ChE classroom

A LARGE-GROUP SENIOR DESIGN EXPERIENCE

Teaching Responsibility and Life-Long Learning

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The subject of this paper is a unique, two-semester, senior design experience in which students learn to be responsible in a team environment and to work in an organizational structure. Under the direction of a student chief engineer, the class works on one design project for the entire academic year, beginning with a feasibility analysis and ending with a detailed, preliminary design. The project emphasizes team effort and teaches lifelong learning skills.

This year-long design project is only one facet of the undergraduate design experience at West Virginia University. In the freshman year, there is an introduction to design through a cross-disciplinary course in guided design and decision making.[1] The initial chemical engineering design experience is the integrated sophomore and junior design project in which students work on progressively more complex versions of the same process as they advance through the curriculum, so that they appreciate the practical applications of what they are learning.[2,3] Another portion of the design experience consists of individual design projects in which students work on three design projects of increasing complexity during the senior year (in parallel with the year-long design project described here), in order to enhance their individual problem-solving skills.[4]

These experiences ensure that each student acquires traditional equipment design and process synthesis skills independent of the large-group project described here. The vertical integration of design through the curriculum, the extensive oral and written communication assignments accompanying these experiences, and the communication assignments required in the senior laboratory, create the backbone of what we call "The Holistic Curriculum."[5] The role of specific required and elective courses is seen as supportive of this backbone, adding strength and breadth.

Professor Harold P. Simons introduced the year-long project into our curriculum in 1941, and many of its details have been presented previously.[6] It has survived the inevitable turnovers in faculty, continually evolving and incorporating the most current resources to define and attack the problem assignment. The central strategies of the program, however, have remained consistent throughout the last fifty-four years. These strategies seek to develop in students, through cooperative learning, skills for life-long learning, critical thinking, effective communication, self-evaluation, problem solving and decision making, and leadership and team building.

Motivation for the year-long project is that the best way for students to learn the above skills is to practice them. Through this project, students learn:

- How a large team works. They learn that each team member can and must have different responsibilities, but that everyone's contribution is important. They also teach each other.
- To identify what they need to know in order to solve a problem, to develop skills for learning technical subject matter not explicitly taught in the standard curriculum, and to develop strategies to teach each other.
- The need for, and develop the skills necessary for, extensive library research work, including patent searches.
- To communicate with professionals from industry and government agencies—possibly their first contact with professionals who work outside of the university setting.
- About management, whether or not they are group leaders or the chief engineer. All are involved in negotiating, communi-

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cating, planning, and evaluating. In addition, the chief engineer and the group leaders gain leadership and management skills and experiences not normally available in an undergraduate experience.

In general, all students get the "big picture" view of a chemical process design, including responsibility within an organization, not usually encountered at the undergraduate level. Results of our outcomes assessment plan provide some support that students are acquiring the skills listed above.[7]

DESCRIPTION AND ORGANIZATION

The year-long design project is a component of the two senior-year, four-hour design classes. In the fall semester there is a typical classroom component consisting of design, economics, safety, and professional ethics. There are also two individual design projects (called "Majors").[4]

Faculty play roles in the project (a similar concept has been used by others[8]), with one faculty member assuming the role of the "client." (At times we are fortunate enough to have someone from outside the University assist in this role.) The client's role may be one of a venture capitalist looking for a profitable investment, or the client may own a company that has an excess of raw material. The client "hires" the student company by communicating initially with their "vice-president," another faculty member. The group "assigned" to the client is the senior class, under the direction of the student chief engineer.

The goal of the fall semester is to do a feasibility study and to present alternatives to the client at the end of the semester. (This first-semester group project counts for 20% of the course grade.) Before the beginning of the spring semester, the client makes a decision based on the alternatives presented in the feasibility study. In the spring semester there are no formal classes. There is the third Major and the second semester of the group project, with the latter being 75% of the course grade. The final product is a detailed preliminary design, as per the client's wishes, presented in a public forum.

The essence of the senior design is that the students, not the faculty, are responsible for the project. The student chief engineer is free to organize the class in any manner; the usual result is one layer of management, with the class divided into groups of 4-6 students, with each group under the direction of a group leader. The chief engineer coordinates and distributes tasks among the groups, and the group leaders then assign the group members component parts of the task. Typical group tasks include researching a patent containing kinetic data, designing a reactor or separation sequence, performing a HAZOP study, or analyzing process economics.

The group leaders are also responsible for ensuring that the task is completed, ensuring that all group members contribute as equally as possible, and reporting the results to the chief engineer and/or the client. Communication is important, between students and the client (described below) as well as among students. Internal memoranda allow all students to keep track of what has been done and to avoid duplication of work.

The vertical integration of design through the curriculum, the extensive oral and written communication assignments accompanying these experiences, and the communication assignments required in the senior laboratory, create the backbone of what we call "The Holistic Curriculum."

There is usually a clear chain of command. If the chief engineer is to be away from campus for any period of time, someone (usually a group leader) is appointed as interim chief engineer. The interim chief engineer should be someone already familiar enough with the big picture to step in and act as chief engineer. The same situation is true for group leaders.

If the students need help, they go to the vice-president—not to the client. The client maintains a professional distance in the context of this project. In fact, part of the role-playing for the client can be to act deliberately ornery, or even unreasonably, forcing students to learn the art of negotiation. Since students participate in the initial definition of the project, any change in its scope involves negotiation between the students and the client.

It should be noted that 30-35 students appears to be a critical number of students. When class sizes exceed this number, we have found that the group is too large for one chief engineer to manage. When this happens, we have two different projects, two groups, two chief engineers, and two clients and vice-presidents (still with two faculty members total, each assuming a role in each project). Our enrollments are such that we have never needed more than two groups. When there are two groups, we make the projects very different. One rationale for this is that the groups will not perceive themselves to be competing with each other. They feel they can help each other and, in fact, we have seen that they do just that. Another important rationale is that the groups learn something about another project in addition to their own. Both rationales are good examples of students teaching students.

The initial problem statement is deliberately vague. Figures 1 and 2 are examples of initial memos from the client to the vice-president. It is up to the students to define more specifically the goals of the project and to obtain written approval from the client. The students must determine what tasks are required to complete the project. They learn to brainstorm and to develop a Gantt chart (milestone chart)[9] such as the one shown in Figure 3. Once the Gantt chart is approved by the client, weekly meetings are held for progress reports. Students are expected to meet the deadlines indi-

cated on the Gantt chart, to justify the situation if they are falling behind, or to justify why the schedule should be renegotiated. Minutes are taken at the weekly meetings and become official once approved by the client and the chief engineer. The minutes serve as a permanent record of agreements and commitments made by the students and by the client.

The primary deliverables for this project include a final oral presentation each semester for which all faculty, college administrators, and underclassmen are invited. The final presentation in the second semester is also open to the public; all of those individuals within and outside the University who provided information during the year are invited, and those who are nearby, in addition to members of the College administration, often attend. An extensive written report accompanies these oral presentations, and, in recent years, a poster presentation has been available prior to the formal oral presentation. The students also give midterm presentations each semester in order to convince the client that the class is on schedule and to provide an opportunity for each student to make a presentation. Written reports often accompany the midterm presentations, although the number, scope, and timing of midterm reports are determined by the client for the specific project.

Among the students' unique experiences are extensive library work and communication with professionals in industry and government agencies. Since the project is ill-defined initially, students must learn to search the various data bases for enough information to define the project better. Much of the information necessary to produce alternatives for the client in the first semester and to gather equilibrium and kinetic data for the final design is in the patent literature. Often, information is available only in obscure resources not in our library, so students must learn to use other libraries. Increasingly, students are finding the Internet to be an additional valuable resource. Since information on chemical processes or on regulations is always necessary, students must contact companies, vendors, and regulatory agencies for specific information. Here they learn that when the information they want is not in the public domain, most companies are very cooperative in providing the information. We are fortunate that there is a network of those who have previously gone through the year-long design course—a first contact to one of our alumni or to a company close to West Virginia University requires no explanation of why the information is needed and usually produces the necessary data.

Student evaluation is also unique and fits the concept of student responsibility:

- *The chief engineer is responsible for developing, early in the project and with the approval of the faculty, detailed grading criteria and for presenting them to the students. Typical criteria are such that every student can earn an A or every student can earn an F. Students are not competing against each other but against an absolute scale. Past grade distributions are comparable to those for other capstone project courses.*

OMICRON CAPITAL CORPORATION

GEORGE B. BERRY
CHAIRMAN
CHIEF EXECUTEIVE OFFICER

August 15, 1991

Dr. R. C. Bailie
Vice President-Engineering Design
Technocats, Inc.
% College of Engineering
West Virginia University
P.O. Box 6102
Morgantown, WV 26506-6102

Dear Dr. Bailie:

SUBJECT: ENGINEERING STUDY OF C-1 CHEMICALS FROM METHANOL

As we have discussed, Omicron Capital Corporation is constantly looking for investment opportunities as a part of our corporate long range plan.

Omicron is currently considering investment in a facility for the manufacture C-1 chemicals from methanol. Our rational for this program is based on the assumption that methanol will experience a substantial price reduction as various world sources return to full capacity and technical advances come to bear. This would result in favorable economics for various C-1 chemicals.

Omicron proposes to engage your firm to provide preliminary engineering and economic feasibility studies leading to a suitably prioritized listing of C-1 chemicals which would offer the greatest economic incentive and a proposal for detailed process design.

Your proposal to perform this first stage should describe the work to be done, provide a general statement of design criteria, scope and limitation to the work, and describe costs, rates and payment terms. The engagement could result in a second phase which would provide process development of one or more of the products identified in phase one.

Omicron will be represented in Morgantown by Dr. Richard Turton, our Project Manager, who will be fully authorized to act in our behalf. If this leaves you with any questions, please do not hesitate to contact Dr. Turton or me.

Sincerely

George B. Berry

cc: Dr. Eugene V. Cilento, Dr. Richard Turton, Dr. Wallace B. Whiting

Figure 1. *Initial memorandum for class of 1992 design project. Note: George Berry is an alumnus and Omicron Capital Corporation is a real company.*

- *At the end of each semester, the chief engineer meets with each group member individually for a performance evaluation, discusses the grade, and provides written justification for assigning a grade. Students have the right to include comments or a rebuttal in the written material provided to the faculty. The evaluation process can be a negotiation, and the chief engineer may assign a different grade than originally intended based on a convincing argument made by the student.*
- *The faculty have the right to alter any recommended grade, up or down, by one letter.*
- *The faculty assign a grade to the chief engineer.*

Students are evaluated based on their assignments and (especially) on their initiative to identify, develop, and execute additional tasks that enhance the team effort. Everyone is judged on the quality of the product produced. Therefore, peer pressure is one mechanism ensuring each student's participation, since one student's grade is partially determined by the result of the group. The group leaders are also evaluated based on how effectively their group worked. The chief engineer is evaluated based on the success of the project as a whole and how realistic the evaluations of others were. For example, a chief engineer who devoted significant amounts of time to routine calculations, distracting from coordinating the group, would probably not receive a good grade. Similarly, a group leader whose group contributed less than expected would receive a poor grade. Evaluation of the chief engineer is usually facilitated by an anonymous questionnaire given to all students and seen by the faculty and the chief engineer.

The chief engineer is also responsible for recommending next year's chief engineer. During the spring semester, the chief engineer visits the junior class, informs them of the role of the chief engineer, and solicits applications. Then the class is asked to respond to a questionnaire about each applicant; in effect, the juniors are taking partial responsibility for selecting their senior-year chief engineer. The chief engineer interviews the candidates. Part of this interview includes the candidates' responses to management problem scenarios. The chief engineer then ranks the candidates, and the faculty choose the top-ranked candidate(s) unless there is a compelling reason not to do so. No current faculty member can remember a case when the top candidate(s) was not chosen. It is important to note that chief engineers have come from all GPA levels.

Davy Jones, Inc.
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August 24, 1993

Dr. J.A. Shaeiwitz, Vice President for Engineering
Technocats, Inc.
417 Engineering Sciences
Morgantown, WV 26506-6102

Dear Dr. Shaeiwitz:

As we discussed, Davy Jones, Inc., is prepared to engage Technocats to perform a preliminary engineering evaluation of opportunities in the chlorine-replacement arena. Increasingly, attention has been drawn to the adverse health and environmental effects of chlorine and chlorine-based products. While there is still considerable debate about the extent of these effects and appropriate regulatory actions, we feel that there should be a niche for us to invest in a plant to produce substitute chemicals that can gain considerable market penetration, regardless of the outcomes of the debates. While others debate, we shall move forward. Thus, time is of the essence in this project; our timetable is ambitious.

Specifically, we need for you to accomplish the following:

1. Report on affected chlorine and chlorine-based chemicals. Research the potentially affected products, paying close attention to health, environmental, and regulatory concerns. On September 30, 1993, please submit a written report and present your findings orally.

2. Preliminary comparison between process options. Based on the above report, we will choose a relatively small number of options to investigate further. You will analyze these options in enough detail that we can choose one niche for detailed evaluation. On December 2, 1993, please submit a written report and present your findings orally.

3. Design of proposed plant. You will design a plant to produce whichever chemical or chemicals that we choose based on your December 2 report. This design should include costs accurate to approximately ±40%. For the kind of high-risk, high-return projects that we like to invest in, this level of accuracy is usually sufficient for financial commitment. On April 21, 1994, please submit a written report and present your findings orally.

Although these tasks are broadly stated, I will be available for clarifications and modifications, as the project progresses. Our president, Dr. R.C. Bailie, will be making two trips to Morgantown to be briefed on your progress this fall. His first visit is on Monday, August 30, and we have scheduled the briefing for 1:00 P.M. Please bring your draft Gantt Chart and a statement of your design team's capabilities.

Please let me know who at Technocats will be assigned to this project. I expect at least weekly briefings, preferably on Thursday afternoons.

I look forward to meeting your design team.

Sincerely,

W.B. Whiting
Vice President for Strategic Planning

Davy Jones, Inc., is a closely held corporation that seeks to identify environmentally conscious opportunities in the chemical process industries for investment. With capitalization of approximately $200 million, Davy Jones is primarily a venture capital organization. After concept definition and preliminary analysis, auxiliary investment partners are sought through preferred-stock or bond offerings.

The office of the president is in New Bern, North Carolina. However, operations are concentrated at the Morgantown, West Virginia, office. Several of the faculty at West Virginia University serve on the Board of Directors.

Figure 2. *Initial memorandum for class of 1994 design project. Note: Davy Jones, Inc., is a "fake" chemical company, "owned" by Emeritus Professor Richard C. Bailie.*

DISCUSSION

Every student benefits from the complex group interaction. Arguably, those who benefit most are those with the lower GPAs and students with high GPAs who might be described as "book smart." The

project requirements are too extensive for a small subset of the class to do most of the work; everyone must share the work load equally. All students learn that their contribution is important and develop confidence in their ability to contribute to the success of the project. They learn that all colleagues, regardless of their successes on timed tests, can make quality contributions to the group effort. For example, in the class of 1992, the most tenacious library researchers did not have high GPAs. In the same year, another student who did not have a high GPA found a fundamental flaw in the project, missed by management, that saved the project. There are always students who become so involved in this project that the amount of effort they put forth could only be described as awesome.

In addition to learning responsibility in a team structure, the students also benefit from other singular experiences. There are always components of the project that require knowledge of processes not taught in the standard curriculum, such as the design of a furnace, a rotary vacuum filter, or a pressure swing adsorption bed. Students develop lifelong learning skills by using library resources (such as patents), corporate contacts, and government contacts that undergraduates do not normally use. They learn valuable nonverbal and informal communication skills (short internal memos, e-mail) in addition to the formal oral and written skills that pervade the curriculum and are reinforced during the year-long project. Through role playing, students learn to communicate with a "client." In general, students get a perspective of chemical engineering far beyond what can be obtained from textbooks or more narrowly defined design projects. It is noted that the class of 1992 visited the same type of plant that they had designed. The equipment sizes, separation scheme, and operating conditions were very similar to their preliminary design.

This type of project gives the instructor tremendous flexibility. The project is extremely open-ended, as can be seen from the memos in Figures 1 and 2. Students learn that faculty do not have all of the answers, especially during the first semester's feasibility study. The instructors usually have a general direction in mind when the project begins, but the project often goes in unanticipated, student-initiated directions (we encourage this). As one example, the class of 1990 found a more profitable direction than the one originally anticipated. Their job was to find a use for the acrolein side-product made during the production of acrylic acid. It was expected that a three-carbon (like acrolein) chemical would be the final product, but students determined that production of *d,l*-methionine, a racemic amino acid mixture used as a nutritional additive for farm animals, would be far more profitable. The instructors also have the flexibility to include as components of the final product rapidly emerging areas of chemical engineering. For example, safety (*e.g.,* HAZOP) and environmental considerations were a part of all of these projects well before formal courses were developed on these topics and before ABET showed interest in them.

The chief engineer and group leaders also acquire special skills. The chief engineer must learn to delegate responsibility, to lead a large group, and to manage people. He or she, usually an organized student with a strong technical foundation, is faced with a disorganized group (at least at the beginning) and a situation in which there is no time to do calculations. Indeed, the toughest part of the job for the chief engineer (and for many group leaders) has been described as "learning to let go." Learning to trust others is something top students do not ordinarily get a chance to do. The group leaders learn a similar lesson. They learn to divide a task into smaller parts, to delegate responsibility, and to synthesize the results into a coherent product. Both the chief engineer and the group leaders gain experience in managing people, all of whom are different and must be treated differently without compromising the group effort.

With a group of 20-30 students, many nontechnical problems arise. In dealing with these problems, together with the delegation of responsibility and the evaluation of personnel, the chief engineer and the group leaders can discover if they like and are suited for management. It is not uncommon for group leaders to be changed (without penalty) during the year, and once a chief engineer resigned when he found that he did not like management.

As with any unique educational program, there are drawbacks. The most common is dealing with the inevitable conflicts that arise between students. In a class divided into groups of three or four students, students can choose their groups (or groups can be assigned) so as to avoid conflicts, but this is not so when the whole class works as a unit. Perceived favoritism, past disagreements, and former per-

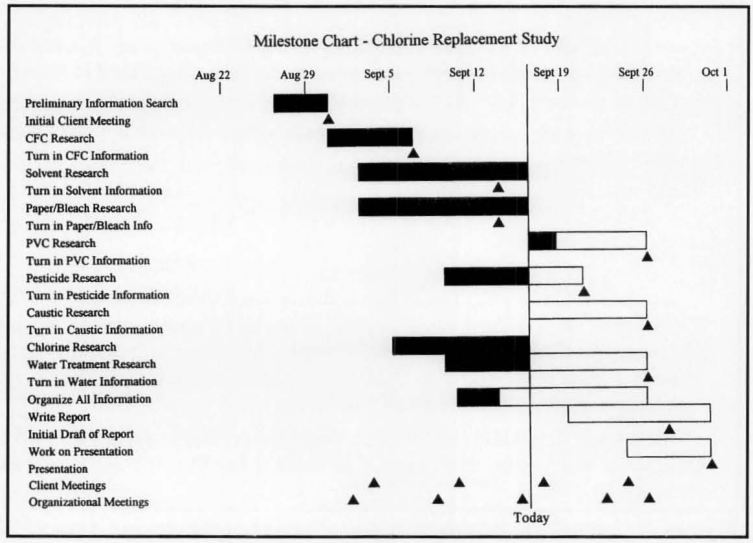

Figure 3. *Example of a milestone (Gantt) chart for the initial portion of the class of 1994 design project.*

sonal relationships are among the most common conflicts that arise. If the chief engineer cannot resolve the problem, the faculty intercede (as faculty, not as client or vice-president). On occasion, this has been time consuming. Since the scope and direction of the project are so open-ended, it is difficult to predict what problems might arise and to prepare fully for them. As mentioned earlier, some students have been known to put an inordinate amount of time into this project. The negative is that, on occasion, it has been known to affect their performance in other classes.

IMPLEMENTATION

Since every chemical engineering department has a capstone design course, the obvious question is why implement a project like the one described here? We believe that the extremely open-ended nature of this type of project gives students insights they do not normally get in the traditional class or in a typical capstone design course. More important, each student learns to work responsibly in a group structure, and the chief engineer and group leaders gain leadership experience.

It is not necessary to have a two-semester sequence to implement a portion of what has been described here. For example, the whole class section (which is defined here as less than 30-35 students) could work on a more well-defined project for one semester. The faculty would have to narrow the scope of the project such that the starting point is the beginning of our second semester. It would also be possible to divide the class into groups of 8-12, appoint or elect chief engineers or group leaders, and work for one semester on a more open-ended project than those normally done by groups of 3-4 students in a capstone design class.

From our extensive experience with this type of project, we can also suggest some key problems to be wary of upon implementation. Regular meetings with the client are necessary. We suggest weekly meetings because they allow sufficient time between meetings for significant accomplishments. It is important that students appreciate the need to make continuous progress, even in the face of other courses and assignments, and regular, weekly meetings achieve this. It is also important that all students be involved. It might appear easy for a few students in a large group to contribute significantly less than other group members, but this problem can be controlled by a firm chief engineer and by peer pressure—if someone does not work, other students complain. Faculty and the chief engineer use interim evaluations to identify these students and attempt to correct the problem. Faculty also adjust requirements to ensure that everyone's contribution is needed to complete the project successfully.

Continuity is also important, both within a given assignment and from year to year, as is the chain-of-command idea. Since continuous progress must be made, when a chief engineer or group leader is absent for extended periods of time (plant trips, visiting graduate or professional schools), someone must be responsible for making key decisions, suggesting new directions, and maintaining project continuity. From year to year, it is not necessary for new chief engineers to "rediscover the wheel." Grading criteria, evaluation forms, etc., from previous years are made available to all chief engineers. Although each new chief develops fresh materials, each can use departmental archives as a starting point. Most important, since underclassmen informally observe the seniors, a standard is passed from "generation to generation." This "culture" that develops over time is a tremendous advantage to the continuity of the program.

A guide for chief engineers was written by one of the authors of this paper (DV). It is available to anyone interested in implementing a design project such as the one described.

CONCLUSIONS

For over fifty years, a unique, two-semester, senior design course has been the focal point of our curriculum, providing students with experience similar to what they will later encounter in industry. They learn responsibility through working as part of a large team; they work on an open-ended project, learning how to gather the information from a wide variety of available resources. The student chief engineer and group leaders gain management and leadership experience and can discover if they are suited for management. All of this learning occurs in a low-risk, university environment. From a faculty perspective, in addition to providing a unique educational experience for students, this type of project permits new material to be added to students' learning experience and it can be done more rapidly than when it is introduced in a traditional classroom setting.

REFERENCES

1. Wales, C.E., A.H. Nardi, and R.A. Stager, *Professional Decision Making,* West Virginia University, College of Engineering (1986)
2. Shaeiwitz, J.A., and R.C. Bailie, "Incorporating Design into the Sophomore and Junior Years," *Proc. of 1992 ASEE Conf.,* p. 1266
3. Bailie, R.C., J.A. Shaeiwitz, and W.B. Whiting, "An Integrated Design Sequence: Sophomore and Junior Years," *Chem. Eng. Ed.,* **28**, 52 (1994)
4. Turton, R., and R.C. Bailie, "Chemical Engineering Design: Problem-Solving Strategy," *Chem. Eng. Ed.,* **26**, 44 (1992)
5. Shaeiwitz, J.A., W.B. Whiting, R. Turton, and R.C. Bailie, "The Holistic Curriculum," *J. Eng. Ed.,* **83**,343 (1994)
6. Gardner, A.A., P.H. Whiting, and A.F. Galli, "From Raw Materials to Profit: Career Role-Playing in a Senior Design Project," paper #74c, Annual AIChE Meeting, Los Angeles, CA (1982)
7. Shaeiwitz, J.A., "Outcomes Assessment in Higher Education," *Proc. of 1995 ASEE Conf.,* p. 1387
8. Woods, D.R., D.W. Lawson, C.A. Goodrow, and R.A. Romeo, "Career Planning and Motivation Through an Imaginary Company Format," *Chem. Eng. Ed.,* **16**, 44 (1982)
9. Dewar, J.D., "If You Don't Know Where You're Going, How Will You Know When You Get There?" *Chemtech,* **19**, 214 (1989) ❐