A Project-Based, Spiral Curriculum for Chemical Engineering

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Abstract

We developed a project-based, spiral curriculum for the chemical engineering sophomore year. The spiral curriculum is a complete restructuring of the traditional curriculum, and emphasizes repetition and integration of topics with increasing complexity throughout the year. It is designed to increase motivation for learning and retention of basic skills and concepts. The new curriculum features multimedia instructional modules, peer-assisted cooperative learning structures, a "just-in-time" learning paradigm, and industrially relevant projects that introduce design concepts early in the year. Our goal is to address problems with the traditional academic structure that include poor retention, segmented learning, and the need to deliver a cost-effective education to a student audience of diverse backgrounds and learning styles.

We will present a detailed description of the spiral curriculum and discuss the results of the first year's implementation. We are teaching the new sequence to a randomly selected group of sophomores and comparing their performance to students in the traditional sequence. Our evaluation design will be described including the variety of tools used. The assessment program includes a balance of formative and summative measurements, and qualitative and quantitative analyses. Results from the first year data collection will be discussed. These cover comparison of student comprehension of basic fundamentals, performance on open-ended problem solving, communication skills, and attitudes and satisfaction with group work and chemical engineering.

Introduction

Engineering education in the United States today faces many challenges including: (1) attracting students with a diversity of backgrounds, learning styles, and pre-college preparations to engineering careers, (2) maintaining interest and motivation during a four-year undergraduate education, while at the same time assuring quality and relevance to engineering practice, (3) preparing students for demanding careers that not only require technical competence in an engineering discipline but also require communication, teamwork and life-long learning skills, and (4) maintaining or enhancing quality programs in the face of increasing financial pressure [1,2]. It is clear to us that the traditional approach to chemical engineering education is not well suited to meet these challenges.

In the traditional approach, the chemical engineering curriculum provides a compartmentalized sequence of courses that aims to build a solid, fundamental foundation before providing integrated, capstone and/or engineering practice experiences in the senior year. Problems that arise from this educational structure include: (1) lack of motivation for learning fundamental material, (2) poor retention of sophomore- and junior-level material that is needed for the senior-year integrated experiences, (3) segmented learning resulting in a lack of ability to integrate material presented in several different courses, and (4) lack of ability to extrapolate knowledge and skills gained in one context (e.g., thermodynamics) to a different context (e.g., thermodynamic limitations in reactor design). All too often, important material is presented once and assumed to be "learned". Moreover, the traditional lecture format has not been conducive to the accommodation of different learning styles, to students assuming responsibility for their own learning, nor to a desirable shift away from passive learning to active learning [3,4].

To address the challenges and deficiencies noted above, we have developed a project-based, spiral curriculum for the chemical engineering sophomore year. By "spiral", we mean that the understanding of basic concepts and their interrelations are reinforced by revisiting them in different contexts with ever increasing sophistication. By "project-based", we mean that students learn and apply chemical engineering principles by actively completing a series of projects, including open-ended design projects, throughout their sophomore year, rather than by simply passing a series of tests on related but compartmentalized subjects in a lecture-based four course sequence. In this paper we describe the new project-based, spiral curriculum, discuss our implementation and assessment procedures, and present some preliminary results from our initial implementation. We anticipate that the new curriculum will be transferable to other settings and other timetables and that our approach can serve as a model for other engineering disciplines.

Developing The Spiral Curriculum

At WPI, the academic year is divided into four terms of seven weeks each. The course sequence for typical chemical engineering sophomores is shown in Figure 1. In the first course, students learn material and energy balances, the basic mathematical tools used by chemical engineers to analyze physical and chemical processes. In the second course, they learn how to apply the first and second laws of classical thermodynamics to analyze processes like steam power plants and refrigeration units. In the third course, they study mixture thermodynamics, reaction equilibria, and phase equilibria, the phenomena that underlies many separation processes. In the fourth course, they learn to analyze and design equilibrium staged separation processes like distillation columns. At other schools, this material would be covered in two 14-week semesters, making up the first sequence of courses in chemical engineering. In this traditional course sequence, students often see thermodynamics as a stand alone subject that has little relationship to the other material. The fact that thermodynamics underlies the material and energy balance and separation process courses is often obscured because in teaching the methodology for those courses, the thermodynamic information is simplified or taken for granted as being given in the problem statements. Also, note that traditional students spend about three quarters of a year acquiring skills and concepts before actually applying them to any design tasks in the last part of the year. Moreover, after two terms of thermodynamics, students tend to forget the material balance skills they learn in the first term. Practicing chemical engineers

Material and Energy Balances	Classical Thermodynamics	Mixture Thermodynamics	Staged Separation Processes

Figure 1. Traditional sophomore chemical engineering course sequence.

need to apply material and energy balance skills together with thermodynamic analysis and property estimation to analyze and design chemical processes. We sought a curriculum that would integrate the material from the four traditional courses and reinforce the fundamental concepts by applying them to different situations throughout the year.

To develop the spiral curriculum, we began by itemizing detailed course objectives for the four traditional courses in our sophomore year. The itemized learning objectives were then prioritized and reorganized into a spiral curriculum that can be explained with the aid of Figure 2. The sophomore year was divided into four levels, shown in the vertical direction on the diagram and corresponding to our four terms (at WPI the four levels correspond to discrete courses, but that need not be the case). Our four traditional courses are shown at the base of the diagram to provide a reference frame for comparison. Students begin the new curriculum at Level 1 where they are introduced to the basic skills and concepts from all four traditional courses. In Level 2, in addition to introducing new material, we build upon the previously acquired skills and concepts by requiring them to be re-used and extended to more complex tasks. The succeeding two levels follow similarly, with the students re-visiting topics met before at lower levels, extending them to more sophisticated uses and ideas, as well as acquiring new knowledge and concepts needed to address more challenging problems. It must be emphasized that each level draws material from all four traditional courses.

This new curriculum forces repetition of important ideas throughout the entire year, and emphasizes their connection to ideas usually presented entirely separately in a later course. Hopefully, by the end of the year, every student will appreciate the integration of the material and none will escape without knowing that chemical engineers are often called upon to combine material and energy balances with thermodynamic information to analyze or design processes.

Cooperative Group Projects

The next step in developing the project-based, spiral curriculum was to develop a series of industrially relevant projects to use as a framework for achieving the learning objectives at each level. Examples of project titles and the topics they cover are presented in Table I. Two or three projects were developed for each level, some that require laboratory experimentation and others that contain engineering design components. Project

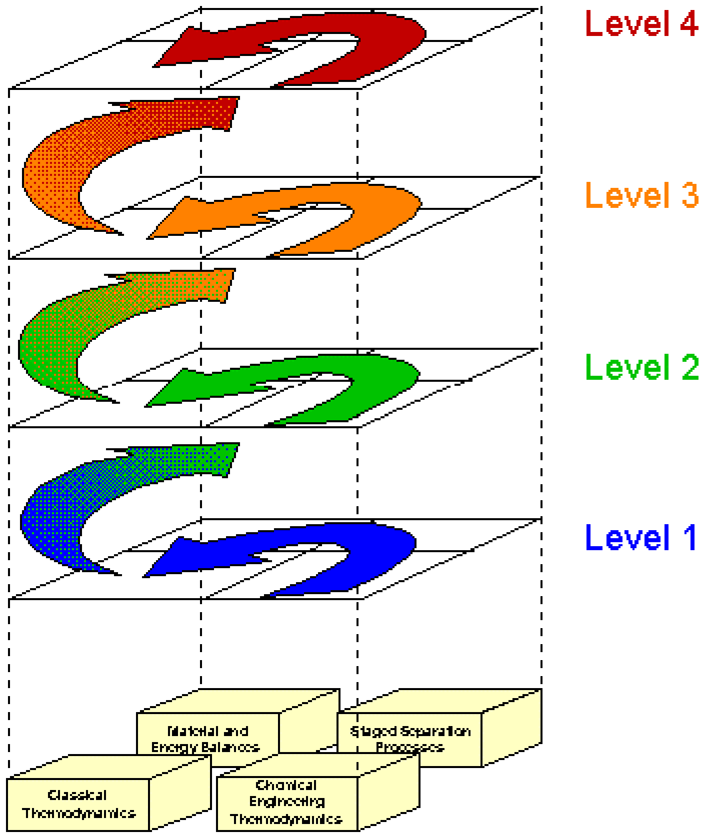

Figure 2. Schematic diagram of the spiral curriculum for sophomore chemical engineering.

deliverables include a written report; the format varies from a brief memo report to a formal report, depending on the project. Some projects also require an oral report.

Student teams are confronted with these projects before they have learned all the fundamentals required to complete the projects. The fundamentals are then acquired on a “just-in-time” basis through an assortment of channels including multimedia computer instructional modules, lectures, workshops, reading assignments, and student discovery from experimentation and/or the literature.

The project work is carried out by four-member cooperative learning groups. The groups are assigned at random with adjustments aimed at distributing the strongest students evenly across the groups. A team of three faculty (the authors) coordinates and evaluates the cooperative learning groups. The faculty team also facilitates acquisition of the information necessary to complete the projects. Peer learning assistants (PLAs) serve as liaisons between students and faculty to help coordinate projects and facilitate cooperative learning [5]. PLAs are upper class students, trained in conflict resolution, group dynamics and cooperative learning strategies. They neither tutor nor grade, but help cooperative learning groups keep on track by asking questions, resolving conflicts and directing floundering groups to the information required to complete the projects. We have shown

Table I. Examples of projects from each level.

Level	Project	Topics Covered
1	Methylene chloride recovery	Simple, steady state, material and energy balance; ideal phase equilibria
2	Ammonia synthesis	Material and energy balances with recycle; phase equilibria; refrigeration analysis
3	Methanol/methyl acetate separation by pressure swing distillation	Non-ideal phase equilibria; material balances; staged separation process design
4	Catalytic reactor regeneration	Reaction equilibria; phase equilibria; material balances with recycle

that the PLA-based cooperative learning structure, developed at WPI, increases student learning and faculty productivity [6, 7].

Computer-aided learning tools are used where possible to help deliver the new curriculum. We utilize the software developed at the University of Michigan for learning chemical engineering fundamentals [8]. We are also developing some interactive learning tools specifically for the spiral curriculum [9].

In addition to the projects, each level includes some traditional homework problems and tests taken individually. The project work, together with supplemental lectures and workshops, provides students the opportunity to prepare for the tests.

Assessment Program and Preliminary Results

We are delivering the project-based, spiral curriculum for the first time in the 1997-98 academic year. Thus, when this manuscript goes to press, we are still gathering data for evaluation of our initial offering. We present here, therefore, only a summary of our assessment program and some preliminary results. Additional results will be presented at the meeting.

We selected, at random, one third of our sophomore class as the “test” group for the spiral curriculum. Their performance and attitudes are being compared to those of students in the “control” group, taught simultaneously in our traditional course sequence. Our overall project assessment goals are to evaluate how the spiral curriculum affects students' ability to: solve problems at several levels of cognition, work in teams, work independently, master the fundamentals of chemical engineering, and integrate material from several courses. We will also learn how it affects student attitudes and satisfaction about chemical engineering and their professional development within the discipline. A longitudinal structure is designed to measure immediate impact (at the end of the sophomore year) and lasting impact (at the ends of the junior and senior years, and following graduation). External consultants are being used to provide objective assessment through a variety or qualitative and quantitative measures. These include surveys, interviews, videotaping of class and project work, student tests and project reports, end of term course evaluations, a design competition, and an end-of-year comprehensive exam. We are also concerned with the costs and benefits of curriculum reform. A cost/benefit analysis of the project costs, including faculty time, and the benefits derived is being conducted.

The spiral curriculum has been well received by students in the initial offering. Preliminary results indicate a qualitatively different attitude toward team work between the test and control group students. The test students have encountered group work throughout the year. When surveyed about the advantages and disadvantages of group work, they found nothing but advantages. The control students have had limited exposure to group project work and their surveys indicate a mixture of perceived advantages and disadvantages that reveal a more individualistic approach than that of the test students. The spiral curriculum also appears to have made a positive influence on student's satisfaction with their major. Retention of students in the test group has been better than in the control. Less than ten percent of the test group changed majors during the first year and all changes were made during the first term. About twenty percent of the control group changed majors with half of those changes occurring during the third term. We are eager to learn about the results of more qualitative and quantitative assessment measures and will report those when they are obtained.

Acknowledgments

Funding for this project by the U. S. Dept. of Education's Fund for the Improvement of Postsecondary Education is gratefully acknowledged.

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