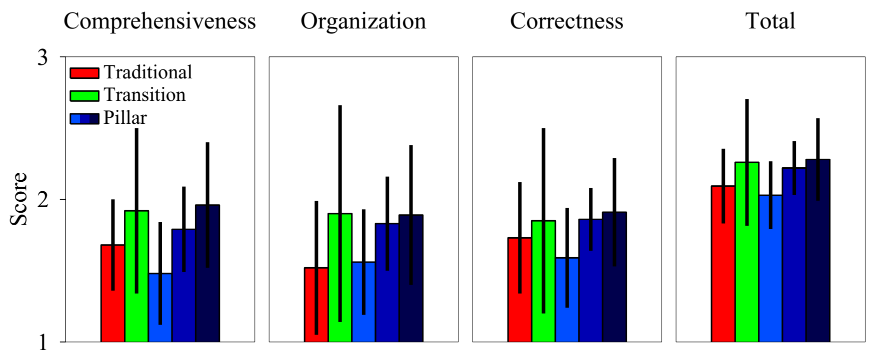


FIGURE 8: *Concept Map Scores. Note that the three shades of blue denote pillars students that have completed sophomore, junior, or seniors years (light to dark), respectively.*

logistically simpler than teaching a comparable number of credit hours in "separate" courses.

As our base of cohort data expands, and the statistics of our assessments (presumably) improves, we hope to port this type of curriculum first to other chemical engineering departments, but ultimately to other disciplines entirely. As a pre-emptive strike against potential issues of textbook availability we have begun an open courseware project, hosted at http://pillars.che.pitt.edu.

## Acknowledgment

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