WEB-BASED DELIVERY OF ChE DESIGN PROJECTS

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Leading chemical engineering faculty, in a series of three workshops titled "New Frontiers in Chemical Engineering Education," have identified a need for case studies to support the unifying curricular themes of molecular transformation, multiscale analysis, and systems approaches.[1] As a result of this workshop series, case studies are sought that provide real-world context, including aspects of safety, economics, ethics, regulations, intellectual property, and market/societal needs. In addition, the desired case studies should provide real-world challenges—open-ended, complex problems with incomplete data that require pruning of alternatives.

Note that the term "case study" has many meanings. There is a large body of literature on using "cases" for the purpose of student instruction, primarily in the disciplines of business and law but more recently in the engineering literature.[2-4] In this context, the "cases" are brief (one- to two-page) descriptions of an actual problem where students are challenged to analyze the situation and formulate a response, taking into consideration all of the facets of the open-ended problem.

Another type of case study is really a short (one- to five-page) problem statement that identifies the product or process, the design basis, associated process constraints or specifications, assumptions, and required deliverables. Several recent chemical engineering design textbooks[5-7] contain text or accompanying CD versions of design problem statements. CACHE, a not-for-profit educational corporation, makes available selected design case studies with solutions.[8] Our concept of a case study involves not only the problem statement, but associated technical briefs and solution information that provide an introduction to the material, both for the students and for the mentoring faculty.

The formulation of design projects presents three major challenges: the project expectations must be challenging yet attainable, the scope must encompass the essence of industrial practice and represent a realistic situation, and—possibly most challenging to the instructor—the technical focus of the topic must be such that the project advisor (usually the faculty member responsible for the course) is able to provide adequate guidance, support material, and mentorship to the students.

For this project the first objective was met by using design projects completed by previous years' design groups. The final reports were then compiled and the best sections or portions of the solutions condensed into a single exemplary solution. Following a review of the "solution," sections deemed incomplete were made part of the deliverables assigned to the subsequent year's project team. This is not to imply that the solution presented is the only reasonable solution available—as with all engineering projects, many solutions can be considered viable and the students are encouraged to think creatively when determining a solution.

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The second objective was realized through the involvement of industry professionals in the formulation of the design problem and the mentoring of the teams responsible for the project report. These practitioners also reviewed the solution material and provided additional suggestions for completion of the case study materials. For example, because of the novelty of the biotechnology-related projects, much of the initial solution material generated by student groups focused on material that was new to chemical engineering practice, *i.e.*, validation protocols for equipment, inoculation and cell cultivation, and biomass processing. The solutions lacked basic engineering data for equipment sizing and utility usage, and thus were vague as to how production costs were actually calculated. This year's students will be addressing these issues and their results will be added to the support material for each exemplary solution.

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The case study represents our effort to address the third challenge. Some chemical engineering faculty members may want support for the biotechnology projects if they lack practical experience in this field. At North Carolina State University (NCSU) we are fortunate to have faculty with biochemical engineering expertise as well as industrial mentors through the local ISPE (International Society of Pharmaceutical Engineering) chapter, with NCSU students also having access to internships with local pharmaceutical companies and manufacturers. The industrial mentors supplied by ISPE were especially helpful in developing the information for the two biotechnology case studies.

TABLE 1
Typical Senior Design Course Projects

- AlphaVax: A Facility Retrofit for Vaccine Production
- SuperPro®-Based Ammonia Plant Retrofit
- Biodiesel Facility Utilizing Waste Vegetable Oil
- Bio-Methanol and Bio-Ethanol Facility: A Feasibility Study
- Ceramic Processing
- Citric Acid Production Facility Case Study
- Production of an Antigenic Co-Protein Line for PeptiVax Pharmaceuticals
- Innovative Design of a Snowboard
- Carbon Dioxide Separation: High Temperature Flue Gas Adsorption
- Reducing the Risk of Cancer from Fried Foods
- 1.2 kW Portable Fuel Cell System
- Combined Heat and Power Fuel Cell System for NCSU
- Gasification of Biomass: Conversion to Higher Value Chemicals and Fuels
- Designing a Gelatin Manufacturing Plant for North Carolina
- Kennametal Waste Minimization
- Medical Waste Treatment Process: for Use in Underdeveloped Areas
- Microfluidic Cooling Device for Microprocessors
- Perchlorate Treatment for Domestic Water Systems
- The Biological Production of para-Hydroxybenzoate
- Thermochemical Processing of Tobacco to Produce Methanol: A North Carolina Facility
- RESS Production of Micronized THC Particles in Solution, for Pulmonary Delivery
- SuperPro® Modeling and Optimization of Conjugate Vaccine Facility

COURSE STRUCTURE AND LOGISTICS

At NCSU, the capstone design class consists of a two-semester design sequence. The complete course Web site for CHE 451 (spring 2004) is included in the "Helpful Resources for Instructors" on the case study Web site. The first semester is primarily focused on instruction, including economic analysis, process simulation, environmental impact, and life-cycle analysis, etc. In previous years the students did not start their capstone project until the second semester; the instructors have found, however, that it is more effective to launch the project early—mid-semester in the fall—and continue it through the spring. This allows much more time for the students to do an in-depth literature and patent search early in the life of the project, as well as to invest considerably more time in the project as a whole. The instructors establish expectations that each student in the project group will invest at least 10 hours per week throughout the project life. The solutions that are available to instructors reflect the effort of one and a half semesters (approximately 6 months), but instructors can "prune" the list of deliverables as appropriate to match the time available.

Typically a capstone class at NCSU has an enrollment of 85 to 95 students. In previous years there were four to five projects (typically traditional simulation-based projects) and four to five teams working on each project in parallel, but in recent years the instructors have tried to come up with as many as 20 to 22 unique projects so that each team has its own project. Typical project titles for the design course are shown in Table 1.

The case studies described in this paper had one team of four to five students working on the case. Again, depending on the class size and duration, it would be feasible to have more than one team working on the problem, each being assigned to different aspects of the design.

As part of the course deliverables, student teams developed team expectations and established a project management system to report time on a weekly basis. Peer evaluations, completed at mid-semester and at the end of the semester, were used to weight individual grades based on group work. The instructors met weekly with teams and/or project managers to monitor progress. Templates for grading written and oral reports, peer evaluation forms, and examples of group time logs are included on the Web site under "Helpful Resources for Instructors."

At the end of the semester, the Chemical Engineering Department sponsored a "Senior Design Day." One student from each group made a brief (2-minute) overview presentation using PowerPoint, and then the group adjourned to a poster session. Each group prepared a poster and responded to questions from those attending the session. Chemical engineering faculty, industrial sponsors, multidisciplinary faculty, and parents were invited to Design Day.

CASE STUDY STRUCTURE

To simplify accessibility of the case studies, the information contained on the Web sites, and the Web sites themselves, are structurally similar. The case study information can be broken up into three major components: the problem statement, support information, and exemplary solution.

The *problem statement* contains the basic information that the student needs to get started on the project. The general purpose of the project, raw-material specifications, basic operating parameters and systems, reaction kinetics, and product specifications are included in this section. *Support information* includes a list of starting references, technical briefs on relevant processes (created by previous years' project teams), facility layouts, equipment lists, and suggested deliverables for the project teams. The *exemplary solution* provides a complete project report, including an executive summary, introduction, technical background, process description, waste management plan, regulatory review, facility design, validation/commissioning plan, detailed manufacturing costs, detailed spreadsheet calculations for material balances, equipment sizing, utility usage, profitability analysis, and process simulation results.

CASE STUDY ACCESS AND EXAMPLE

The Web site contains three complete case studies for the production of vaccine co-protein, ammonia, and citric acid. The structure of the Web site, and exemplary material based on the co-protein project, illustrate the nature and detail of the case studies. The reader should keep in mind that this is not "Web-based instruction," but rather a source of instructional material which can be accessed via the Web. While this material may be adapted to a Web-based instructional scenario, that would be the responsibility of the faculty implementing the material.

Students and faculty can access all of the case studies shown in Figure 1 from the main page of the Web site at

<http://www.ncsu.edu/checs/>

The Web site is divided into two levels of access: student and faculty. As shown in Figure 2, students have access to descriptive information about the project, information on each case study, and resources related to the case studies (Web-based, books, journal articles, PowerPoint tutorials, etc.) Faculty can access the same information as the students, but in

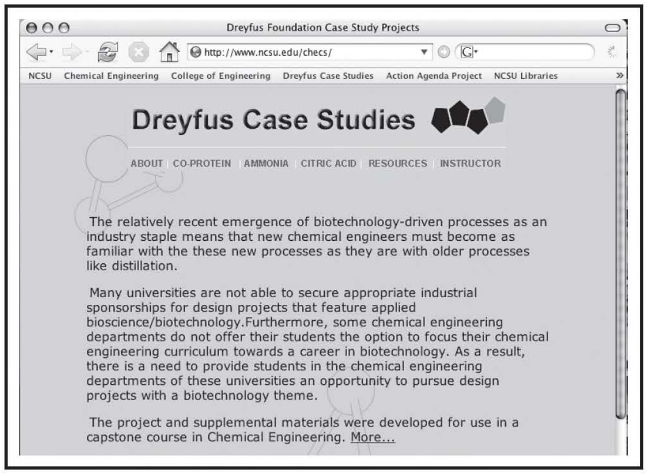

Figure 1. *Home page for case study Web site.*

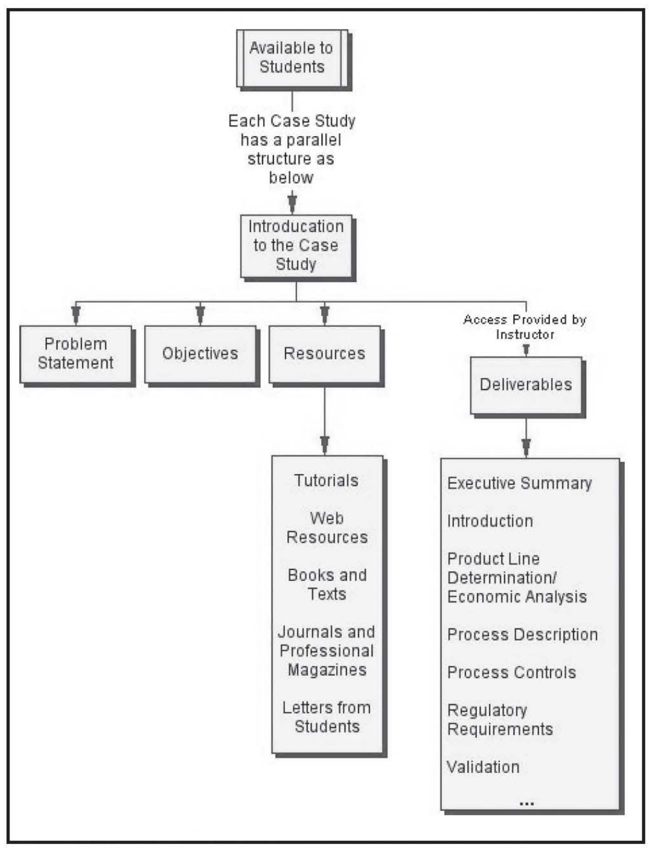

Figure 2. *Web site structure: Student view.*

addition, the exemplary solution and additional resources are available to them through a password-protected protocol. Examples of materials that are available to the instructor are shown in Figure 3. The instructor requests password access through an online registration page marked "Instructor" on the main page. The instructor's request is forwarded to the authors, who will verify the instructor's status and provide a user ID and a password. The authors will solicit feedback from faculty who use these cases regarding questions, problems, or suggestions for additional material to be included. This feedback will be used to improve the case study materials.

CASE STUDY INFORMATION: CO-PROTEIN

To indicate the organization and the ease of comprehension of the Web site, examples of the problem statement, a list of deliverables, student letters, and tutorials are described below.

Problem Statement and Deliverables

The problem statement is detailed since most chemical engineering students have little experience with biological systems, and the proteins and processes described are "disguised" so as to avoid disclosure of proprietary information on the part of the original project sponsor.

> **PeptiVax Inc., a biotechnology company, has developed several co-proteins that may help in the fight against several common viral diseases. In test animals, each co-protein attaches to a target virus and the virus-protein complex stimulates the production of antibodies against the virus. This cooperative system may also enable the human body to produce a small amount of antibodies that will limit the spread of the virus. Several of these antigenic "co-proteins"—co-Hep B, co-Hep C, co-Human Papilloma Virus, co-RSV, co-Rotavirus, and co-HIV—are now in Phase I clinical trials (see Table 1** *[contained on the Web site]* **for protein characteristics). The management of PeptiVax Inc. would like your group to evaluate and recommend a proposed product line, design the corresponding *Escherichia coli*-based processes for protein production (see Table 2** *[contained on the Web site]* **for *E. coli* growth data), and determine the required modifications to their existing facility (see Figure 1** *[contained on the Web site]* **and Tables 3 and 4** *[contained on the Web site]*).
>
> **PeptiVax's senior management would like to see the following information and deliverables:**
>
> - **United States Target Market and Market Size**
> - **Intermediate and Final Product Descriptions**
> - **Major Regulatory Requirements of the U.S. market**
> - **Project ROI and Product Cost**
> - **Process Summaries**
> - **Descriptions of all Facility Modifications**
> - **Capacity and Annual Schedule, Based on Market Potential**
> - **Preliminary Design/Construction/Validation/Regulatory Schedules**
>
> **PeptiVax's technical and regulatory personnel would like to see the following:**
>
> - **Process Flow Diagrams (PFDs)**
> - **Process Description**
> - **Material Balances (Raw Materials, Product, Waste, etc.)**
> - **Equipment Lists, with Specifications**
> - **Control System Requirements (new systems)**
> - **Facility Floor Plan, Indicating Material/Personnel Flows**
> - **Utility Requirements**
>
> **Product line proposals should be accompanied by an economic analysis of the potential market value of each co-protein. This should include a detailed description of the corresponding viral infections combated by each co-protein, and the current United States infection rates. The design process for any proposed product line should be based on the assumption that all the co-proteins are produced extracellularly by a specialized strain of the recombinant host organism, *Escherichia coli*. Each recombinant strain of *E. coli* will be able to produce one and only one of the potential co-proteins. The individual co-protein characteristics are presented in Table 1** *[contained on the Web site]*. **Keep in mind**

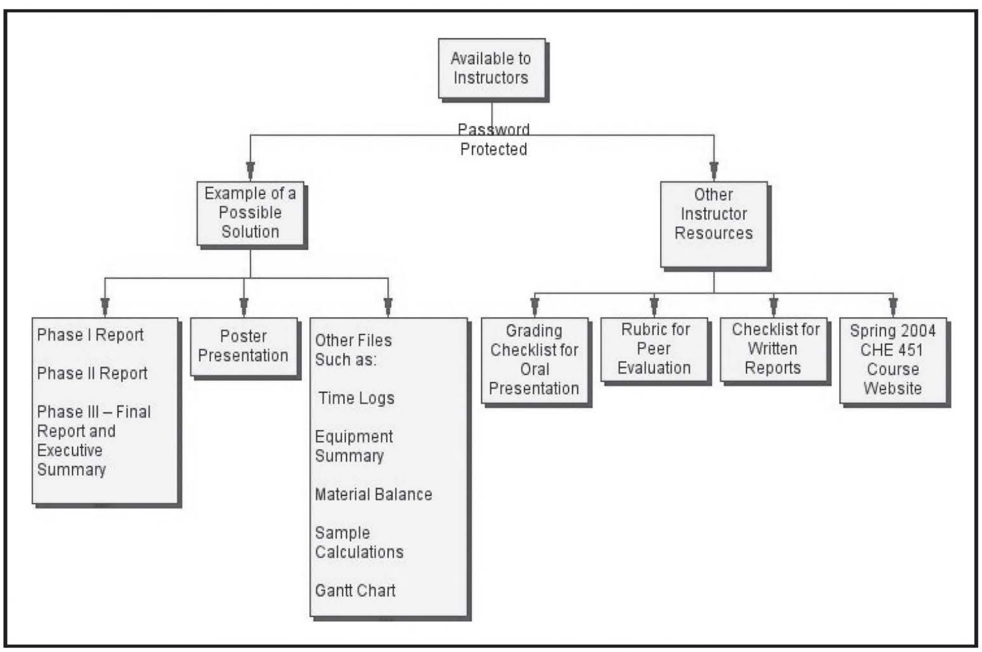

Figure 3. *Web site structure: instructor view.*

that the required modifications to the existing PeptiVax facilities should take into account the amount of each co-protein needed to capture the desired market share over the course of one calendar year.

This information is sufficient for the design team to understand the needs of the project sponsor.

This section is followed by the table of contents for the project deliverables, shown below.

1. *Executive Summary*
2. *Introduction*
3. *Product Line Determination/Economic Analysis*
4. *Process Description*
5. *Process Controls*
6. *Regulatory Requirements*
7. *Validation*
8. *Waste Management*
9. *Facility Design*
10. *Detailed Costs of Proposed Product Lines*
11. *Conclusions*

Each item in the table of contents is a link to a page in the Web site that contains a brief (one- to two-paragraph) definition/explanation of that item. For example, the Process Description link will take you to a page with the following information:

> *What is expected: The economic analysis performed above gives upper management at PeptiVax enough information to determine what drugs should be produced. This is based on the anticipated market capture and on approximating the cost of producing a recombinant drug. The numbers generated are rough estimates, however. In order to calculate a detailed manufacturing cost and to design the facility to accommodate the equipment necessary for the production of these co-proteins, the specific manufacturing process for each co-protein is required. Before a specific process can be developed, it is necessary to understand the different equipment that can be used in a biotechnology process. This information can then be used to streamline the process by using the minimum number of unit operations required for each co-protein production. To be included in this deliverable are:*
>
> - *Overall description of protein production process*
> - *Complete process block flow diagram*
> - *Unit operation descriptions of each process unit*
> - *Material and energy balance*
>
> *Need more help on Fermentation and Purification overviews? See the Fermentation and Purification tutorials in the Resources section.*

The explanations are sufficiently general to allow further refinement by the individual instructor but sufficiently detailed to allow the team to begin work on the item in question. There are also links to relevant tutorials through the Resources link (note: the Resources link is on the home page).

Letters from Students

This section contains letters from former design teams with advice regarding project management, preparing oral and written presentations, and general words of encouragement. A brief example regarding oral and written presentations is shown below.

Recommendations and Lessons Learned from Co-Protein Group (taken directly from student comments):

Written Report

1. Create outline for proposal and phase reports before actually writing.
2. Don't underestimate the importance of writing versus technical content.
3. Get connected with technical advisors and use to full advantage.
4. Schedule regular meetings with advisor.
5. Schedule regular weekly or biweekly meetings with group.
6. Get an outside English teacher or technical-writing advisor to review all reports.
7. Set goal to complete technical aspects of report the week before due date, so that the last week may focus on writing quality (i.e. grammar, sentence structure, etc.)
8. In group meetings, whether before or after each phase has been completed, discuss each person's section. Each person should have a thorough understanding of everything in the report, including all assumptions made and all calculations.
9. Use reader's comments from each phase, to build on them for the next phase.
10. Choose a project that you have sincere interest in. This will help keep you motivated and interested throughout the semester.
11. Don't get discouraged—everything comes together.
12. There is no "real" structure and requirement for what is to be included in the final project—it really depends on how you got there.
13. Do not look for specific outline of what needs to be done when starting project—start on your own and think of what seems reasonable to accomplish.

Oral Presentation

1. Transition between every slide.
2. Go over "pretend" responses to question-and-answer period—be prepared for questions (or how to respond to questions) you do not know.
3. Request to go first.
4. Don't use white background—always use blue or a dark color.
5. Make sure that all figures and tables are legible. If this is not possible, make handouts for everyone to see.

6. All group members presenting should stand.
7. Practice, practice, practice.
8. Assign a person responsible for every section of the presentation so that they can field questions. This will prevent confusion and looks of helplessness during the question-and-answer session.

While much of this advice is identical to that which the professor would give, there is added validity when it comes from the mouth (or pen) of a peer!

Tutorials and other Resources

The Resources link from the main page takes the students to a list of references (Web sites, tutorials, books, and professional journals) that will help them get started on uncovering the technical background for their project. The resource page for the co-protein project is summarized below.

Co-Protein Case Study Resources
Web resources/tutorials/texts and books/journals/professional magazines
Web Resources (these are links to other parts of this page)

CDC Hepatitis Information Page
<http://www.cdc.gov/ncidod/diseases/hepatitis/index.htm>
MedicineNet.com <http://www.medicinenet.com>
HIVandHepatitis.com <http://www.hivandhepatitis.com/#hepc/tmhepc.html>

CDC Rotavirus Information Page
<http://www.cdc.gov/ncidod/dvrd/revb/gastro/rotavirus.htm>

CDC Human Papillomavirus (HPV) Information Page
<http://www.cdc.gov/nchstp/dstd/HPVInfo.htm>

The Respiratory Syncytial Virus Info Center
<http://www.rsvinfo.com>

American Lung Association RSV information
<http://www.lungusa.org/diseases/rsvfac.html>

CDC HIV/AIDS Information Page
http://www.cdc.gov/hiv/dhap.htm

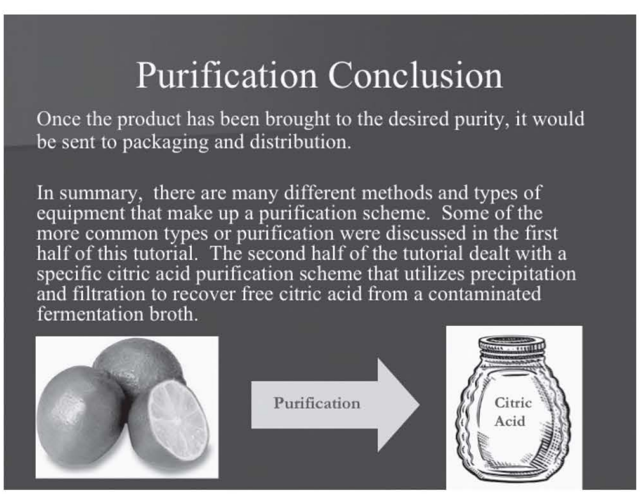

***Figure 4.** Example from purification tutorial.*

Technical Briefs:
Overview of Fermentation (ppt) (pdf)
Overview of Purification (ppt) (pdf) (see Figure 4)
Validation Tutorial (ppt) (pdf)
Overview of Facility Design (ppt) (pdf)

Books and Texts:
Bailey, J.E., and D.F. Ollis, *Biochemical Engineering Fundamentals*, 2nd ed., McGraw-Hill Book Co., New York, NY 1986
Shuler, M.L., and F. Kargi., *Bioprocess Engineering Basic Concepts*, 2nd ed., Prentice Hall, Upper Saddle River, NJ, 2002

Journals/Professional Magazines:
Pharmaceutical Manufacturing, PutmanMedia
<www.pharmamanufacturing.com>
Chemical Processing, PutmanMedia
<www.chemicalprocessing.com>
CONTROL for the process industries, PutmanMedia
<www.controlmag.com>

Note that the tutorials are available in both PowerPoint and pdf formats (**ppt** denotes a PowerPoint file: will open in Internet Explorer or Microsoft PowerPoint; **pdf** denotes an Adobe pdf file: requires Acrobat reader.)

SUMMARY

Three case studies have been developed for use by the chemical engineering community. Two of the three case studies are in the area of bioprocessing, which allows faculty who may not have extensive background in this area to provide students with relevant materials. The authors would like to encourage readers to use these case study materials and provide feedback on enhancements, gaps, or other opportunities for improvement.

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