

# INTEGRATING DESIGN THROUGHOUT THE CHE CURRICULUM

## *Lessons Learned*

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One of the complaints heard most often from engineering undergraduates is that they do not see anything practical until late in the curriculum. To the students, course material becomes a seemingly endless stream of apparently useless equations and concepts. This situation is typical for most students in a traditional curriculum because the early years are filled with engineering science, with the final year addressing process design, including a capstone design project in the last semester or quarter. There has been considerable discussion for a number of years about integrating design throughout the chemical engineering curriculum. Much of the discussion has been driven by faculty trying to find a better way to do things and ABET criteria that encouraged the introduction of design elements before the senior year in engineering programs.

The objectives of design integration are for the students to apply engineering science earlier in the curriculum and, if the integration is set up properly, for the students to realize the interconnections between various courses in a difficult curriculum. The latter objective relates to the students getting a broader view of a process design. For example, a portion of a chemical plant may consist of a reactor, distillation column, condenser, reboiler, and pump. The students

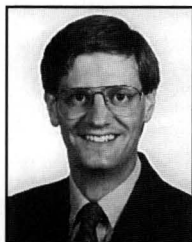
need to realize that they cannot view something in isolation ("I learned about heat exchangers in my heat-transfer class. I don't need to know that for distillation."); if there is a disturbance in one part of the process, that disturbance may affect other parts of the process.

Many departments have integrated design elements into single, lower-level courses or throughout an entire curriculum, and many more departments are thinking about it.<sup>[1]</sup> This paper discusses the lessons learned from a program of design integration that involves a significant number of courses over a period of five semesters. The program is similar to work being performed at West Virginia University,<sup>[2]</sup> the major exception being how to handle the design integration when a significant fraction of the students are co-op students.

### PROJECT IMPLEMENTATION

Perhaps the most popular method of integrating design into a curriculum is through the use of case studies, which is analogous to problem-based learning.<sup>[3]</sup> In our program, we refer to a case study as an evolving design project because the students work on the same project as they proceed through the curriculum and the level of detail increases with time. The intent of this early-design experience is for the students to continue to work on the same case study through a critical portion of the curriculum. Using our program as an example, the courses and the average number of students that are involved in the case-study approach are summarized in Table 1. Note that several courses are offered twice a year to accommodate the schedules defined for co-op students.

The concept of an evolving design project is best understood by describing, in general terms, a particular case study.



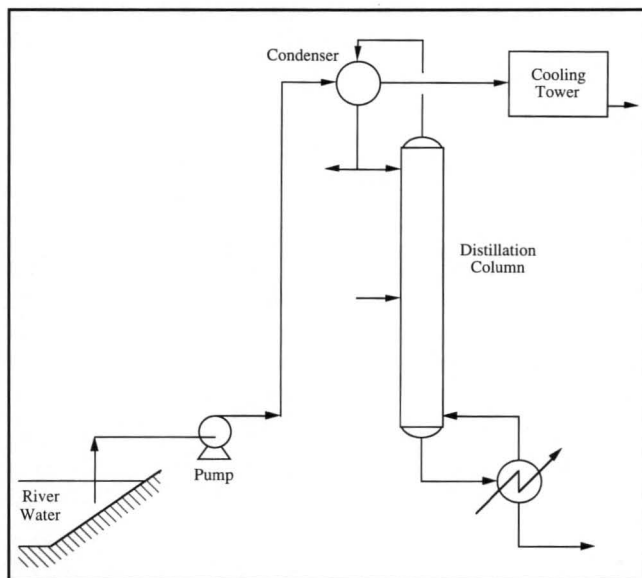
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**TABLE 1**  
**Typical Number of Students in the Case-Study Program**  
*(numbers vary depending on the cyclic nature of ChE enrollment)*

| Course Number                    | Course  | # of students, normal-sequence offering | # of students, off-semester offering* |
|----------------------------------|---|---|---------------------------------------|
| <i>First-Semester Sophomore</i>  |   |   |                                       |
| ChE 211                          | Introduction to Chemical Engineering                                  | 45                                      | 25                                    |
| <i>Second-Semester Sophomore</i> |   |   |                                       |
| ChE 220                          | Thermodynamics I  | 40                                      | 20                                    |
| <i>First-Semester Junior</i>     |   |   |                                       |
| ChE 311                          | Fluid Flow (including pumps)  | 35                                      | 20                                    |
| <i>Second-Semester Junior</i>    |   |   |                                       |
| ChE 312                          | Heat and Mass Transfer (including heat exchangers and humidification) | 35                                      | 20                                    |
| <i>First-Semester Senior</i>     |   |   |                                       |
| ChE 413                          | Separations (including distillation)                                  | 35                                      | **                                    |
| ChE 450                          | Reaction Engineering  | 35                                      | **                                    |
| ChE 431                          | Process Design I  | 35                                      | **                                    |

\* Off-semester offerings are provided primarily for students in the co-op program, although other students also enroll in these offerings for various reasons.

\*\* Off-semester section not offered.



**Figure 1.** Schematic diagram of one portion of an ethanol case study. (Exercise: ask the students if there are any problems associated with pumping river water directly through the condenser.)

***A program of this type offers advantages because it is flexible. It has the ability to handle any number of students, and the evolving design concept can be integrated into a single course, a sequence of courses, or across an entire curriculum.***

The case study used as an example here is taken from Felder and Rousseau<sup>[4]</sup> and involves the fermentation of grain to produce ethanol. It is given to the students as first-semester sophomores in the first chemical engineering course, and it initially consists of a written description of a chemical process. Groups of students sift through the description and then develop a flowsheet of the process as they envision it.

This first activity gives the students an opportunity to see how the various pieces of equipment can come together to form a successful design. The students then perform detailed material and energy balances around the entire process and around selected pieces of equipment (material- and energy-balance problems associated with this case study may be found in the reference cited above).

Depending on the timing of the case study during a semester, the material and energy balances either replace or reinforce homework problems. We emphasize that, at this early stage, the students are not expected to know every detail of the design, but that by the end of the curriculum they will be able to understand all of the design elements.

The students working on this case study then move on to Thermodynamics I and perform a thermodynamic analysis of a refrigeration system that uses CO<sub>2</sub>, which was produced during the fermentation process, as an environmentally safe refrigerant. This homework assignment demonstrates how thermodynamics can be valuable in understanding a "real world" process, and it serves to maintain the continuity of the case study as the students move through the curriculum.

This particular case study involves separating ethanol from water in a distillation column. As Figure 1 shows, a mixture of ethanol and water vapors exits the top of the distillation column and passes through a heat exchanger where the vapor is condensed by cooling water. In the class discussion we emphasize that the cooling water somehow has to be delivered to the condenser. Although not part of the original process description, we explain that the cooling water is pumped from a river, through the condenser, and then to a cooling tower that is used to reduce the temperature of the water before it is discharged back into the river. In the Fluid Flow course, the students are given additional specifications about the process, and (using the actual pump curves) they select the most cost-effective pump and piping for the flow system. In the Heat and Mass Transfer course, we give the students more information and ask them to "design" the

condenser (we also discuss the fact that it is not good practice to pump water from a river directly into the condenser because of the likelihood of fouling). After studying humidification in the Heat and Mass Transfer course, the students size the cooling tower. In the first semester of their senior year, the students size the distillation column and a reactor in their Separations and Reaction Engineering courses, respectively, and in the Process Design course they perform an economic analysis of one portion of the process or the entire process, depending on the complexity of the case study.

The objectives of these open-ended assignments are to

- ▶ Reinforce the classroom lectures with real-life applications
- ▶ Have the students perform calculations and make engineering judgments
- ▶ Show the students that changes in one part of a process may affect the performance of other pieces of equipment

For example, we address the issue of what happens if the feed flow rate to the distillation column increases. Will the cooling-water pump be able to handle the increased load in the condenser? Should the pump be oversized to handle the possibility of an increased load? By how much? What happens if the temperature of the river water changes? Does that affect the performance of the pump, the condenser, or the cooling tower? It is important to have the students wrestle with these questions; otherwise, they perceive the design calculations as just another homework exercise, and they do not realize the interactions that exist between process components.

## PROJECT LOGISTICS AND LESSONS LEARNED

Each year a case study is initiated with the sophomores. The students work on that evolving case study from their sophomore year through the first semester of their senior year (five semesters altogether, as shown in Figure 2). All of the assignments and solutions for a given case study are kept in a three-ring binder, which is available for the faculty. Likewise, the students are strongly encouraged to maintain a portfolio of their work. This program works well for students who proceed through the curriculum outlined in the course catalog. In fact, a similar program is in place in the chemical engineering department at West Virginia University.<sup>[2]</sup> Minor problems arise when students drop or fail a

course. When those students retake a course, they work on a subsequent case study and lose some of the continuity provided by the evolving design project. Continuity is maintained, however, for the vast majority of the students.

A major logistical difficulty arises when there is a large number of co-op students involved, because they are continually rotating on and off job assignments. Funded by the NSF SUCCEED coalition, this program was intentionally set up to determine how to accommodate a relatively large number of co-op students (120, or 60%, of our students are in the co-op program). Since we have students who start the Introduction to Chemical Engineering course in either the

fall or spring semester, there are two options: 1) initiate a different case study in each semester, or 2) use the same case study for the fall and spring semesters in a given academic year.

The first option is a theoretically reasonable approach, but from a practical standpoint it is difficult to carry out because of what happens in the upper-level courses. As co-ops go to and return from job assignments, they are not in the natural progression of the curriculum as depicted in Figure 2, so there are students in junior- or senior-level courses who began with different case studies. In fact, it is possible that an instructor would have to be aware of three or four different case studies in a senior-level course, which is impractical. Therefore, it was determined that the best way to incorporate design integration with a large fraction of co-op students was to use the second option. The same chemical process is used in the fall and spring semesters of the sophomore year, but some of the specifications (flow rates, temperatures, pressures) may be changed slightly from one semester to the next. In this way, only one "type" of case study is initiated each year, and instructors in upper-level courses do not have to keep track of as many types of projects.

But, even this is not a panacea. Depending on how many co-op students took the maximum five work assignments, a faculty member in a senior-level course could still be confronted with up to three different case studies (the situation with three case studies is rare; two is more common). In this instance, the instructor may either develop similar but separate assignments for each of the case studies (which can be a daunting task) or identify the case study used by most of the students and focus on it. We have found that the latter option is a good compromise because it reduces the time pressure placed on the faculty member while still affording the students an opportunity to apply what they are learning in a

|               |                 |                 |
|---------------|-----------------|-----------------|
| <b>Year 1</b> | <b>Soph. 1</b>  | <b>Soph. 2</b>  |
| <b>Year 2</b> | <b>Junior 1</b> | <b>Junior 2</b> |
| <b>Year 3</b> | <b>Senior 1</b> |                 |

**Figure 2.** Five-semester sequence in which students work on their evolving design project. A certain percentage of students follow this sequence and the logistical problems are minimal. Co-op students typically do not follow this sequence, and logistical difficulties have to be managed.

design situation. To minimize the logistical difficulties in upper-level courses even further, it is possible to introduce the same case study to the incoming sophomores for many semesters in a row, but a different case study should be initiated at the sophomore level every two or three years.

There are several things that must be considered when using evolving design projects.

- *The selection and development of a case study is crucial. It should be simple enough so that sophomores do not feel overwhelmed by the experience, but it should contain all of the elements that are desirable in order to demonstrate the connections between topics in a course or a curriculum. If an instructor chooses to have several case studies used at the same time in an upper-level course, the projects should have common elements so students can be working on the same types of problems even though they may be working on different case studies (e.g., each process should contain a distillation column so that the students are all sizing a distillation column regardless of whether the student is working on case study X, Y, or Z).*
- *Tell the students why this case-study approach is being used. Explain to them that this is not simply another homework assignment. Explain that the main goal is for them to be able to understand the interconnections between design elements and that they will be better engineers because of that understanding.*
- *Have the students work in groups. Most of the assignments should be developed so they can be tackled by student groups ranging in size from two to five people, depending on the size of the class and the complexity of the task. A vast majority of the students say that they value the group interactions.*
- *If possible, assign projects at different times during a semester. Try to avoid dumping an open-ended design project on the class near the end of a semester. Students do not appreciate that and it can easily kill all of the momentum that has been accumulated up to that point.*

- *Sources abound for ideas for case studies.<sup>[4-7]</sup> Once the main idea for the case study is fixed, then it takes a little creativity and time to integrate the various design elements,<sup>[8]</sup> but the students will benefit from it.*

## ASSESSMENT OF THE CASE-STUDY APPROACH

An ideal plan with which to assess the effectiveness of the case studies would involve forming parallel sections of each course, with some of the students enrolled in the "traditional" sections and the remaining students enrolled in the sections that incorporate a case study. Also, the same professor should teach both sections of a given course, the cohorts of students should be similar in terms of defined criteria (e.g., GPA, fraction of commuting students, fraction of co-op students), and the students should not cross over from the traditional to the modified sections and vice versa. Once the two groups of students finished the curriculum, they would be evaluated

**TABLE 2**  
**Student Responses Before and After Working on Case Studies**  
*(1=strongly disagree; 2=disagree; 3=neutral; 4=agree; 5=strongly agree)*

| Statement   | Mean (Std. Dev.) |                  |
|---|------------------|------------------|
|   | Before<br>(N=89) | After<br>(N=148) |
| I am an effective problem solver.                     | 3.8 (0.6)        | 3.9 (0.7)        |
| I would rate my written communication skills as good. | 4.0 (0.7)        | 4.1 (0.7)        |
| I would rate my oral communication skills as good.    | 3.7 (0.8)        | 3.8 (0.8)        |
| I would consider myself an effective team member.     | 4.4 (0.6)        | 4.3 (0.6)        |
| I would consider myself a capable leader.             | 4.1 (0.7)        | 4.1 (0.8)        |

through various means to determine if there is a difference between them. This ideal scenario is extremely difficult, if not impossible, to achieve. Therefore, we decided to integrate the case studies in many of our core courses (shown in Table 1) without forming special sections and to assess the program using several questionnaires.

To evaluate the effectiveness of the case-study approach, a survey was given to sophomores before they worked on their particular case study. The survey was then given to these same sophomores after they worked on their case studies in the Introduction to Chemical Engineering course and to juniors who had worked on several assignments related to their case studies. The survey consisted of a set of five statements (shown in Table 2) and the students were asked to indicate the extent to which they agreed with the statements (1=strongly disagree, 2=disagree, 3=neutral, 4=agree, 5=strongly agree). These statements were used because they represent the major attributes that industry looks for in new engineering graduates. Results for the mean and standard deviation for each statement are presented in Table 2.

The total number of responses was about 90 before the implementation of the design project (encompassing three semesters of Introduction to Chemical Engineering). The total number of students responding after they had worked on case-study assignments was about 150, including stu-

dents from the same three sections of Introduction to Chemical Engineering and from one section each of the Fluid Flow and the Heat and Mass Transfer courses. The surveys were staggered so that different students were contributing to the 150 "after" responses (e.g., the juniors in the Fluid Flow and the Heat and Mass Transfer courses were different groups of students). As shown in Table 2, the mean and standard deviation remained roughly the same for "before" and "after" responses to each survey statement. These data indicate that the case-study approach does not seem to significantly influence the students' perception of their capabilities with regard to the five attributes referred to in Table 2, but their responses to other questions provide additional information.

To further investigate the potential effect of the case studies on the comprehension of topical material in a given course, we asked an additional question of the juniors in the Fluid Flow and the Heat and Mass Transfer courses: "Do you think that you learned course content better from homework problems in the textbook or from the case study? Explain your answer." As shown in Table 3, about 40% of the students thought that the case studies were more effective in terms of learning the course material, and 35% felt that the combination of conventional homework problems and case-study projects helped them learn the material better. The latter result was particularly interesting because the question was phrased as an "either/or" question, yet a significant number of the students responded that both types of assignments are needed. To supplement the statistics, a representative sample of student comments is included in Table 3.

We then asked the students to list what they liked most about the case studies and what they liked least. Although not comprehensive, a listing of many of the comments is provided in Table 4. The responses concerning what the students liked about the case studies affirmed most of our expectations. Many of the comments about the dislikes were also expected, and some of these comments can be used to take corrective actions and improve subsequent case-study assignments. Most of the student dislikes, however, can be viewed as desirable results as indicated by the faculty replies shown in parentheses in Table 4. Finally, even though it can be a little more work for the students (and the faculty), the case-study approach has a definite influence on how students relate to course material, as evidenced by the positive written comments from students. For example

- *"The design project has been a real pain in the neck, but after each part gets done, I really do feel like I've learned something and actually been able to apply it."*
- *"I think the project was very instructive. It gave life to the problems in the book and gave a feel for how it might be in the real world."*
- *"The design project is an excellent tool in this*

**TABLE 3**  
**Student Responses Concerning**  
**Homework Problems vs. Case Studies**

Question:

"Do you think that you learned course content better from homework problems in the textbook or from the case study? Explain your answer."

| Response   | No. of Responses<br>(% of Total Responses) |
|------------|--|
| Homework   | 12 (24%)                                   |
| Case Study | 21 (41%)                                   |
| Both       | 18 (35%)                                   |

Student Comments:

"Homework problems. By the time we did the case study, most of the concepts that we used were common sense."

"The homework problems were good for learning the course content. However, the case study allowed for more than one topic at a time and helped me to learn the application of course content."

"Better from homework problems, but learned real-life applications from case study."

"I felt better doing homework (as if I accomplished more) but I believe I learned more through the case study."

"In order to do the case study effectively, you had to do the required homework problems. I don't think I learned more from one approach over the other. I do think that both approaches helped each other out and tied everything together that we learned over the course of a semester."

"The case study was more like the test questions in that it was much more complicated than the homework problems. Therefore, it provoked more in-depth [thought] and helped me to learn more."

"I learned more about pumps from the case study than from the homework problems. The case study seemed to be more detailed than the homework problems."

"The case study and homeworks each tend to be very helpful. The homeworks narrow down specific problems while the case study combines all problems together to see how they are used together."

"Both are required, but I will retain more from the case study. If we were assigned a case study first, we would have no foundation on which to start work, so homework is necessary to build up our skills before delving into a case study."

"I feel I have truly learned from the case-study approach. Case studies required me to analyze situations and to use judgment skills. Sometimes homework can be 'follow the formula,' 'right-or-wrong' type questions that make it easy for one to just go through the motions rather than understand why."

class. It increases the student's knowledge by incorporating ideas learned throughout the semester into one unit."

**TABLE 4**  
**Student Likes and Dislikes About Case Studies**

**What did you like most about the case study?**

- Real situation
- Thought provoking
- Learned a lot
- The math involved
- It requires analysis and judgment skills
- Learning how to actually use what I learned to solve a real-life problem
- Gaining new insights on particular strategies
- Struggling for hours and resolving the problem
- Allows students to get more in-depth than "usual" homework assignments allow
- Enjoyed the group work
- Allows us to see the big picture
- Putting the ideas of several people together to come up with better combined efforts

**What did you like least about the case study?**  
*(Faculty comments are in parentheses)*

- Had to make too many assumptions  
*(develops judgment)*
- Had to learn some of the topics at the last minute  
*(plants the seed for life-long learning)*
- Writing the report  
*(develops communication skills)*
- Not knowing where to start  
*(develops judgment)*
- Time consuming; getting stuck for hours  
*(perseverance is an attribute)*
- Working with those incapable of problem solving  
*(develops personnel-management skills)*
- Finishing the project and finding out some small error that affected the overall outcome—this probably happened at least six times  
*(promotes more careful work habits)*
- Some people like to take charge and do all the work without conferring with others or giving them a chance  
*(develops teamwork skills)*
- Having to arrange convenient times for everyone to meet  
*(develops teamwork skills)*
- Unsure of answers  
*(real-world experience)*

## SUMMARY

These case studies are not meant to replace the capstone design project. The program is formulated to teach the students to think about design and to prepare them for the capstone design experience in the second semester of their senior year. The use of evolving design projects can have a significant positive effect on the education of chemical engineering undergraduates. The students discuss the various case studies, they exchange ideas, and they even look forward to open-ended projects. Evolving design projects create a unique mode of learning for the students.

A program of this type offers advantages because it is flexible. It has the ability to handle any number of students, and the evolving design concept can be integrated into a single course, a sequence of courses, or across an entire curriculum. Logistical difficulties can be encountered if the department has a substantial co-op program in place. Nevertheless, in terms of student development, an evolving design project offers a common thread through the curriculum that can lift the students to the next level of understanding engineering design and its consequences.

## ACKNOWLEDGMENTS

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