A Spiral Curriculum for Chemical Engineering

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1. Introduction

The broad goal of our work is to transform the educational experience of undergraduate students in chemical engineering. Towards this end, we are developing and implementing a "multidimensional spiral curriculum" by integrating concepts from core courses at the sophomore, junior, and senior level. In the first step described below, our implementation focuses on students who transfer from two-year community colleges into a four-year baccalaureate program at the University of South Florida (USF).

2. Spiral versus sequential curriculum: critical considerations

The traditional curriculum that is offered in most engineering departments is sequential in nature and students cover core topics in their major discipline through a series of courses. For example, in Chemical Engineering departments across the US a student starts with basic concepts such as material and energy flows in chemical processes (Figure 1). Typically, this is followed by thermodynamics and transport of mass, momentum, and heat courses. Progression through the final years of a degree program involves courses on chemical separations, reaction engineering, process control, and a capstone design course. These core courses are supplemented with various technical electives that differ from one program to the other or depend on the professional track that a student will follow. The sequential arrangement separates the core curriculum into smaller units, expose students to each unit in succession, and require mastery of each unit before stepping on to the next unit.

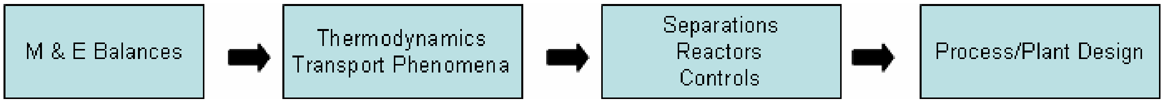

Figure 1. Traditional Sequence of Core Topics in a Chemical Engineering Curriculum

For a student in a four-year program, the traditional sequential curriculum has both advantages and disadvantages. From an institutional perspective the sequential curriculum is easier to teach. The modularity of a sequential curriculum provides structure to the course offerings for an engineering discipline and defines boundaries to the content of courses for a degree program. Proponents of sequential curriculum argue that this approach is better from a student perspective as well since the concept of "Mastery Learning" wherein one ensures that students have mastered each increment of a subject in a hierarchical sequence before going

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on to the next is a superior learning approach. On the other hand, in each course within a sequential curriculum a final examination is the primary mechanism to test the competency of the student in the topic that is studied and satisfactory performance allows a student to advance to the next stage of study. Thus, the sole motivation for a student is to work for a passing grade in one course and progress to the next course in sequence. Typically, little consideration is given on how the knowledge and skills in one course will be used in subsequent courses or its contribution to the whole curriculum. Implicitly, this integration between concepts is left to students and is expected to happen automatically in the capstone design course. Furthermore, even though there are many unifying and common concepts between courses, there is no systematic emphasis on these linkages unless an individual instructor focuses on this unification at his or her own discretion.

Regardless of these merits or demerits, it is clear that the linear sequence approach to the curriculum fits best to programs where students can begin in a specific major discipline as freshmen and proceed through the series of courses towards graduation. For students that transfer from two year community colleges, the disadvantages of the sequential offerings become exacerbated because they cannot benefit from the gradual spacing of courses.

The spiral curriculum is an alternative model to the sequential curriculum and was first proposed in 1960 by an educational theorist named Jerome Bruner [1]. Here, a set of interlinked and basic concepts are presented briefly and simply to students on a first traverse around a spiral path (Figure 2). As a learner completes a traverse, the thread is then continued at a higher level around the fundamental ideas of the spiral in greater detail, breadth, and sophistication. Thus, the spiral focuses on introducing higher cognitive content with progress along the spiral path. The model of a spiral curriculum has been frequently applied in K-12 education of science and mathematics topics [2], where it is often referred to as *incremental learning*. In higher education, the spiral curriculum has only recently gained an entry with applications in the study of nursing, medicine, and optometry [2-5], design of a course for non-computer science majors at Michigan State University[6], and the sophomore year for chemical engineering students at Worcester Polytechnic Institute[7].

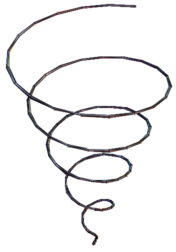

Figure 2

3. Multi-dimensional spiral curriculum in chemical engineering

Our goal is to address student learning by undertaking a curriculum transformation in Chemical Engineering such as that depicted in Figure 3a where all the core concepts of material & energy balances, thermodynamics, transport processes, reaction engineering, controls, and design are simultaneously present in a spiral curriculum. Figure 3b shows a schematic of the **multi-dimensional spiral curriculum** that we propose to implement for transfer students using three inter-locking spiral paths. Along one direction of this curriculum the students will progress from the conceptually simple steady state systems and equilibrium units to the more complex task of large scale systems integration while in the second direction the students will learn the core technical concepts for analysis and design that are essential for a professional chemical engineer.

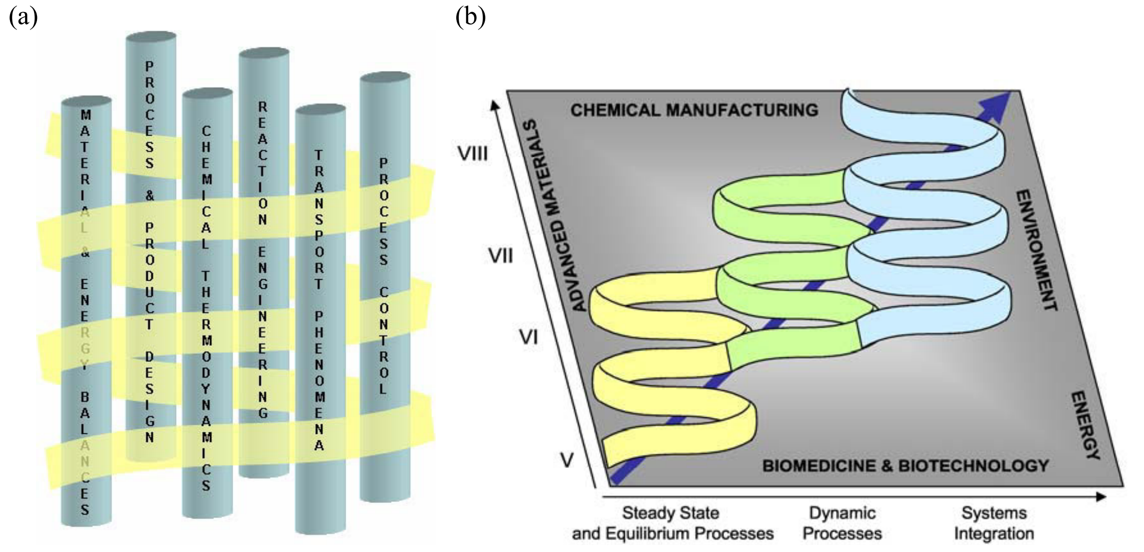

Figure 3. Schematic illustration of (a) spiral model adapted for core curriculum in chemical engineering, and (b) a multi-dimensional spiral curriculum.

For instance, the students may begin with a material balance in non-reactive systems and upon revisiting the concept a second time may learn how to incorporate reactions and on the third time may learn how to go from macroscopic to differential balances. Concurrently, students may begin with phase equilibrium for a single substance first that is necessary for material balances, then learn about phase equilibrium in multi-component ideal mixtures on the second visit, and then learn about non-ideality, which requires a higher level of sophistication. Thus, a spiral curriculum puts into practice the philosophy that "Learning is an organized process with acquisition of new knowledge requiring prior core knowledge"[8].

In this spiral approach, *links between different traverses* of the spiral are emphasized which allows students to reinforce the prior concepts and begin grasping the application to new knowledge. For example, when students learn heat exchanger design and heat transfer, the link to first solving a mass balance is stressed. *Vertical integration* between learning loops is achieved by choosing themes that are central to the overall outcome that is desired. For example, if the development of skills to design a chemical product or process (e.g., energy requirements of an automobile, drug delivery system, miniaturized chemical assay system) is a desired outcome then the spiral of core topics is sequenced around one or more illustrative chemical systems (e.g., a fuel cell, drug loaded nanoparticles, microfluidic device, respectively) in increasing level of sophistication as each loop of the spiral is traversed.

A steady and continuous **deepening of knowledge** is incorporated in the spiral curricular approach as students move from simple to complex concepts. **Organization and**

integration are implemented in the spiral approach as the complex relationships between different engineering topics can be correlated and sequenced. This feature is especially relevant in current times where a multitude of engineering educators are focusing on integrated curricula. Our implementation also takes advantage of **reinforcement based learning,** where a spiral approach allows students to be exposed continuously to previously learned topics.

4. Results and Discussion of First Cycle of Implementation (2006-2008)

Implementation of the curriculum and enrolment of transfer students in the new curriculum began during 2006-2007 academic year. From a common pool of students that typically begin their studies in chemical engineering at USF, three groups of students were identified. **Group 1** included students who had not taken a pre-requisite course in engineering thermodynamics. This group composed largely of students who began at USF in the College of Engineering in a traditional sequential curriculum. It also included a few transfer students who did not consent to be part of the curriculum reform research. **Group 2** was composed of students who had taken a pre-requisite course in engineering thermodynamics either at USF or an equivalent course elsewhere. Students in **Group 3** were transfer students who consented to be part of the new curriculum. The range of GPA of the students in the Group 3 was similar to the students that were in Groups 1 and 2.

The students participating in the multi-dimensional spiral curriculum were assessed in several different ways. Figure 4 indicates the different paths that the students in the three groups took during the first implementation. It is clear that intermediate stages such as the end of year 1 exist where students have cumulatively experienced course topics that are quite similar in range though by different instructors. Therefore, common quantitative exams in the courses indicated by a green border were used as a tool to compare student proficiency and grasp of concepts in the different groups. Additionally, there are several other points of intersection where the performance of students can be assessed alongside one another. We chose three laboratory courses because they offer an opportunity to test how well students can build on concepts from the classroom courses and it requires students to engage in hands-on activities in teams. They have to write reports, give oral presentations, and also take traditional quizzes. Student performance was also tracked in classroom courses such as Numerical Methods, Materials Science, Engineering of Biological Systems, and Capstone Design. These courses were not part of the transformed curriculum and therefore, offered an opportunity to assess students without ambiguities from different instructors or class size. Finally, the students were asked to complete exit surveys and participate in an exit interview at the time of graduation for assessing their perceptions of the curriculum.

As an illustrative example, Figure 5 shows the plot summarizing the comparison of student performance in the three common laboratory courses. In the plot, the maximum, minimum, and average grade points for the letter grades are shown for students in Group 3 separately from all other students. Even though a direct cause and effect relation is difficult to establish because of differences in class size for the spiral and non-spiral courses, the plot in Figure 5 indicates that range of grades and the average for the students who participated in the novel spiral curriculum was higher. Similar trend was found in the other common courses suggesting that curriculum reform and implementation can be lead to valuable gains.

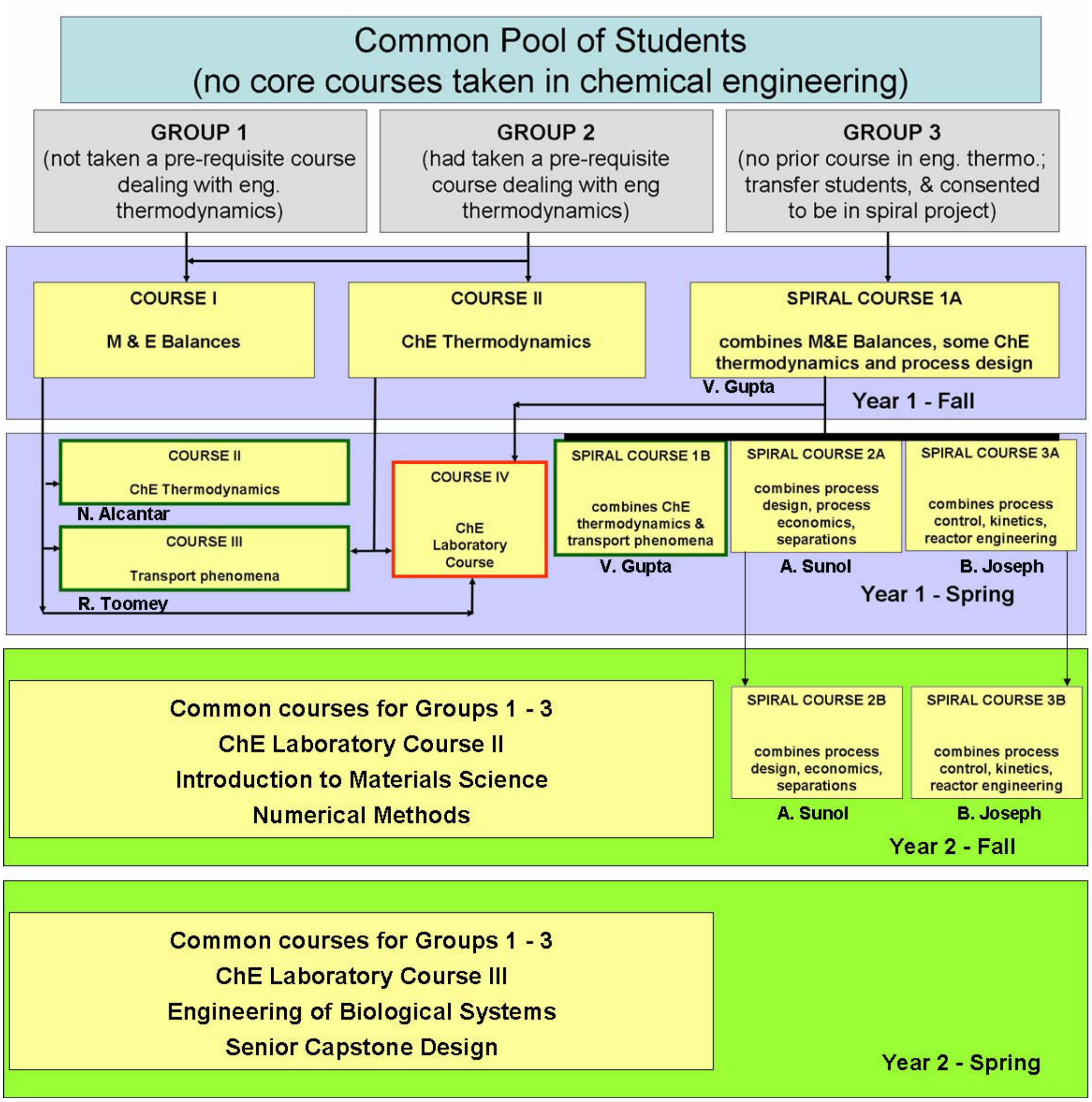

Figure 4

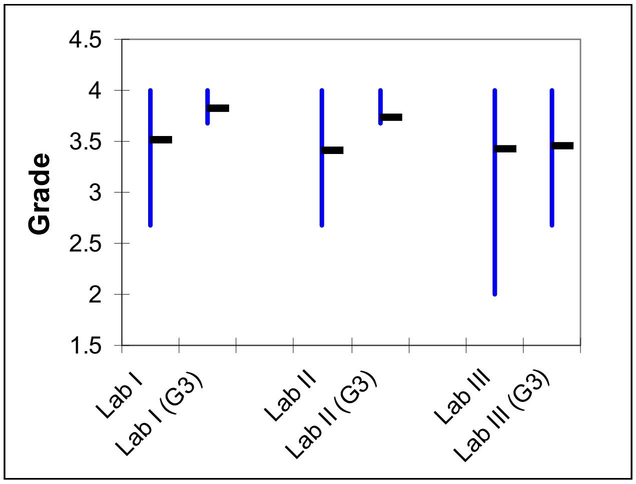

Figure 5

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