Capstone Design Course – Divide and Conquer

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Abstract – The capstone design taught as part of the chemical engineering curricula at Mississippi State University (MSU) has experienced steady enrollment increases from a low of 14 students in 2003 to its current class size of over 50 students. The capstone design consists of a series of two courses involving a Fall – Process Design course addressing cost estimating and process design specifics, and a Spring - Plant Design course addressing the design and costing of a grass roots chemical plant.

As the course has evolved and enrollment has grown, this generated the need to divide the Plant Design course into sections allowing course flexibility. Over the past three years, students were presented with the option to participate in the American Institute of Chemical Engineers (AIChE) national student design competition, to compete in the WERC National Design Competition, or to complete a traditional design project. This paper details the specifics of each design alternative, and presents the approaches used in the Process and the Plant Design courses to address larger class size. The general assessment of the three alternative approaches was that each was successful and improved the effectiveness of the course.

Keywords: Capstone Design, Chemical Engineering, Process Design, Plant Design, Education,

BACKGROUND

Recently, the majority universities have experienced unprecedented increases in enrollment. This has especially been observed at major public state institutions. This has resulted in substantial increases in the number of students within most departments. In fact, within the chemical engineering department at Mississippi State University (MSU) departmental enrollments have increased from approximately 170 students a few years ago to projected enrollments for 2012-2013 of over 250 - 275 students. As a result the class size has increased. In addition to increased enrollments, State universities have been faced with unprecedented budget cuts and reductions in the number of new hires. This has affected the chemical engineering department at MSU with the number of faculty reduced from a high of 13 in 2007 to a low of 8 faculty members in 2011. In an attempt to address these issues, many classes that were traditionally taught every semester are now only offered once per year. This has also increased the sizes of the classes.

The senior design courses within the chemical engineering department have traditionally been offered with class sizes of 15 -20 students, but with the recent changes, the typical design course now has a class size of over 50 students. This has resulted in a shift from the past approach in teaching the design courses to that which is outlined in this paper.

TRADITIONAL OFFERING OF CHEMICAL ENGINEER DESIGN

Most chemical engineering curriculum has involved traditional senior capstone design courses as an integral part of the student's experience. In fact Biegler, et. al. [1] stressed the importance and history of such courses within chemical engineering. At MSU this has been the model followed. Capstone design involves a year long experience divided between two semesters. The first course titled "Process Design" and the second course titled "Plant Design" focuses on the topics listed in Table 1. Process Design focuses on traditional lectures and depending on the instructor, students may or may not be assigned a design project. If a design project was assigned in Process Design

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it typically was a short 2-3 week design project assigned near the end of the semester. Plant Design typically consisted of additional traditional lectures and a single larger design project assigned near the end of the semester. All design projects were assigned as group projects and thus, conducted by teams of 3 to 4 students.

CHEMICAL ENGINEER DESIGN – DIVIDE AND CONQUER APPROACH

As the curriculum was assessed Process Design was modified from a 3 hour course to a 4 hour course. With this modification our offering of the process simulator material (using the Chem Cad simulation program) was moved from a sophomore/junior level course to the capstone design course. The simulation instruction is offered as a 2 hour computer lab once per week. The curriculum was also modified to require all engineers to take an engineering economics course that is offered outside the department. These changes along with the increasing class size have dramatically increased the course work load for the instructor.

In 2004 it was noticed that the students, while required to take technical writing as part of their curriculum, had a distinct lack of report writing experience and skill. In addition, it was observed that students were not concentrating on the design experience but in contrast were receiving a greater focus on the more traditional lecture and testing mode of instruction. Thus, in an effort to address these shortcomings, these courses were modified as discussed in the following sections.

Process Design

Process Design was modified by bringing more designs into the course, and focusing on the student's writing skills. Although most of the material previously covered in the traditional Process Design course as previously discussed is addressed in current course, a greater emphasis is placed on design. Instead of the single design approach, 4 design projects are assigned throughout the semester. In addition, students are required to write a full report on an engineering topic as assigned. This writing effort focuses on citation, organization, writing skills, and proper reference documentation. The design projects require different levels of reporting and reinforces the skills developed with the full report. Specifics of the 4 design projects are discussed as follows.

First Design Project - The class assigned the paper requirement on the first day, and for a separate effort assigned to teams of 3 on the second day of class. After being divided into teams, they are presented with an in-class design consisting of a coffee distribution system for the chemical engineering faculty. This design was modeled after that present by Moor [2]. This is a quick design, catching most of the students off guard, requiring them to use previously developed skills, including: research, data collection, critical thinking, and preparation of a presentation. The design culminates at the end of second class period with teams presenting their results to their classmates in a short 10 minute brief.

Second Design Project – The next design problem is assigned approximately 1.5 weeks in to the semester and is due 3 weeks after it is assigned. This design is a less technical problem focusing on the trouble shooting and removal of bottlenecks in a chemical process. Students are required to meet regularly in their assigned groups, to discuss and address the problems. All of these meetings occur outside of class, thus only limited class time is used to address design issues uncovered by the student teams. While mass balance calculations are required to resolve some of the issues, problems such as the recycle of waste water streams (after treatment) to the head of the plant are typical. The progress of each team is monitored through progress reports which are submitted each class period. An example of a progress report is shown in Table 2. The trouble shooting project culminates in a short but full report, detailing the team's findings and actions taken to resolve the various problems identified.

Third Design Project – The third design is assigned the class meeting after the second design is submitted. This assignment is due 6 weeks after it is assigned. With this design problem students are provided with a fully designed process, including process flow diagrams, stream tables, and equipment specification tables. Students are asked to determine the net present value (NPV) of the plant. Teams of 3 students are assigned as well as groups of 3 teams (a total of 9 group members). Each team receives a different process for which they determine the NPV. After this is completed each team must discuss the outcome of their design with the other teams within their group. Information is exchanged and each 3-member team must submit a final report recommending the most cost effective process, while considering the safety and the environmental friendliness of the process. This is an involved design and typically a challenge for the students. Almost all of the work for this project is conducted outside of the scheduled

class meeting time and like the second design project, the progress of each team is monitored using bi-weekly progress reporting.

Fourth Design Project – The fourth design project is associated with the simulator lab, and while part of the class, it is offered separately. This design project is assigned to each individual student in an effort to force each student to use the simulator to design a complete process and address process optimization. This simulation design is assigned to the students before the completion of the third design. The simulation design project is required to be submitted the last day of class, which is approximately 3 weeks after it is assigned. The process assigned to the students contains several recycle streams and the students must deliver a simulation that converges. Students must size selected equipment using their results, perform optimizations, and address "what-if" scenarios.

Process Design Instructors Responses

The students taking Process Design have benefited from the added design tasks. Students are better prepared to address open ended problems and think critically. Unfortunately, as class sizes have increased, the grading requirement has become overwhelming. This issue was addressed somewhat by seeking assistance from the instructors teaching the engineering technical writing at MSU. The technical writing team is assisting with the grading of the papers but it still requires substantial input from the process design instructor. Currently no assistance is available for grading of the design projects, so this is a time consuming effort. Regardless, most agree that this is the most effective method for training the students for their upcoming transition into the working world. If this course size continues to grow other alternatives will be considered. Thus, referring back to the "Divide and Conquer" approach, the Process Design course at MSU has been divided (with many design projects) but the work load is about to conquer the instructor.

After the students complete Process Design, they transition to Plant Design. Plant Design benefits significantly from the preparation and design work of Process Design as discussed in the following section.

Plant Design

As discussed previously, Plant Design was traditionally a more lecture based course. In the modified Plant Design course, with its emphasis on design, the instructor's roll has changed from that of teacher to facilitator. During the first 3 weeks of the course, traditional lectures are provided. The content of these lectures focuses on the softer aspects of design and to stress the Accreditation Board for Engineering and Technology's (ABET) criteria that are only addressed remotely by other courses in the MSU curriculum. Subjects as ethics, environmental, and safety are the focus of these lectures. In addition, the aspects of writing a quality design report are addressed. While these lectures are being offered (approximately 2 weeks into the course) the design project for the remainder of the course is assigned. Formal lecture are offered from the beginning of the course up to week 4, after this 4 week period formal lectures are discontinued but students must meet every scheduled class period. The purpose of these class meetings are to:

- Insure the students are meeting as a team at least 2 hours per week
- Insure the instructor has the opportunity to address any question or issues with the designs
- Have the students submit their progress reports
- Formally schedule periods where the teams can have one-on-one time with the instructor to discuss specifics regarding their projects.

While this is the general structure for the course, three design options are available from which student teams can choose to pursue: the Class design option, the Waste Education Research Consortium (WERC) design option, and the American Institute of Chemical Engineers (AIChE) design option. Each is discussed as follows.

Class Design Option – The class design option is a design project selected by the instructor consisting of the full design of a chemical plant. Teams of 3 students are assigned by the instructor to address the design. These designs initiate with a research effort. Research is conducted to determine:

- the market size and demand of the chemical being produced,
- the optimal site location,
- the cost of raw materials and pricing information for the generated products,
- the type of reactors available to make the chemical conversion, and
- the details regarding the physical and chemical properties of the raw materials and products.

After 3 weeks of information gathering, teams are required to present their search results (what is called a 10% design) in a written report. The teams must also present their findings in an oral briefing before a committee (consisting of the instructor, other chemical engineering professors, and industrial representatives). Feedback on the 10% design is provided to the students.

Next, the Class Design requires a 30% design. This consists of:

- a complete block flow diagram (BFD) of the process
- a partially complete Process Flow Diagram (PFD) of the plant
- the initiation for the design of the reactor
- the initiation of the sizing of the equipment
- the initiation of the process simulation using the software Chem Cad version 6.4 [3]

Again, students must prepare a full report outlining their progress and findings. An oral brief is also required as with the 10% design, and feedback is provided.

Next the students must complete a 65% design. This consists of:

- a complete PFD for their plant,
- a working Chem Cad model of their plant,
- sizing of most of the equipment for their plant.

Once again students must prepare a full report and orally brief their findings. As discussed before, feedback is provided regarding their performance.

The final portion of the Class Design project is a 100% design. This 100% design includes:

- sizing and costing of all plant equipment
- generation of the cost of manufacturing for their products
- generation of the plant's net present value (NPV)
- a cumulative cash flow diagram for their process
- a Monte Carlo simulation for the uncertainties associated with the NPV of their facility.

A full repot is required as with the 10%, 30%, and 65% design but there is no oral brief. Instead of the oral brief, students prepare a poster presentation on their projects. This is presented in a forum with AIChE Design participants and the WERC design participants. Local industrial experts from neighboring chemical plants experts, environmental experts, and subject experts review these posters and assist in grading the final projects. The top three poster presentations are awarded a cash prize for their success.

WERC Design Option- This design consist of participating in the WERC [4] design contest. This is conducted by New Mexico State University (NMSU) and consists of a design project which must have a working prototype of the design team results. To encourage students to participate in the WERC program students are allowed to self select their teams in the Process Design Course. Once selected, the team members cannot be changed and remain in place through the completion of the Process Design and Plant Design courses. The teams, consisting of 3 to 4 students,

compete in the WERC contest as part of the course (although WERC does not restrict team size). Once the students make a commitment to do the WERC project they must compete in the WERC competition and are graded on their success.

The WERC contest involves a number of steps. First, WERC participants are presented with 5 or more tasks which can be conducted as part of the WERC contest. Tasks consist of a multitude of design areas some that are amendable for the Plant Deign class and some that are not. For example the 2012 tasks consist of:

- An open Task
- Solar Power Array
- Treatment Technology Validation for Water Softening Technology
- Product Stewardship in the Copper Value Chain
- Green reverse osmosis (RO) pretreatment
- Microhydro Power Generation

As one can see, some of the WERC tasks are not acceptable for a chemical engineering plant design course (i.e. Solar Power Array). The instructor provides a list of appropriate tasks to the design teams and the teams are allowed to select the task for with they will address the remainder of the semester. Students are provided with a budget of $500 to buy materials and supplies to construct their prototype. Teams are provided with limited lab space and are supervised by a graduate student which is assigned to each team. Generally the number of participating teams are limited to 3 to 4 teams due to funding restrictions. As part of the WERC design teams must prepare:

- A safety report and Flow Sheet of their process and prototype and this must be approved by the WERC committee at NMSU prior to any fabrication of the prototype
- A written report on their project which is due in mid March
- A chemical inventory of every chemical used as part of their projet
- A demonstration of the teams working prototype at NMSU – this is reviewed and judged by a team of industrial experts
- A oral defense of the written report before a team of industrial experts
- Teams must also Travel to NMSU – (generally in early April)

The instructor attends all the presentations and reviews the written report and Plant Design class grades are awarded based on the team's performance. As part of the Plant Design course, teams are required to design a full scale plant using their prototype data, use the process simulator (Chem Cad) to assist with sizing the plant equipment, and provide a full costing profile for the full scale facility including the plant's NPV.

AIChE Design Option – With this option students select to participate in the 30 day AIChE design competition [5]. As with the WERC Design options the student's incentive to participate in this design is that teams can self select their members in the Process Design course and the same team members work together in the Plant Design Course.

The AIChE design contest consists of participation by individuals, or teams of three members. For the Plant Design Course individual submissions are not allowed. The AIChE design is produced by a member panel of experts and is distributed to the Advisor of the AIChE student chapters at each university. Design problems are generally available by January 1 each year. AIChE requires that all participating teams work independently, so once the team has received the design, no advice regarding the design can be provided by anyone. This prohibits the instructor of the Plant Design course from interfacing with the students during their 30 day working period. Teams are encouraged to accept the design 1-2 weeks prior to their Spring break to allow the teams to focus on the design and to avoid any distraction from their other courses. By receiving the design statement prior to Spring break, students can conduct the majority of their research and have all reference material available by Spring break. Some of the teams elect to have the AIChE project completed prior to Spring break regardless of the advice of the instructor. Regardless of

when the teams elect to initiate the AIChE design project, at the end of the 30 day working period teams must submit the final project. After the project is submitted as final, the instructor reviews the submission.

If the submission is of sufficient quality, the team's AIChE design is forwarded to the National competition without any modification and the students receive an "A" for plant design. At this point the students in these teams have completed the entire course requirements for the Plant Design course and are not required to attend any subsequent class meetings. These teams are only required to participate in the class poster competition typically held during the last week of class.

If the team's AIChE design is substandard quality, the team is informed that their design will not be submitted to the National AIChE for the design competition. The report is critiqued and the comments are provided to the teams for revisions. The teams must address all comments and shortcomings of their reports. If properly addressed their course grade will be modified. Depending on the time frame (when the team chooses to initiate the 30 day clock), teams may be provided with more than one commenting iteration. When the class is completed, the students are awarded a course grade based on the final AIChE design report.

Instructors Responses

As discussed above, the Plant Design class activities are divided between the three projects. This provides project variety to the students but also provides variety to the instructor. With a class size of 50 there are typically 14-15 teams. If the class works on a single project, reviewing 15 reports addressing the same topic is monotonous. The "divide and conquer" approach of three projects appears to be well received by the students and by the instructor. Regardless of the project selected, the students cover similar material with each team being exposed to a simulation, and the cost estimation for their design.

As a side note – MSU has won 3 awards at the WERC contest. MSU has also won the National AIChE design competition several times since the implementation of these course design modifications. In 2008, MSU tied for first place and in 2011, MSU won first and third place. The AIChE contest is a blind contest judged by many experts from industry and academia. Typically over 50 of the nation's best chemical engineering programs compete head to head. MSU award winning status reflects well on the quality of MSU's chemical engineering students and the program.

REFERENCES

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