AC 2009-2241: CROSS-CURRICULAR TOPIC INVENTORY: STRATEGIC TOPIC PLACEMENT AND RESULTING STUDENT ACCOUNTABILITY

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Cross-Curricular Topic Inventory: Strategic Topic Placement for Concept Reinforcement and Enhanced Student Accountability

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Abstract

Every 5 to 10 years, as faculty members transition in and out of a department, it can be beneficial for the faculty as a whole to periodically re-examine material coverage and placement in their curriculum topic by topic. This effort is usually performed in concert with preparations for ABET accreditation every six years, but the focus is generally on demonstration that the entire curriculum satisfies ABET requirements rather than a specific focus on the structure and placement of curricular topics amongst specific courses. This approach, with its inherent compartmentalization among courses, can mask unnecessary overlap or duplication between courses, can fail to reveal additional opportunities for horizontal and vertical concept reinforcement, and if not done properly, adequate content coverage can be difficult to confirm through such an effort. As an alternative, this paper describes an effort to conduct an inventory of specific concepts and skills that form the foundation for many chemical engineering courses. The goal of this ongoing effort is to identify each point in our program where these concepts are currently being taught, identify duplication, and then realign concepts/topics within courses in the curriculum (if necessary) to ensure that students possess and master the necessary skills/tools as they advance through our undergraduate curriculum. The advantage of the entire faculty participating in the effort is that each becomes familiar with the concepts/topics typically covered in courses which they may not have had the opportunity to teach yet. Strategic placement can provide timely reinforcement of key concepts in concurrent or sequential courses, remove duplication and repetition of concepts, and offer a means to expand course content to incorporate new technologies and topics of interest to the ever changing chemical engineering profession. Elimination of redundancy enables professors to cover concepts previously eliminated due to program credit hour reductions. By discussing topic coverage and timing within a course, faculty can incorporate material in other courses that builds upon or reinforces these concepts. Concurrent with this effort was a consensus among the faculty to instill in our students the value of conceptual understanding and material retention as essential elements of learning both as part of their degree program and life-long learning. An additional benefit of this learning philosophy is the ability of students to be functionally literate in core concepts and use them appropriately in later courses with little or no review. In this paper, the authors will describe our department's effort to review course topics and concepts to identify duplication among courses, and to strategically arrange concepts and skill development within our existing course structure to reduce redundancy as well as maximize student proficiency and knowledge as they matriculate through our undergraduate program.

Introduction

Our department, which is comprised of 12 faculty members, has experienced substantial change over the last 7 years including the addition of 6 junior faculty and 2 established faculty from other institutions, multiple retirements, and 2 promotions to administrative positions. Concurrent with these changes, the department underwent two reductions in total credit hours from an original 138 credit hour curriculum to the current 128-hour curriculum. The length of the semester has also been shortened such that the final exam period is now counted towards the student contact hour requirements, meaning that our regular semesters now consist of 42 fifty minute lecture periods in contrast to the 45 periods in place previously.

In response to student interest, the department has also established three new concentration areas: chemical engineering practice, chemical engineering research and development, and biomolecular engineering. These concentration areas differ by a set of 22 semester credit hours that were strategically selected to provide the desired concentration without negatively impacting the foundation of chemical engineering training; core math, science, and chemical engineering components of our original degree program were preserved in these new concentrations. The concentrations preserved the chemical engineering component, while adding flexibility for students to gain depth in biological sciences and simultaneously satisfy prerequisite requirements for medical school, dental school or vet school (biomolecular engineering concentration) and mathematics (R & D concentration). Students can follow any of the three concentration areas and earn a B.S. in chemical engineering. Most of these changes were made from a broad course/scheduling perspective with limited discussions of the course subtopics either being eliminated or re-timed in the student's academic career. In response to course reduction and schedule modification as well as changes in individual faculty topic coverage in courses, a subset of the faculty in the department decided to embark on a year-long curriculum inventory effort to discuss course concepts at a detailed course level and then work to strategically position concepts within the courses (and subsequently in the curriculum) in order to minimize duplication and improve the timing of student exposure to important and diverse chemical engineering concepts. As part of this effort, a discussion of adopting pre- and post-course curriculum inventories took place with the goal to provide a measure of instructional success and also to hold students accountable for retaining information learned in prior classes in the curriculum. One additional factor that influenced our approach was that a large number of our students participate in the cooperative education program, and another significant fraction transfer from Mississippi's community college system. Thus, students from these various groups could be expected to complete our curriculum following significantly different pathways and this was considered during our efforts.

One guiding principle of our effort was to establish better coordination of topics within a given class and among different courses, so that students on different curriculum schedules would have similar exposure to material in a given course independent of the instructor or the semester in which they enrolled. The faculty members involved in this effort believe that complete curriculum inventories compiled for each course enable

a) strategic elimination of unnecessary duplication. Unnecessary duplication was defined as re-teaching the same concepts from the beginning.
b) sufficient coverage of necessary information,
c) student accountability for material presented in previous classes,
d) strategic reinforcement of core concepts. This was also termed necessary (and beneficial) duplication because it reinforced and drew parallels between key concepts by expanding student knowledge.
e) inventory of curriculum content, including areas for improvement, that compliment the ABET assessment process, and

f) delivery of the best education possible through efficient and effective use of our limited classroom contact time (i.e. minimize review material and maximize exposure to essential and elective topics to provide appropriate depth and breadth).

In addition to this topic-level inventory, the faculty coordinated in order to communicate a consistent level of expectations from our students. All want our chemical engineering graduates to be effective problem-solvers possessing a flexible approach that allows them to successfully navigate both the familiar as well as the more novel problems they are likely to face during their careers. For this reason, the faculty adopted standardized homework formatting guidelines with a mandatory comments section at the conclusion of the problem where students explain why their answer makes sense and contextualize it within their evolving chemical engineering knowledge base. While discussing the individual topics in the course, the faculty strategized ways to incorporate the following elements in their courses such that there is vertical integration of concepts as well as coordination of concepts between courses in the same semester:

a) implement flexible problem solving through connectivity of topics/concepts,
b) utilize parallel terminology for similar concepts,
c) demonstrate applications that connect one concept to another,
d) identify and generate alternate approaches to achieve a specific task,
e) synthesize tools from multiple course curricula to approach larger challenges, and
f) demonstrate attitudes and skills for life-long learning.

This paper discusses each of the required chemical engineering core courses in our curriculum (see Figure 1 as an example) separately. For each course, the faculty involved in this effort have provided a course description, the identified knowledge and skill set students need when entering the course, the knowledge and skills taught during the course prior to any changes, and concludes with the areas of duplication and integration that were identified. Elimination of redundant information, reposition of information, and vertical and horizontal integration of concepts will be implemented in our courses during the next academic year. This paper focuses on the first stage of this cross-curricular topic inventory process, identification of opportunities for improvements in strategic topic placement and student accountability.

During the curriculum review process, special care was put into complimenting each professor's unique teaching approach, active learning exercises, and projects. Weekly meetings were held and all faculty were invited. A schedule and agenda were circulated prior to each meeting and minutes with action items were circulated afterwards. The focus was uniformly on valuing everyone's contributions to find ways that each professor's course content, approach, and teaching style was complimented in concurrent courses or subsequent courses in the curriculum. Informally, this newfound knowledge of the different teaching styles and content helped each individual professor point out to students' parallels between skills in their own class and Professor Y's class. This familiarity with the topics in the curriculum with both formal and informal reinforcement of content, skills, and expectations was viewed as a valuable asset to students and their synthesis of chemical engineering concepts.

FRESHMAN YEAR							
First Semester		Credit Hours	Grade Earned	Second Semester		Credit Hours	Grade Earned
CH 1211	Inv. in Chemistry	1		CH 1221	Inv. in Chemistry	1	
CH 1213	Fund. of Chemistry	3		CH 1223	Fund. of Chemistry	3	
CHE 1101	CHE Freshman Seminar	1		CHE 2213	CHE Analysis	3	
EN 1103	English Comp. I	3		EN 1113	English Comp. II	3	
MA 1713	Calculus I	3		MA 1723	Calculus II	3	
	Humanities Elective	3		PH 2213	Physics I	3	
	Social Science Elective	3					
	Total	17			Total	16	

SOPHOMORE YEAR							
First Semester		Credit Hours	Grade Earned	Second Semester		Credit Hours	Grade Earned
CHE 2114	Mass and Energy Balances	4		CHE 3113	CHE Thermo I	3	
CHE 3203	Fluid Flow Ops*	3		MA 2743	Calculus IV	3	
MA 3113	Intro Linear Algebra	3		MA 3253	Differential Equations	3	
MA 2733	Calculus III	3		IE 3913	Engineering Economy I	3	
PH 2223	Physics II	3			Fine Arts Elective	3	
	Total	16			Total	15	

JUNIOR YEAR							
First Semester		Credit Hours	Grade Earned	Second Semester		Credit Hours	Grade Earned
CH 4511	Organic Chem. Lab I	1		CH 4523	Organic Chemistry II	3	
CH 4513	Organic Chemistry I	3		CHE 3213	Heat Transfer Ops**	3	
CHE 3123	CHE Thermo II	3		CHE 3223	Mass Transfer Ops**	3	
MA 3353	Differential Equations II	3		CHE 3331	Professional Dev. Seminar*	1	
	Technical Elective	3		GE 3513	Technical Writing	3	
	Humanities Elective	3			Statistics Elective	3	
	Total	16			Total	16	

SENIOR YEAR							
First Semester		Credit Hours	Grade Earned	Second Semester		Credit Hours	Grade Earned
CH 4413	Physical Chemistry I*	3		CHE 4223	Process Controls**	3	
CHE 3222	CHE Lab I*	2		CHE 4233	CHE Plant Design**	3	
CHE 4134	CHE Process Design*	4		CHE 3232	CHE Lab II**	2	
CHE 4113	CHE Reactor Design*	3		CHE 4313	Transport Phenomena	3	
CHE 3413	Engineering Materials*	3			Chemistry Elective	3	
					Social Sciences Elective	3	
	Total	15			Total	17	

Figure 1: Chemical Engineering's 128-hour curriculum worksheet; The Research and Development concentration is shown.

Topic Organization in the Curriculum

Freshman / Sophomore Level Courses

ChE 1101 Chemical Engineering Freshman Seminar

This course is designed to introduce incoming freshman and transfer students to 1) chemical engineering as a major and as a discipline, 2) basic chemical engineering skills such as unit conversions, interpolation, extrapolation, etc, 3) time and stress management, 4) ethics, and 5) the departmental community including student organizations. Since this is an entry-level course students, skills attained at the highschool level are assumed including logic reasoning skills, perform basic data acquisition and interpretation, participate in foundational problem solving, and composition for lab reports. No primary text is used for this course, but a number are used as references and supplemental texts [1-3].

Prior to this curriculum inventory process, this course focused on 1, 3, 4 and 5 listed above. Class efforts focused on familiarizing the students with chemical engineering, the department, and the student organizations. The course finished with student teams researching a selected chemical process and presenting the chemistry and manufacturing process to their classmates.

Since this is a freshman course, no overlap/duplication of information with other courses was identified. However, this course was viewed as an opportunity to communicate foundational principles which could improve student's background for their subsequent chemical engineering courses. Through selective incorporation of foundational concepts in this course, opportunities to include additional/complementary topics in subsequent courses were identified. For example, concepts including unit conversions, basic statistical analysis (mean, standard deviation) and basic chemistry concepts including average molecular weight were moved from the mass and energy balances course into the Freshman Seminar. It was thought that these activities could also provide a means to reinforce to the freshman student the importance and complimentary nature of the foundation chemistry and mathematics courses they concurrently complete. These activities replace the discussion on different chemical process and the associated activities.

ChE 2213 Chemical Engineering Analysis

This course focuses on basic engineering problem analysis and solution techniques and engages students in a variety of individual and team activities to address different learning styles. Freshmen and junior college transfer students enroll in ChE Analysis, which serves as a bridging course between our Freshman Seminar and the Mass and Energy Balances courses.

Calculus I is a co-requisite for this course, though most math, chemistry and physics concepts are reviewed as needed during the course. Some prior exposure to Excel is expected and is generally possessed by the majority of our students. The following list of topics are addressed in a project-based environment: algorithm development; team-building, brainstorming and engineering design; basic and advanced Excel skills; basic statistics; experimental design, data collection and analysis; graphing techniques and association of experimental data with appropriate models; Visual Basic; analytical versus numerical solutions; and, an overview of techniques like Simpson's rule, numerical differentiation, interpolation and experimental error.

Projects are structured around the LEGO NXT robotics system with applications to chemical engineering processes. For example, in a recent offering of this course students developed a physical system and control program for maintaining liquid level in a tank using the LEGO robotics sensors, microprocessor and motors. From this system, data collection and analysis allowed students to gain some sense of the importance of controls in chemical engineering processes and of key terms in the process control area. In the spring 2009 semester, students are amplifying this project to integrate multiple tanks feeding reactants to a central reactor, thus investigating mass balance concepts in a highly visual, practical manner.

By design, this course builds upon some material (e.g. basic Excel skills) introduced in Freshman Seminar the previous semester. Additionally, some topics are introduced that will be covered in depth in future courses (e.g. mass balance concept). This topic inventory enabled coordination of basic analysis skills between our introductory chemical engineering courses. This analysis course, however, is presented in a unique problem-based, team-oriented learning environment to enable students to deepen their working relationships with one another while collaboratively discovering new ideas essential to engineering practice. The environment has regularly proven its value by enabling students to discover the "bumps and wrinkles" of different personalities interacting on goal-oriented, open-ended design projects with tangible, working products as deliverables. The students find this an excellent environment for engaging in the practical applications of their university core math and science classes as well as a valuable introduction to team projects encountered in upper level chemical engineering courses.

ChE 2114 Mass and Energy Balances

The purpose of the Mass and Energy Balances course is to introduce the students to chemical processes through application of the laws of conservation of mass and energy along with evaluation of physical properties to evaluate batch and continuous processes. The students are expected to be able to utilize basic algebra, calculus, and physics principles. The students are also expected to have a fundamental knowledge of chemistry including stoichiometry and component balances. The text used in this course is Felder and Rousseau [4].

The students are taught how to graph functions and perform statistical calculations with and without the aid of Excel using data collected from chemical processes. Other sources of information that would provide assistance when performing material and energy balances are brought to their attention. Students are trained how to read and understand descriptions of processes, analyze them, and write algorithms to solve them. The skills to breakdown a chemical plant into individual unit operations and analyze them are emphasized during the semester.

It was determined that many of the basic math principles taught at the beginning of the semester, such as statistics and linear functions, could be strategically moved into Freshman Seminar and / or Chemical Engineering Analysis. The statistics component was moved to Freshman Seminar in the Fall of 2008. With our recent curricular changes, both traditional students and transfer students would take Mass and Energy Balances simultaneously with the Fluid Flow Operations course. One area of duplication identified between these two courses was the hydraulic equilibrium (i.e., fluid statics) and evaluation/analysis of manometers and pressure measuring devices. Moving this topic exclusively to Fluid Flow Operations provides an opportunity to devote those lecture periods to further explore energy balances and transient balances. Coverage of these topics in greater depth provides a stronger foundation for subsequent courses in Heat Transfer, Mass Transfer, Reactor Design, and Process Controls.

ChE 3203 Fluid Flow Operations

Fluid Flow Operations is the first course in our three-course transport operations sequence (Fluid Flow Operations, Heat Transfer Operations, and Mass Transfer Operations). Topics typically covered in the existing course include: hydrostatic equilibrium, centrifugal decanter design, fluid dynamics including viscosity/momentum flux, flow regimes, flow profiles, flow in conduits and thin layers, the Bernoulli equation, flow past immersed bodies, and transportation and metering of fluids. Students are expected to firmly grasp fundamental concepts of forces and vectors from mathematics and physics and "process" concepts from the Mass and Energy Balances course. The course relies heavily on momentum, mass and energy balance equations. Basic mathematical and computer programming skills (primarily using Excel tools) retained from Chemical Engineering Analysis is expected. Some familiarity with equations of state, particularly the ideal gas law is anticipated. Concepts of enthalpy, work, heat and other thermodynamic quantities (covered in the freshman chemistry and physics courses) should be familiar. Noel de Nevers' *Fluid Mechanics for Chemical Engineers* is the required text for the course.

Skills and learning objectives for students successfully completing this course include: familiarity with the methods used to analyze and design fluid processing equipment; an understanding of design parameters applicable to processing equipment for compressible fluids; an ability to analyze and size piping systems, pumps, valves, compressors and flow meters with some familiarity with pressure relief devices; a growing perspective on the relationship of fluid dynamics to the broader analogies of transport phenomena (i.e. relationships among momentum, heat and mass transport); and, an introductory comprehension of analysis of a wide range of processing equipment (e.g. evaporators, separators, fluidized beds, reactors).

This course provided one of the most beneficial discussions of the entire curriculum inventory effort. It was determined that three chapters of material could be split between Mass and Energy Balances and Fluid Flow Operations classes to avoid duplication. There was discussion that this extra time could be used to cover process safety.

Junior Level Courses

ChE 3113 Thermodynamics I

The first semester of ChE thermodynamics focuses on the application of mass, energy and entropy balances to evaluate processes and process equipment. A strong focus on the volumetric behavior of pure fluids is combined with exposure to ideal gas behavior, cubic equations of state, and generalized correlations for both liquids and gases. Heat effects in reacting mixtures are also examined. Exposure to the use of physical property tables for steam and other fluids is coupled with an examination of steady state behavior of devices (turbines, pumps, compressors, nozzles) and common cycles (Rankine, Air-standard, and refrigeration). The text of Smith, van Ness and Abbott is used for both thermodynamics courses in our curriculum [5].

Students entering this course have completed their freshman chemistry courses, calculus-based physics courses, and at least the first two semesters of calculus. They may be simultaneously enrolled in Mass and Energy Balances and Fluid Flow Operations if they have transferred from a community college. Thus, basic skills include a familiarity of thermodynamic concepts from freshman chemistry (enthalpy changes associated with sensible heat effects, with phase changes, with reaction), as well as the first law of thermodynamics (primary exposure from physics).

They should be knowledgeable of the ideal gas law and its use for evaluation of volumetric properties.

This course provides a strong foundation for other upper level chemical engineering courses. Students are expected to start with the governing general mass, energy and entropy balances, and simplify them as appropriate given keywords regarding process or device operation. Students will be conversant in the use of the ideal gas law and physical property tables for calculating and obtaining properties of fluids. Students learn to evaluate the energy effects associated with chemical reactions. Students also learn to analyze the Carnot cycle, the Rankine cycle and use the concept of isentropic efficiency to analyze equipment performance. Limited exposure to CHEMCAD is provided [6].

The primary area of duplication noted in this course is examination of unit systems as well as temperature and pressure measurement and conversion between different temperature scales/pressure scales. These topics are well-covered in Mass and Energy Balances and in Fluid Flow Operations as well as in prerequisite physics and chemistry courses, thus, it was decided that a quick review of these topics in the first thermodynamics course was sufficient.

ChE 3123 Thermodynamics II

The second semester of ChE thermodynamics focuses on the impact of non-idealities on fluid behavior, both pure components and mixtures. Also examined in this course are phase and chemical equilibria. Students entering the course are expected to be well versed in the use of the ideal gas law for pure components and steam tables to evaluate performance of various devices through application of the mass, energy and entropy balances. Some exposure to generalized correlations for both gases and liquids is expected, as is exposure to qualitative equations of state (compressibility EOS, van der Waals, RK) for evaluation of volumetric behavior.

The major topics covered in this course include thermodynamic relationships, the effect of pressure on properties, phase and chemical equilibria. Students gain more practice in simplifying first and second laws given a problem statement and keywords in making and justifying assumptions (a critical skill needed in later design courses). Given chemistry and process conditions, students learn to select an appropriate physical property model. Also examined in this course in great depth is solution thermodynamics, including non-ideal liquid phase behavior. Multi-component phase equilibria is covered, with students leaving the course with the ability to properly predict phase behavior (VLE, VLLE, LLE) using appropriate models. A strong focus is on the recognition of conditions that lead to applicability of common physical property models (i.e., ideal gas, ideal liquid solution, non-ideal liquid phase, single non-condensable component, Henry's law, real gas behavior). Students are also exposed to additional topics in process simulation, including widely used estimation techniques for phase equilibria such as UNIFAC as well as group contribution methods for pure component properties.

One area of duplication noted is in the use/preparation of phase equilibrium data and evaluation of bubble and dew points for chemical mixtures. Historically, this material was covered in exhaustive detail during the later half of the second thermodynamics course. For students progressing through the CHE curriculum following a standard 4 year program, they would take this course the semester prior to enrolling in the separations course. However, for both transfer students and students participating in the cooperative education program, it is very likely that they would be enrolled in the second CHE thermodynamics course and the separations course during the same semester. Thus, coverage of phase equilibria data generation and use during the later half of the thermodynamics course results in the need to also cover this topic in the separations course at the start of the semester.

One strategy discussed to avoid this poorly coordinated duplication is to rearrange the topics covered in this second CHE thermodynamics so that the essential elements of use/generation of phase equilibria data/bubble points/dew points using Raoult's law and using Depriester charts are incorporated at the start of the semester. Thus, these concepts would be covered in sufficient depth that they are immediately available for use in the Mass Transfer Operations course. These concepts represent only a small portion of the phase equilibra material typically covered in the thermodynamics course. The use of Depriester charts to evaluate phase behavior in hydrocarbon systems where pressures are typically much higher than those where the ideal gas law (and hence, Raoult's law) would be valid provide a strong motivation for further study of the behavior of fluids (both gases and liquids) under high pressure conditions. Thus, there would be a natural transition from this topic to the effect of pressure on thermodynamic properties.

ChE 3213 Heat Transfer Operations

Topics currently covered in the junior level Heat Transfer Operations course include: conduction in 1-D and 2-D systems (Cartesian, cylindrical and spherical coordinates); conduction through composite walls; evaluation of resistances; heat transfer enhancement using fins; convective heat transfer (laminar and turbulent flow, flow past immersed bodies and tube banks); overall heat transfer coefficient; and heat exchanger design. The current course text is Incropera and DeWitt's "Fundamentals of Heat and Mass Transfer" [7].

Students entering Heat Transfer Operations need a solid background in conservation of energy principles, which they obtain in the sophomore level Mass and Energy Balances course. Also, the students need to retain and utilize knowledge of fluid flow including the physical understanding of fluid sheer near a surface, flow properties in different Reynolds number regimes, and velocity profiles in and around objects. The students need to be proficient in the understanding of equations, slopes, derivatives, and gradients in the context of how they can mathematically represent a physical system. Computer skills in plotting data, determining equation behaviors, slopes, etc., and solvers are taught in ChE Analysis and utilized in Heat Transfer Operations.

Heat Transfer teaches tangible skills in developing and interpreting temperature, heat flux, and concentration profiles both from a physical perspective and a mathematical perspective. This is the first course where students utilize their knowledge from differential equations in our curriculum and link the physical constraints of boundary conditions to a mathematical representation. For example, students make connections between a mathematical expression, curve shape and physical behavior (e.g. zero slope of the temperature profile at an adiabatic surface). This course also reinforces the concept that multiple sources act on a system concurrently and teaches students how to approach these problems. Lastly, this is typically the first semester in our curriculum where students encounter a longer-term group design project typically focused on the design or optimization of a heat exchanger.

Faculty discussions elucidated that use of visual aids (radiation black bag, fluid flow videos from YouTube [8], disassembled heat exchangers, open coffee maker, etc.) enhances student understanding of concepts. It was determined that the use of a fluid flow quiz at the beginning of class would assist students in refreshing the essential foundational knowledge from prior courses. Further, opportunities were identified where energy balance problems covered in Heat Transfer could provide a foundation for temperature changes within reactors in Reactor Design. It was decided that the heat transfer course would feature a problem or two on heat generation in a packet catalyst bed and heat transfer in a jacketed reactor and these same examples would be extended in Reactor Design. Discussions in this course suggest that explicitly reinforcing connections between Reactor Design, Mass Transfer Operations, and Heat Transfer Operations would provide the students with a transitionary framework for Process Design in the senior year.

ChE 3223 Mass Transfer Operations

The junior level Mass Transfer course focuses on analysis of equilibrium staged separation processes (distillation, both binary and multi-component; absorption and stripping, both binary and multi-component; and extraction). The current course text is Wankat's "Separation Process Engineering" [9].

Entering students should be able to perform overall mass and energy balances on single process units or on a sequence of two or more process units including heat exchangers, flash drums, distillation towers, and other separation units. Students must also be able to evaluate properties of a stream (density, viscosity, thermal conductivity, surface tension) given composition, temperature, and pressure of the stream. Another skill required is the use of different representations of composition (mole fraction, mass fraction, concentration) and flow (molar flow, mass flow, standard volumetric flow). In addition, students should have the general concept of equilibrium as well as know Gibbs phase rule.

During the Mass Transfer Operations course, students become effective users of phase equilibria data, including use of Raoult's law and Depriester charts for data generation, bubble and dew point evaluation. Students learn to evaluate separation performance in binary and in multi-component distillation. Students leave the course with the necessary skill to evaluate and size separation equipment, including flash drums, distillation towers, absorption/stripping towers, and liquid extraction units. Further exposure to process simulation is realized through use of the shortcut model and the rigorous distillation models in CHEMCAD [6].

The major area of duplication identified was in the extensive coverage of phase equilibria. Elimination of this duplication through strategic placement of the material at the start of the second thermodynamics course provides an opportunity in the Mass Transfer Operations course to include additional separations topics, including membrane separation processes, rate-based analysis of separations, and the concept of mass transfer coefficients. Incorporation of this latter topic would provide a stronger link with topics from heat transfer as the heat/mass transfer analogy could be further explored.

ChE 3413 Engineering Materials

Our Engineering Materials course is currently a junior-level course taught from Callister's "Materials Science and Engineering: An Introduction" [10]. This is a service course available to students from all majors who meet the Chemistry II and Physics I prerequisites, but primarily is attended by engineering majors. For the past 3 years, the chemical engineering enrollment has ranged from 47.5% to 72% and included other engineering majors with the majority of the students electing to take this course in their senior year. The purpose of the Engineering Materials course is to introduce students to the physical, chemical, and mechanical properties of engineering materials and the relationships between these properties and the service behavior of ceramic, metal, and polymeric materials.

Students are expected to have retained the concepts covered in the Chemistry II and Physics I prerequisite courses. Specifically, students need to understand the basic principles of atomic and molecular structure, energetics and dynamics of materials, conservation laws, and Newtonian mechanics. Because students from different engineering disciplines attend this course, there are no expectations of specific engineering knowledge other than conservation laws. In Engineering Materials, a context is presented for material classification in order to introduce different materials and their representative properties. Typically a wide range of topics are then covered in this introduction class including atomic structure and bonding, structure and imperfections in solids, diffusion, mechanical and electrical properties, applications and processing, corrosion and degradation, and the selection and design considerations for metals, ceramics, plastics, and composites.

The primary outcome of our curriculum review was the idea of moving Engineering Materials earlier in the curriculum so that other classes can build upon the information presented. This would seemingly benefit not just chemical engineering, but the other engineering disciplines as well. For instances if students have already been introduced to how physics and chemistry affect material properties, such as thermal conductivity, chemical resistance, viscosity, density, and thermal expansion, then the instructors in Unit Operations, Process and Plant Design, Reactor Design, and the technical elective courses (e.g. Intro to Polymers) can build-upon this knowledge instead of covering foundational material in detail, as is currently done. In addition, less review and introduction and more application-relevant discussion may result when discussing material selection for design, safety, and even environmental impact in Fluid Flow (pumps, valves), Heat Transfer (insulation, heat transfer fluids, heat exchangers), and Process and Plant Design (piping, tank selection, and all other unit operations).

Senior Level Courses

ChE 3222 Unit Operations Lab I & II

These two courses are comprised of application-driven experiments featuring thermodynamics, momentum, heat and mass transfer in chemical engineering process equipment. Prerequisites for

UO Lab I include Fluid Flow, Thermo I, and Heat Transfer. UO Lab II requires the completion of UO Laboratory I, Heat Transfer, and Mass Transfer. Students generally have completed the reactor design course before taking UO Lab II (though the material is presented in such a way in the laboratory that this is not a course pre-requisite).

Students engage in experimental design and operation of various types of process equipment or simplified process models that physically demonstrate a particular concept or principle (e.g. convective heat transfer); data collection and analysis; health and safety analysis; and, reporting in oral and written formats. McCabe, Smith, and Harriott's Unit Operations of Chemical Engineering is used a reference text [11].

Both laboratory courses are designed to enable students to demonstrate the following learning objectives: applying knowledge of chemical engineering unit operations to design and conduct experiments, as well as analyze and interpret data; functioning on teams, in various roles, with team members of diverse personal backgrounds to accomplish laboratory experiments and related assignments; identifying health, safety and environmental issues associated with unit operations experiments; utilizing a critical review of one's laboratory report or other laboratory assignments to improve the work; recognizing the contributions of others in technical reports, oral presentations, and other formats; delivering competent performance throughout all phases of laboratory experimentation; communicating Experimental Objectives, Design, Procedures, Problems, Solutions, Analyses, Results, Conclusions, and Recommendations to a variety of audiences such as people who are specialists in the technology, other technical professionals, chemical operators, and non-technical individuals and in a variety of formats such as laboratory operations, team meetings, technical reports, status reports, written procedures, diagrams, and oral presentations; engaging in lifelong learning in engineering safety and engineering design/experimentation; exhibiting knowledge of contemporary issues at a chemical plant (e.g. environmental and social impact); using spreadsheet software to record, organize, manipulate, analyze, and present experimental data and results in tabular and graphical formats; and, using word processing software for writing technical reports and presentation software for presenting oral reports.

Discussions on this course focused on how the prerequisite courses could help develop student skills such that the quality of experiment reports and data analysis could be improved. Further, this course is by definition intended to be a reinforcement and synthesis of concepts from prior courses, so no effort was put into eliminating duplication. Instead, strategic reinforcement of concepts was discussed and will be expanded upon in further meetings. New laboratory experiments/apparatus are being designed and built (e.g. absorption column, a micro-scale reactor and a biodiesel production experiment) and will be coordinated with concepts from the mass transfer course. Some new experiments are designed to incorporate applied experiences in biology in accordance with relatively new ABET chemical engineering criteria.

ChE 4113 Reactor Design

This course trains students to solve reactor design problems integrating topics from earlier chemical engineering classes such as Mass & Energy Balances, Thermodynamics I and II, Heat Transfer Operations, and Fluid Flow Operations. The course also introduces students to the more complicated reactor designs and multiple reactions systems that are commonly used in industry. The students learn tools required to model these more complex systems, including the numerical analysis software Polymath 6.1 [12]. To measure achievement of these goals, students proficiency is tested on calculations to determine required reactor volume, catalyst weight if applicable, conversion, residence time if applicable, pressure drop effects if applicable, reactor selection, and operating temperature for plug flow, continuous stirred tank, packed bed, and batch reactors. Scott Fogler's "Elements Of Chemical Reaction Engineering" is the course text [13].

The course requires an understanding of differential equations, mass and energy balances, and thermodynamics. Students must be able to solve analytically first and second order ordinary differential equations. It is expected that students will be able to develop mass and energy balance equations for steady state systems. Finally, students must be familiar with equations of state, equilibrium constant, Gibbs free energy and enthalpy calculations. To measure achievement of these goals, students are tested on proficiency to perform calculations to determine required reactor volume, catalyst weight if applicable, conversion, residence time if applicable, pressure drop effects if applicable, reactor selection, and operating temperature for plug flow, continuous stirred tank, packed bed, and batch reactors. The students are also evaluated on team work, and written and oral explanation of technical concepts.

Discussions revealed the potential for coordinated problems between Reactor Design, Heat Transfer, and Mass Transfer in order to reinforce concepts in student's minds. The faculty team made plans to meet separately to formulate a problem or two on reactant conversion in a packet catalyst bed and / or conversion dependence on heat transfer into a reactor's jacketed reservoir.

ChE 4134 Process and Plant Design

This two semester capstone design sequence is designed to further integrate student knowledge from the sophomore and junior level chemical engineering courses into a knowledge base that can be used effectively in analysis, evaluation and synthesis of chemical process plants. The first course in the sequence, Process Design, is designed to strengthen the connections between the various prerequisite topics, and develop the student's design skill set with well-focused design projects. A laboratory associated with this course is designed to provide additional instruction in process simulation, building on previous exposure to process simulation gained through the thermodynamics sequence and the Mass Transfer Operations course.

Entering this first course, the student is required to have a strong background/understanding of a number of concepts/topics. These are shown in Table 1. With the curriculum hour reduction from 138 to 128, a prerequisite change was made requiring students to complete engineering economics prior to enrollment in Process Design.

The skills gained by students during the process design course include chemical process evaluation, costing of chemical equipment, economic evaluation of processes/process plants, preparation of design reports and presentations. Additionally, students are exposed to advanced process simulation topics including data regression, sensitivity analysis and flowsheet optimization. Additional skills are dependent to some degree on the chosen design projects. For

Table 1: Skills Required for Students Entering Senior Design Sequence

1. Perform mass and energy balances, for single process units including:	a. heat exchangers b. flash drums
2. Perform mass and energy balances, for processes involving two or more process units of 1.a through 1.d.	c. distillation towers and other separation units (extraction columns, absorbers, strippers) d. reactors i. ability to evaluate enthalpy of reaction ii. ability to evaluate equilibrium constant 1. apply Le'Chatlier principle (excess reactant, excess product, or inerts in feed 2. effect of temperature on equilibrium 3. effect of pressure on equilibrium 4. use of van t'Hoff approximation iii. ability to identify limiting reactant, reactants fed in excess
3. Evaluate stream properties, given composition, temperature, pressure of stream for pure component streams or for mixtures	a. calculation of density b. calculation of transport properties (viscosity, thermal conductivity)
4. For mixtures, recognize conditions that lead to common physical property behavior;	a. Ideal gas behavior b. Ideal liquid solution behavior c. Non-ideal liquid phase behavior (activity coefficient models) d. Single non-condensable component e. Henry's law f. Real gas behavior (compressibility, equations of state) for pure gases and their mixtures
5. Given flowrate, stream composition, and stream conditions (temperature, pressure), be able to	a. convert molar flowrate to mass flowrate b. convert mass flowrate to molar flowrate c. convert to standard volumetric flowrates for gas streams (SLPM, SCCM) d. convert to standard volumetric flowrates for liquid streams
6. Sizing of:	a. Pumps (liquid streams) b. Compressors (gas streams) c. Heat exchangers d. Flash drums e. Separation equipment (distillation towers, extractors, absorbers, strippers)
7. Process simulation: use of process simulator for analyzing:	a. Pump b. Compressor c. Turbine d. Flash drum e. Heat exchangers f. Generation of phase equilibrium diagrams (P-x-y, T-x-y, x-y)
8. Use of engineering economics	a. Simple interest, compound interest b. Future value of money c. Cash flows – bringing cash flow forward in time or backward in time d. Preparation of discrete and cumulative cash flow diagrams e. Annuities f. Use of discount factors g. Use of depreciation, calculation of depreciation charges h. Assessment of profitability i. Net present value, net present worth, j. Comparison of investments

example, inclusion of pinch technology was included one semester to provide students with useful tools to examine heat integration. During another semester, one project required an understanding of gas separations using membranes, so instruction was provided in this topic. Technical report preparation and writing skills are a central focus of the course. Rather than have a full design report on each project, students are required to submit intermediate reports which focus on different components of the report. For example, for the first project, students are required to include only the following sections: Executive Summary, Process Description, Process Flow Diagram, Appendices (extensive, documenting the design process and all design decisions). For the second project, all of these sections are required and an additional section entitled Discussion of Design Results is required. The focus of this section is to lead the reader through the choices the design team made in arriving at the submitted design, including alternatives considered. For every decision in the design process, justification was required. The final project report added Letter of Transmittal, Table of Contents, Introduction and a Conclusion and Recommendations section.

As the capstone design sequence, there were no areas of duplication identified. However, students are not required at this time to complete the Technical Writing course as a prerequisite to enrolling in the design sequence. Faculty are currently exploring the possibility of having all seniors enrolled in the first design course (Process Design) while simultaneously enrolling in a Chemical Engineering only section of the Technical Writing course. The Electrical and Computer Engineering department has successfully adopted this strategy. This would provide additional support for development of writing and technical communication skills specifically focused on chemical engineering projects. Currently the Technical Writing projects are non-specific as to discipline.

ChE 4223 Process Instrumentation and Controls

Process Instrumentation and Controls is a senior level chemical engineering course that provides the students with the skills/tools to control process operations in a variety of chemical processes. The industrial practice of process control requires a sound knowledge of instrumentation, control loop design, controller tuning, control strategies and an understanding of interactions between processes in a process plant facility. Entering the course, students need to have a strong background in dynamic mass and energy balances and differential equations. However, due to the time constraints in the Mass and Energy Balances course, preliminary coverage of dynamic balances had been dropped. With the re-allocation of concepts into ChE Analysis and into Fluids, this topic will again be included in Mass and Energy Balances and the foundational background of the students is expected to increase. It is assumed that students have no exposure to control loop elements (valves, transducers, sensors, transmitters) prior to this course. A new text is being used this year, with the addition of bio-process control [14].

Students become adept at simplifying dynamic balance equations for the process. The formalism of block diagrams is extensively used and developed in the course. Students learn how to size and select control valves, and other components of the control loop. In the dedicated laboratory for process control, students conduct a sequence of hands-on activities. These activities focus on wiring of instruments, creation of the control strategy, including basic strategies such as feedback and advanced strategies such as ratio, feedforward, and cascade control, and tuning of the control loop. Interactive controller tuning software is also used to examine response and behavior in more complicated unit operations.

As a senior course, there is little duplication with the lower division courses. However, this course relies heavily on the exposure to dynamic balances in lower level courses (thermodynamics, fluids, heat transfer, etc.); even though the time dependence may be quickly cancelled out because of a steady state assumption, starting with the full balance including the time dependence would provide students with a stronger link/connection between the modeling and balance equations they see/use in the process control course and those seen in earlier CHE courses.

ChE 4313 Transport Phenomena

In the undergraduate Transport Phenomena course, the primary objective is to employ a unified approach to study the fundamental principles of momentum, heat, and mass transport. The students learn how to model simple systems, where exact solutions can be found, and use this knowledge to create models to describe more complex systems, where only approximate solutions can be found. To be successful, the students must be able to transition and make connections easily between mathematics and physics. An overarching goal of the course is to develop the ability to recognize and describe relationships between transport processes and the physical property distributions in fluids and solids, so discussion is dispersed throughout the semester regarding how topics in Transport Phenomena overlap with Fluid Flow, Heat Transfer, and Mass Transfer, and subjects as diverse as biology, materials science, and agriculture. The current text is Bird, Stewart, and Lightfoot's 2nd edition of "Transport Phenomena" [15].

Since Transport Phenomena naturally assimilates material from the chemical engineering unit operation courses (Fluid Flow, Heat Transfer, and Mass Transfer) students must be proficient in their knowledge of these subjects. A student's initial performance in this course is dependent on their prior math preparation, especially experience in applied or engineering math. By (re)introducing students to calculus and differential equations as part of problem solving in the unit operations series and Reactor Design, students have the background to proceed into the conceptual course material without the math hindering their progress.

A very important principle in the study of transport phenomena is the analogy between momentum transfer (fluid flow), heat transfer, and mass transfer. For example, momentum, energy, and mass can all be transferred by diffusion. (The drag experienced by a rain drop as it falls is an example of momentum diffusion. The rain drop loses momentum to the surrounding air through viscous stresses and decelerates. The conduction of heat in a solid is an example of heat diffusion. The spreading and dissipation of chemical vapors in air is an example of mass diffusion.) Historically, undergraduate students in our department have compartmentalized these subjects and one of the first tasks for the Transport Phenomena instructor is to tear down these 'walls' in order to facilitate the formation of analogies and connections between different subjects that subsequently supports the development of more advanced problem solving skills [16-18]. The course has traditionally progressed through the transport of momentum, energy, and then mass while making linkages between the three using combined problems. Both the shell balance and generalized equations of change approaches are covered with an emphasis on the latter.

As part of the curriculum inventory review process, each core course was discussed and so duplicated or missing (sub)topics could be identified along with the generation of ideas for reinforcing concepts between courses. At the beginning of the Transport Phenomena course, currently significant time is spent reviewing and (re)introducing calculus, differential equations, vector and tensor mathematics, and special functions. While some 'new' math instruction is unavoidable, by requiring students to retain their applied math skills in the earlier unit operations and Reactor Design courses, it was felt that the calculus and differential equations review required for Transport Phenomena course could be substantially reduced. Opportunities for reinforcing concepts and preventing duplication between the core chemical engineering courses and Transport Phenomena abound and these are listed below:

- Gas and Liquid Viscosities, Power Law Model, and Non-Newtonian Fluids (Fluid Flow; Heat Transfer)
- Energy Balances, Continuity Equation, and Shell Balances (Mass & Energy Balances; Fluid Flow; Heat Transfer; Mass Transfer)
- Generalized Equations of Change (Fluid Flow; Heat Transfer; Mass Transfer)
- Velocity, Temperature, and Concentration Profiles and Relationships Between Gradient Equations and Physical Systems (Fluid Flow; Heat Transfer; Mass Transfer)
- Boundary Layers (Fluid Flow; Heat Transfer; Mass Transfer)
- Flow Over/Around Objects (Fluid Flow; Heat Transfer; Mass Transfer; e.g. packed beds, tube banks)
- Coupled Momentum and Energy Problems (Heat Transfer; e.g. convective heat transfer, extended surfaces)
- Multi-variate Systems (Fluid Flow; Heat Transfer; Mass Transfer; Reactor Design; e.g. unsteady systems, 2-D and 3-D transport, multicomponent mass transfer)

Conclusions:

This paper describes a year-long, preliminary, cross-curricular concept inventory effort by members of the chemical engineering faculty to coordinate material coverage and placement in our curriculum at the concept level. This effort is in its infancy, but this paper can potentially be useful for other departments considering the need for a renewed examination of course content. The first round of course-by-course discussions yielded changes in course material coverage in the form of elimination of duplicated information and reinforcement of key foundational concepts between courses. Further, this optimization of content delivery for our students has brought forth opportunities to coordinate and reinforce key concepts while including new technologies in the chemical engineering field.

One of the major shifts in faculty attitudes that arose from this effort was in regards to student responsibility for retaining information from prior courses. After this effort, the faculty consensus was that the responsibility should be shifted to the student to re-study and retain foundational information from their prior courses. This accountability is essential for inter-connection and synthesis of superficially disparate topics. The hypothesis is that this attitudinal shift will do more to instill the habits of life-long learning in our students than any other learning activity in our courses. So what constitutes unnecessary duplication? It is the opinion of this team of faculty that reinforcement of concepts does not mean re-teaching the concepts from the beginning, it means purposefully pointing out the parallelisms and links between the concepts, but still placing the onus on the student to review as necessary on their own to fully understand all foundational material.

This coordinated faculty effort will continue in order to develop a well-cataloged topical inventory of our entire curriculum. Once the depth and breadth of chemical engineering concepts are properly optimized between courses in the curriculum, the student's chemical engineering proficiency will be maximized.

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