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IMPLEMENTATION OF MULTIPLE INTER-RELATED PROJECTS WITHIN A SENIOR DESIGN COURSE

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Capstone design courses typically involve many groups of students all working on identical design projects. This approach leads to fierce competitiveness between groups for limited resources, in terms of library materials, computer resources, instructor feedback, and innovative ideas. At the same time, employers are looking for ìteam playersî who can work cooperatively with other employees from all departments for the overall good of the company. The standard approach to process design instruction also yields a large number of very similar reports, which can be quite tedious to evaluate. Another difficulty encountered in many capstone design courses is the wide variety of (ABET required) topics covered, which leaves many students wondering how they are all related and what relevance each has to the overall design process.

This semester a novel approach was investigated, wherein each design group was assigned to study a different production process within the petrochemical industry. The projects were inter-related through feeds and products, just as different production facilities are inter-connected within a large chemical processing complex. Students completed mid-term reports that analyzed different aspects of their process and produced a final report that encompassed their full semesterís work.

The use of different projects for each group greatly reduced the competitive demand for limited resources and provided the instructional staff with a more interesting variety of reports to evaluate. The design projects also served to tie together the different course topics, by serving as a focal point upon which to apply each major topic as it was covered. The relationships between projects caused students to take interest in other groups' work, and in some cases inter-group cooperation was achieved.

The Course

The course in which this procedure was developed is the first semester of a two semester senior plant design sequence. Due to a number of scheduling restrictions, many students are allowed into the course without having completed their separations, heat and mass transfer, or reactor design courses. This course also suffers from the common practice of putting all ABET requirements that do not fit anywhere else in the curriculum into the capstone design sequence[1]. As a result, this course delivers a wide variety of design related material to students of varying backgrounds. Some of the major topics covered in the first semester course include ethics, safety, economics, metallic crystal structures, phase diagrams, materials of construction, pressure vessel codes, and environmental issues, all considered from the point of view of the design engineer. Students apply these topics to the development of original designs in the second semester of the sequence, which is normally taken during their final semester.

A major complaint which students have expressed about this course in past years is that it is a collection of miscellaneous topics having little apparent relationship to each other or to the semester design project. Another problem with previous years' projects is that students have tended to wait until the last two weeks of the semester to begin working on them, which leads to sleep deprivation and strained nerves when 150 students descend upon the finite resources of the engineering library and computing center just before the project deadline.

The Project

Two of the major goals of this year's design project were to provide a central focal point that would tie together the myriad of topics covered in the course, and to provide a vehicle for students to apply the material covered in class to demonstrate mastery of important concepts as each topic is completed. It was also desired to focus heavily on the analysis level of Bloom's taxonomy of educational objectives[2]. During the first week of class, students were assigned to groups and each group was assigned an industrially important chemical that was to serve as their focal point for the semester. Their first assignment was to conduct a thorough literature search to gather the information and background knowledge that they would require during the rest of the semester. Later, as each major course topic was completed, students would hand in mid-term reports that analyzed their process from the point of view of the topic just completed. A final comprehensive report at the end of the semester was naturally commenced by compiling the five mid-term reports into five sections of a large complete report. The benefit of this approach is that it forced the students to work on their project continuously all semester, and by the end of the semester their projects were 80 to 90% completed.

The Chemical Processes

The chemical processes assigned to the students were not chosen randomly. Rather they were chosen so that every group's production process would be related to at least one other group's process through common feeds and products. The basis for these inter-related groups was a series of charts in "Chemical Origins and Markets"[3] showing the production relationships between key products of the petrochemical industry, and the Ph.D. thesis work of the course instructor[4]. Forty groups were subdivided into sections based upon derivatives of ethylene, propylene, n-butane, butylene, and benzene as shown in Figure 1. The chemicals assigned to the students are shown in bold face, with the group number given in parentheses in one location on the chart for each assigned chemical. The multiple instances of several chemicals in Figure 1 illustrate the variety of production methods available for most chemicals. The unassigned chemicals show students where their chemical fits within the petrochemical industry and in relation to the other students' projects.

Mid Term Reports

The students were asked to complete five mid-term reports regarding their assigned chemical's production process, covering aspects of background, economics, materials of construction, safety, and environmental concerns as described below:

Background: The first mid-term assignment, dealing with background information, was designed to send students into the library to find as much information as possible concerning the production processes used to manufacture their chemical. The research that they conducted for this report then provided them with the information they would need for the rest of the semester's reports. In addition to production methods, the students were also asked to report on the industrial significance of their chemical, what industrial and consumer products were produced from their chemical, the feedstocks used to produce their chemical, the economic role their chemical played in the global economy, (imports, exports, and trade patterns), and any other information which was either significant or interesting. The purpose behind this additional information was to illustrate the importance of their chemicals and to heighten student interest in the overall project.

Economics: The first major topic that the class covered was economics in process design, specifically the estimation of process equipment costs, capital investment costs, and manufacturing costs[5]. One week after completing the material on economics, the students handed in their second mid-term reports, which analyzed their processes from an economics standpoint. Students were specifically asked to demonstrate their mastery of the economics material by estimating the equipment, investment, and production costs for their process. A serious hindrance to this evaluation was the lack of sufficient information in the literature to accurately determine equipment sizes, or even identify all of the correct processing equipment. Students were therefore given a list of wild assumptions that they were allowed to make, <u>for the purposes of this assignment only</u>. Due to the highly inaccurate nature of these equipment sizing assumptions†, the results for the economics mid-term reports were completely unreliable. However they did allow students to exercise their cost estimation skills, which was the point of the exercise. Surprisingly enough, at least half of the class was within an order of magnitude of the published price per pound of their chemical, as listed in "Chemical Marketing Reporter" [6].

Selection of Materials: The next major topic covered by the class was the selection of materials for chemical production service[5,7,8]. This topic included coverage of corrosion mechanisms, mechanical strength, high and low temperature effects, chemical attack, alloying properties, machinability, and cost.

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† **Examples: All unspecified distillation towers are 50 feet high, 10 feet diameter and contain 25 trays. Unspecified reactors are 5000 gallon stirred tanks. Storage tanks hold 30 days supply of feed or products.**

Besides the traditional coverage of metals, some attention was also given to alternate materials such as polymers, (both plastics and rubbers), concrete, refractory brick, ceramics, wood, glass, and glass lined steel. Upon completion of this topic, students prepared a third mid-term report analyzing their process from a materials-of-construction viewpoint. Students were asked to first identify all process conditions which would have a significant impact on the selection of materials, and then to determine the appropriate material(s) of construction for their production process. Constraints were imposed of no more than five materials for the construction of the entire plant, including up to three primary materials for the majority of the construction, plus secondary materials for special purposes. Students were also asked to evaluate how their materials selection would affect their economic analyses, without going back and re-calculating any costs. Although the more logical approach would be to select materials first and then perform the economic analysis, the impact of materials choices on the cost estimation is emphasized by performing the steps in the wrong order. Students were later asked for similar judgment evaluations regarding design changes made for safety and environmental reasons.

Safety: Following selection of materials, the class received two weeks instruction on safety in chemical process design, specifically one week on fires and explosions, and one week on hazards evaluation[9]. Students then prepared a mid-term report analyzing the safety and hazards of their chemical production processes. These reports started with identification of the chemicals and process conditions present that were cause for particular safety concern. MSDS‡ information gathered from the world wide web was particularly useful for this portion of the semester project. The students performed a sample HAZOP analysis of one portion of their process, and concluded with recommendations for precautions to be taken to properly handle the safety concerns that had been identified. In many cases this assignment required students to study safety related material that was not specifically covered in class.

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‡ **Materials Safety Data Sheets.**

Environment: The final major topic covered was environmental issues in process design. The material covered in class included nine major environmental regulations§ that apply to the chemical processing industry[10], industrial methods for processing solid, liquid, and gas waste streams, and methods of designing processes to minimize the amount and toxicity of waste generated. The mid-term assignment for this topic asked students to analyze and reduce the environmental impact of their production processes, by first identifying all potential sources of environmental concern and then making recommendations regarding process modifications. The recommendations were to consider both design adjustments prior to plant construction, and modifications appropriate to existing plants.

Final Report: At the end of the semester, students were asked to submit a final comprehensive report on their assigned chemical. Naturally most groups started these final reports by compiling the five mid-term reports into five sections and correcting the errors from their earlier work. They were also expected to assemble the whole into a cohesive unit, and to add any material that they felt was necessary for complete coverage of the subject.

Summary Sheets

Each mid-term report included an unfastened, single page summary sheet. Ungraded copies of the first summary sheets (background) were compiled into a large hallway display so that students could see the inter-relationships between the assigned processes and the rest of the petrochemical industry. This display also served to inform other students and faculty of the projects being conducted by the plant design students. Copies of the background, safety, and environmental summary sheets were distributed to all students in the class, so that everyone could gain some understanding of the chemical production processes being studied by their peers. The economics and materials summaries were not distributed because there were not enough differences between groups for the students to gain appreciably from viewing their peers' work, and in the case of the economics reports, the lack of sufficient design details made the results of the analyses highly questionable.

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§ TSCA, CERCLA, RCRA, CWA, CAA, EPCRKA, PPA, OSHA, and FIFRA

Poster Presentations

During the course of the semester there arose departmental interest in the activities of the design class. Some of the students in the class also expressed regret that the hard work they were performing would never be seen by anyone other than the graders. Because logistics prevented the use of oral presentations in this particular class, it was decided to display the students' work in the form of a poster presentation along the corridors of the chemical engineering department. The choice of venue was both due to the space requirements for 38 posters and to address student concerns that no one would bother to view student posters during the last hectic week of the semester.

Some students expressed concerns that poster production would require a lot of time at the end of the semester, and that the experience would only benefit the small fraction of the class that was planning to attend graduate school. A number of steps were therefore taken to increase the value of the poster display for all students. First, it was pointed out that the preparation of effective visual aids is an important skill in engineering, whether presented in a report, a poster, or transparency, and that many of the same skills are required in either case. Second, each group of students was given a choice of either preparing a simple poster for homework credit only, or producing a more elaborate poster that would also count for up to 20% of their final project report. Third, engineers from nearby chemical companies were invited to judge the posters, with prizes** awarded to the best entries. The industrial judges were chosen to appeal to those students that were on the job market, by giving the students a chance to discuss their work with the industrial contacts. However no students elected to avail themselves of this opportunity.

Several of the prize winning posters are shown in Figure 2. Although many of the posters were quite colorful, the judges based their evaluations only upon the overall quality and impact of the information presented. Color only made a positive impression when used to effectively present information, as in the case of the second place award winning bisphenol-A poster, which used color coding to indicate materials of construction, operating conditions, and equipment types. On the other hand, the n-butanol poster, which also won a second place award, was completely black and white but presented a great deal of quality information in a clear orderly fashion. The first place winner, sec-butyl acetate, used clear overlays to show recommended design modifications for safety and environmental improvements, as well as clearly describing what the costs and benefits would be from implementing the proposed changes.

There were several unplanned benefits of the poster display, one of which was the chance for sophomores and juniors to learn something about the petrochemical industry and to see how their engineering skills might eventually be used in industry. Another benefit was the positive impression the display made upon a number of departmental visitors, who expressed appreciation for the student's work.

Logistical Issues

Group Assignments: The assignment of students to groups can be conducted in a variety of ways[11]. In past years, students were allowed to choose their groups, which led to a concentration of experience within certain groups. (All the students that had taken reactor design together re-formed themselves into plant design groups, leaving the remaining groups with no reactor design background.) This semester, students were allowed to request their group assignments, but the instructional staff made the final assignments, with the criteria that each group have a certain minimum background and that no group have an excessively skewed GPA.

Group Participation: In any group project situation there is the potential problem of students that do not perform their share of the work, or conversely, students that take over the project and do not allow their partners to contribute appreciably. For this project there is the added temptation for students to divide the mid-term reports among group members and then work individually rather than collectively. The latter approach would be acceptable if the work were divided fairly, except for the fact that each student would then learn only one portion of the course material, rather than the broad coverage that is desired. To ensure a complete understanding by all students, questions were placed on the exams that required students to be familiar with all aspects of their project, including portions completed by their partners.

Teaching Assistants: In order to evenly distribute the supervisory responsibilities of the four teaching assistants (TAs) assigned to this course, the class was conceptually divided into four sections based upon principal derivatives of ethylene, propylene, butylene/butane, and benzene, as shown in Figure 1. Each section had a particular TA assigned as the primary source of assistance for the groups within that section. Students were asked to first seek assistance from the TA assigned to their chemical and then seek further assistance from an alternate TA or the course instructor if they still had unresolved questions. In this manner each TA was responsible for understanding no more than ten (related) production processes, while the primary instructor oversaw the activities of all the groups.

Report Grading: Grading 38 mid-term reports every two to three weeks is too much work for any one person to reasonably handle. Neither is it fair to have different students graded by different graders. Therefore the mid-term grading was shared on a rotating basis, with the course instructor grading the first (background) reports, and each of the other mid-term reports being graded by different TAs. The final semester reports were graded by the instructor while the TAs graded the final exams.

Personalized Assignments: The first project assignment was personalized using the form letter capabilities of a popular word processor and data taken from the class roster spreadsheet. Each assignment included the individual student's name, group number, and assigned chemical wherever appropriate in the document. The problem with this technique was that it took an unacceptable amount of class time to hand out the assignments to individual students, as well as requiring a long time for the computer to print 155 assignments. As a compromise, later assignments were personalized by groups, with five stapled copies of the group assignments handed out to each group.

STUDENT RESPONSE

The University of Michigan employs a course evaluation system similar to that used by many universities, in which students rank various aspects of the course on a scale from one to five at the end of the semester[12]. The year that the design project described here was first implemented, 21 out of 25 questions showed an increase in student rankings from the previous year. The average ranking of all 25 questions rose from 3.31 to 3.71. For the questions specifically related to the design project, the rankings rose even more dramatically, from 2.97 to 3.87. The lowest ranking increased from 2.48 to 3.02, and the highest ranking rose from 3.85 to 4.08.

Of the rankings that decreased, one of the questions dealt with the amount of work required for the credit received. This ranking decreased slightly, from 3.83 to 3.76. However another question, dealing specifically with the amount of work required <u>for the design project</u>, increased its ranking from 2.96 to 3.71. Students were apparently more satisfied with the project workload, but slightly less satisfied with the overall workload for the course than in the previous year.

The other three questions that showed declining rankings involved the assignment of grades, with the average of the three questions declining from 3.78 to 3.47. One cause of this lowered ranking is believed to be student frustration caused by the changing of graders for each mid-term report. Students felt that although they worked hard to address the weaknesses pointed out by each TA, they would just be rebuked for something different on the next report. However another contributing factor to student dissatisfaction with grade assignment involved some re-grading of the first exam, which was totally unrelated to the design project.

Student responses on open ended questions also show an appreciation for the design project and an increased appreciation for the class as a whole. Although there were no specific questions regarding the design project during previous years, several students addressed the topic anyway, all negatively. The general consensus of the previous year was that the course as a whole was disjointed and the design problem was completely irrelevant to the topics being studied. Some students indicated that they had not learned anything and still did not understand the point of the course at semester's end.

The year that this design project was implemented, a specific question was added to the open ended form requesting student evaluation of the design project. Overall response was highly favorable, with positive responses outnumbering negative ones by four to one, and also being much stronger in their opinions. Some of the positive responses included: " This was a great idea; Best aspect of the class", "I thought it was an immense contribution to the course; I'd encourage it in the future", " The [design project] was the only thing that pulled together the course materials and made it relevant to life", "I thought [the design project] was valuable to the class and helped to reinforce class material", "I think the idea was excellent", "I liked the project format, and how each group got a different chemical; Good job", and "The [design project] is very valuable and interesting."

The negative comments were primarily from students who dislike group work of any kind and from a few students who felt the workload was too high, particularly when a mid-term report would happen to fall due the same week as other assignments. The poster contest also drew criticism from some students, who felt that it was a lot of extra work with no educational benefit, and that it had no relevance to their future careers in industry. It should be noted, however, that the poster presentation was the only component of the semester's workload that was not announced at the beginning of the semester.

CONCLUSIONS & RECOMMENDATIONS

The design project format outlined in this paper has been highly effective in providing focus for a highly disjoint course, and has been an interesting educational experience for both students and their instructors. End of semester student tensions were still high, as they probably always will be in senior design courses, but there was much less frustration expressed regarding competitiveness for limited resources. Student evaluations of the course improved significantly, especially for the questions relating to the design project portion of the course.

There are, however, some areas for improvement with the method presented. There needs to be a clear well-defined set of report grading criteria, used by all graders and clearly understood by all students. (Those criteria could adapt from one report to the next, so long as they are well understood by all concerned.) The poster display adds a definite benefit to the course, and should prove more palatable to students if the requirement is announced at the beginning of the semester. The safety and environmental topics are not identical, but they are similar enough that they could be combined into a single assignment. Equality of effort in a group project is a serious concern, but one that is common to all group activities, and not specifically to the approach outlined here. This approach does entail a lot of work for all concerned, but it is also more interesting and more educational for both the students and the instructional staff than the traditional approach.

ACKNOWLEDGMENTS

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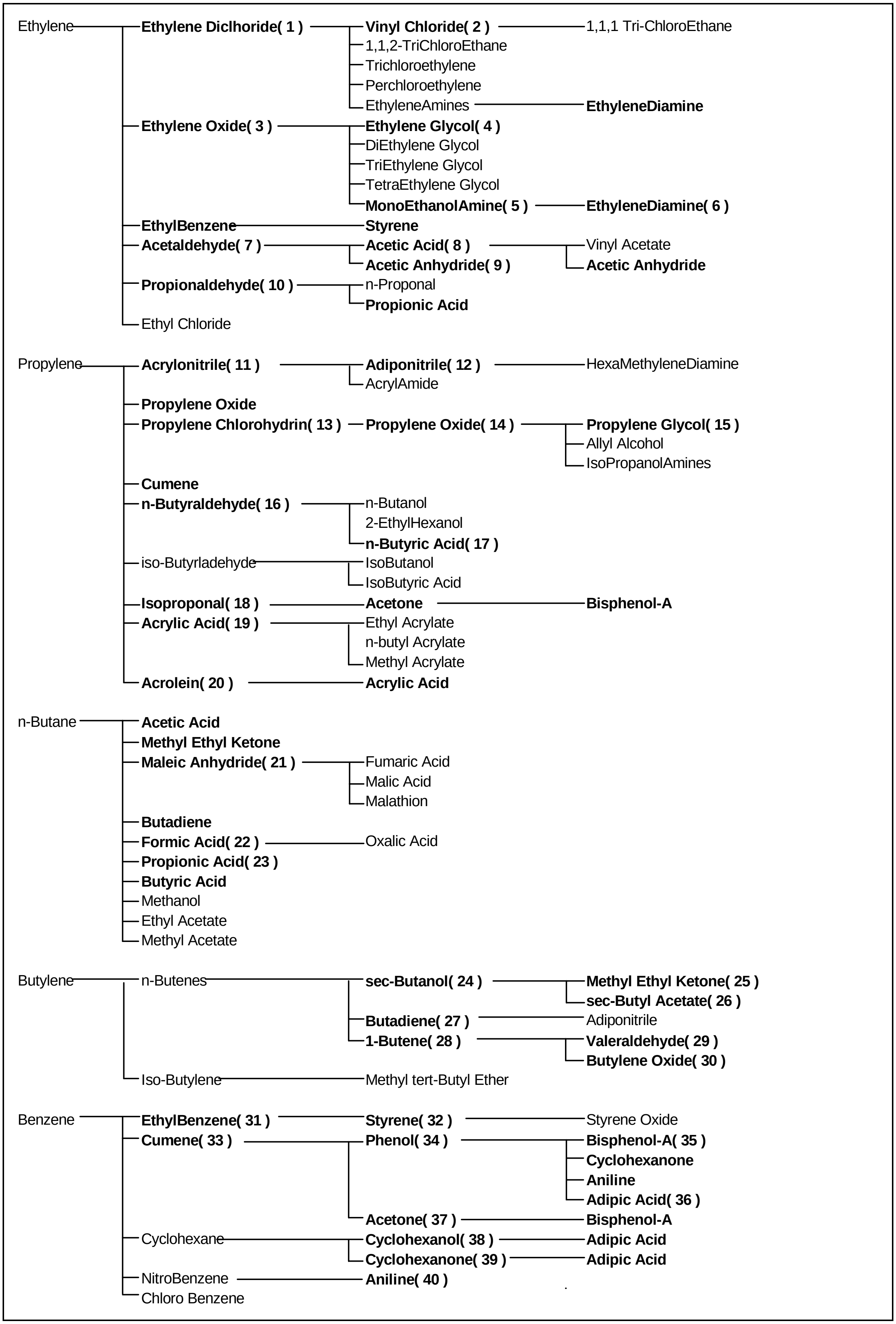

Figure 1: Chemical Production Processes Assigned to the Design Students.

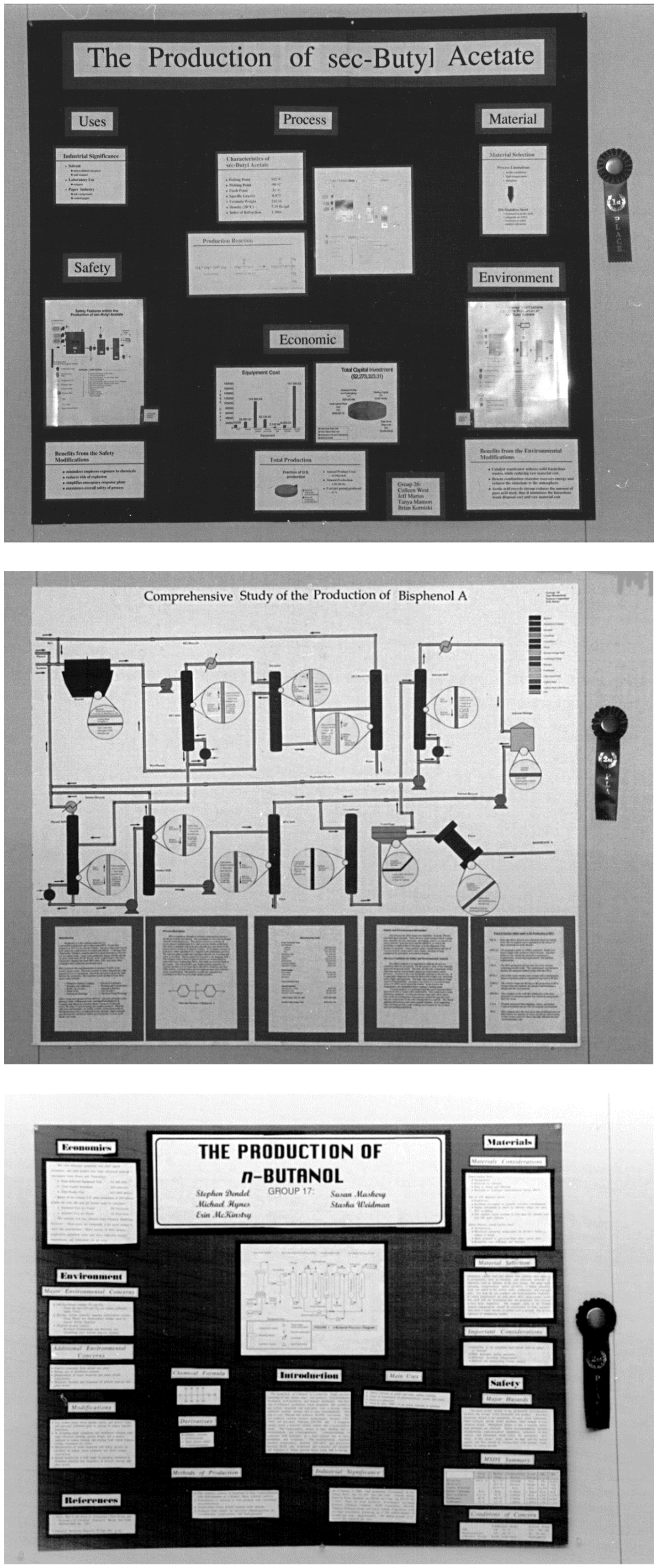

Figure 2: First place poster sec-butyl acetate; Second place winners bisphenol-A and n-butanol.

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