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Board 11: Work in Progress: Best Practices in Teaching a Chemical Process Design Two-course Sequence at a Minority Serving University

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Introduction

Students complete their capstone design experience in the Chemical Process Design II and III sequence of courses in chemical engineering at Texas A&M University-Kingsville (TAMUK), a Hispanic-serving institution (HSI). Three principle objectives of this process design course sequence are to instruct students in the development of a complete chemical process using process simulators as a primary tool, to complete this project in a team-oriented environment, and to communicate effectively with their peers and instructors. These three principle objectives are directly related to the ABET student outcomes c (an ability to design a system to meet desired needs [new ABET student outcome 2]), d (an ability to function on a team [new ABET student outcome 5]), and g (an ability to communicate effectively [new ABET student outcome 3], which our program has allied with this sequence of senior design courses [1]. There are also a number of secondary objectives that are fulfilled in this design course sequence. These include recognizing and addressing process safety issues, developing people skills, and introducing topics relevant to the impending student transition from the academic environment to the professional environment, such as the need for life-long learning and the benefits of professional registration for chemical engineers. Observations of student team formation, team performance, and team functioning problems are presented, along with improvements in course practices developed to address these issues. These practices are compared with other reports of capstone design team issues found in the literature.

Literature Review

Formation of teams for capstone design projects in engineering may be accomplished by a variety of methods, such as random selection and instructor assignment based on prior performance [2]. However, two of the most common methods are either instructor-assigned teams based on results from student personality testing or student-selected teams with little to no input from the instructor [3, 4]. Some instructors believe the former method is more valuable in order to ensure that teams consist of members with differing personalities, to promote student compatibility. However, some design programs have found the method employing personality testing can lead to a greater incidence of internal team conflict, when compared with teams formed on the self-selection approach [3]. Student–selected teams have, in some instances, been found to perform better because such teams commonly display a greater level of student passion and commitment to the design task at hand [4].

An aspect of the capstone design experience that is frequently unanticipated on the part of the students is team conflict [5]. There are a variety of reasons that conflicts arise within an engineering design team, ranging from personality conflicts and poor communication to a single team member's lack of commitment to the group goals [6, 7]. Experiencing team conflict, and with that, learning appropriate behaviors, responses, and strategies to deal with the conflict, are important experiences for engineering students about to enter the industrial work force [2, 6].

The instructor for a capstone design course has the responsibility to guide student design teams in a manner that promotes success of each team, while assisting the team in navigating problems that may arise from team formation and team conflicts [7]. Aspects of the Design III capstone project at TAMUK that the instructor has control over and that promote team success include (a) providing a clear definition of the goals of the senior design project; (b) requiring groups to complete a project planning phase that serves as a roadmap for their experience; (c) encouraging assignment of tasks to individuals rather than condoning 'group work'; (d) conducting regular checkups of team progress; and (e) coaching teams or team leaders in dealing with non-performing team members or other team dysfunction. All of these aspects of team guidance by the instructor are deemed critically important to project success [2, 6].

Approach to Capstone Design Experience

The project groups or teams for the capstone design in chemical engineering at TAMUK are formed in the fall, at the beginning of the two-semester senior design course sequence (fall-spring sequence, also known as Design II and Design III). The students are allowed to choose their own teams, with the restriction that each team must ideally have four or five members, which is a common team size for capstone design [5]. The instructors have chosen this approach to team formation because it results in teams that include students that have previously worked together in informal study groups. These teams already have bonds of friendship and trust that are a time advantage during the project startup period. There are always a few teams that form last and consist of members that are unfamiliar with each other, for which this advantage is lost. At this time of team formation, each team also chooses a process topic from among topics presented by the course instructors.

The students spend a significant portion of the Design III class (second course) conducting their chemical process design capstone project. The instructors in the capstone course serve as both the course manager and the faculty project advisor. The novel aspect of the capstone course is the individualized mentoring approach that is used by the instructors to guide the students through the challenges each individual team inevitably faces. This individualized mentoring is accomplished by weekly instructor meetings of 30 minutes duration with each team at a regularly scheduled time, which allows the instructors to focus solely on the technical or programmatic issues of just one group. An alternate method for this capstone project contact time used in other engineering departments of our college is for the instructor to talk informally with groups during a three hour design laboratory period that is held once per week. However, the course instructors in chemical engineering have selected the dedicated meeting approach described above rather than this alternate approach, because it guarantees a completely devoted time period for each team with the instructor. Thus, the practice of a regular checkup espoused by Davis [2] is accomplished. In the laboratory checkup scenario described above, not all teams may get individual time with the instructor each week. The preferred approach is more time consuming for the instructors, however it is worthwhile, since it better ensures the success of all teams in each course offering. The effectiveness of this approach is reinforced by the primary course instructor's high student ratings (average 4.80 out of 5.0 for four most recent Design III course offerings) in the course rating categories "takes time to answer questions", "available during office hours" and "sets high academic standards", categories which are directly related to the student-instructor team interaction [8]. The 2019 spring semester offering of Design III is the first time that the second course instructor has taught this course, so previous data for this instructor in Design III is not available.

The instructors coach all project teams to address their technical issues by self-discovery of the information they need to move their project forward, and then guide the students in applying this information in conjunction with engineering principles they have learned from previous courses, a recommended approach by Fogler [6]. This technique encourages development of the students' skills in life-long learning, and gives them experience and confidence in open-ended problem solving. Most of the lectures presented by the instructors in the Design III course, as well as a few in the Design II course, are on topics that the students need to complete their design, and on topics that introduce the students to ancillary aspects of process design such as they would encounter in an actual industrial design experience [3]. Additionally, the variety of topics required for incorporation into the final design provides each team with more opportunities for delegation of tasks, which is helpful for students that may not be adept at the process simulation side of the senior design project. Delegation of tasks pushes the team to further experience relying on each other and expecting all members to contribute, an important aspect of efficient functioning teams and for promoting creativity [6].

These ancillary topics presented in the Design III course include project management, process safety, process sustainability, and handling of process wastes. Figure 1 presents a diagram of the manner in which these ancillary topics are incorporated into the design experience, as compared to a basic capstone experience that includes only process design and economics. The course is a designated writing intensive course for our discipline, and the students satisfy this requirement by writing ten 500-word essays on a variety of design-related topics, including the ancillary topics listed above. The student increase in understanding and incorporation of these ancillary topics into their design is partially reflected in the upward-trending average score for the writing intensive assignments, which went from a mid-B (86) in the 2016 course offering to a high-B (89) or low-A (91) in the 2017 and 2018 course offerings.

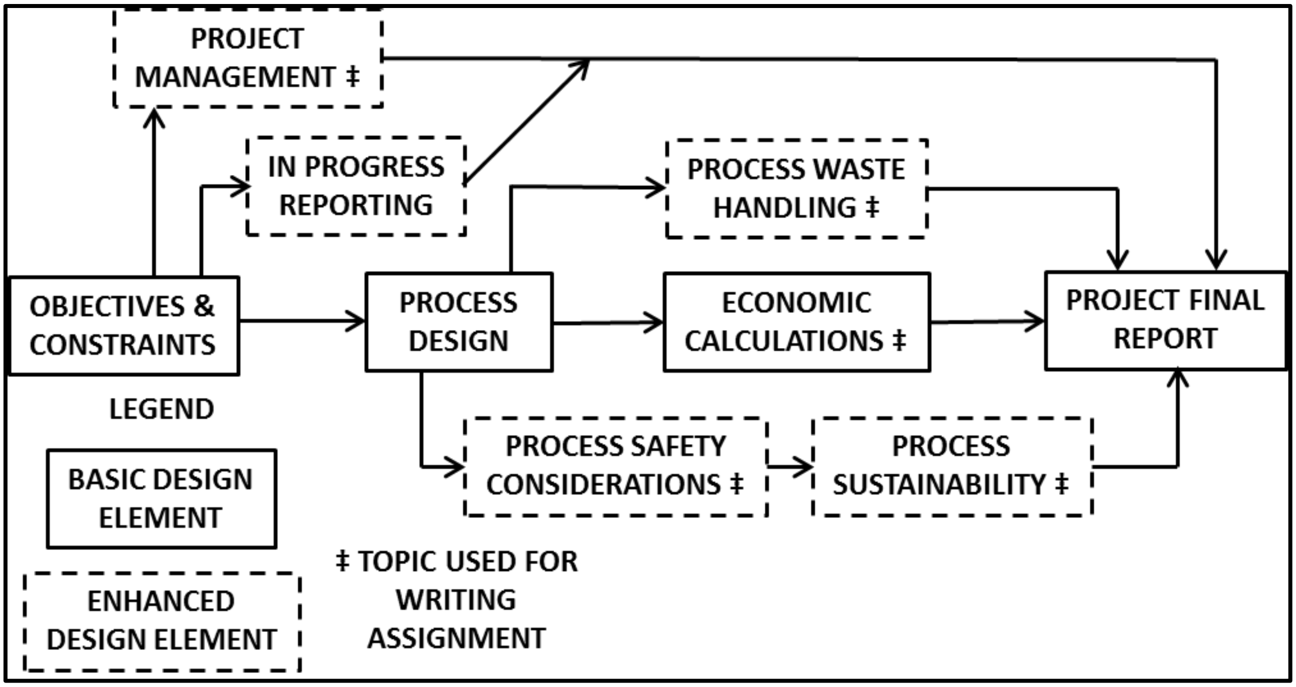

Figure 1. Enhanced Structure and Functionality of TAMUK Chemical Engineering Capstone Design Experience

Performance of Student Teams in Capstone Design

Table 1 presents some of the factors that may be unique to Hispanics or other minority undergraduate students in engineering at a Hispanic serving institution, as observed by the primary instructor in our capstone design sequence and also as discussed in HSI workshops attended by one of the instructors [9]. These items may be additional stressors to group function and high performance. Family commitments (caring for offspring or aging parents, or serving as the primary financial support for a family unit) may interfere significantly in the student's day-to-day ability to contribute to the team effort. Typically, in prior higher education coursework, students with these types of demands may settle on a particular study approach or time to study that fits with the other family demands. However, when it comes to working on a long-term project team, some students find it very difficult to adjust to the higher time demands of the capstone design team project, considering the other previously-mentioned school/job/family demands [7]. Hispanic students also commonly have a higher incidence of being the first in the family to attend college. Those students may not have a complete understanding of what college entails, and how to navigate the college and engineering education experience successfully. The primary instructor has observed these factors adversely affecting team performance, as described below.

Table 1. Student Factors Unique to a Hispanic Serving Institution

Family time commitments (single parent, care of aging parents)
Family financial commitments (need for outside job)
High incidence of first generation in college
High incidence of transfer from community college

A variety of good and bad situations regarding team function have been observed by the primary course instructor over the previous three years of the Design III course offering at TAMUK. The course instructor has used these observations to develop and implement several best practices for team management. Design teams will sometimes bring to the instructors' attention personal disputes within the group. The instructors either coach the students to work through the issue by themselves, or offer to the students the opportunity to discuss the issue of discord with all team members together [5, 6]. In the latter case of a group discussion, the instructor takes on the role of an engineering manager to which the group would be reporting in an industrial setting. The instructor reviews the groups' project goals and the expectation of equal contribution from all team members. He also reminds the team members that, in the industrial setting, their continued employment would depend on satisfactory contributions to the group, while in this educational setting, it is their course grade that depends on the satisfactory contributions to the group. This is a common approach to handling group discord taken by industry managers. One technique to address team conflict resolution that has not yet been implemented by the Design III instructors is including a lecture presented to the students early in the course on proper team function expectations and team conflict resolution, which has been the focus or recommendation of several other authors who have written on student engineering team dysfunction [5, 6, 10]

Table 2 presents items that are the most common causes of tension within a senior design group, and how the tension or group conflict most commonly manifests itself or affects the performance of the group, as observed by the instructors over the four most recent offerings of the Design III course. The principle causes of tension in an engineering design team are either poor availability for group meetings due to outside conflicts (commute time, off-campus job) [9] or poor performance on an expected work product or assigned task. Recently, the department chair altered the departmental schedule of courses by scheduling multiple sections of most all senior-level courses at the same time. This has helped to reduce the first cause of group tension by reducing team meeting scheduling conflicts amongst members in a team. The issue of poor performance on tasks by individual members in a team typically comes down to motivation and accountability issues [9]. Unfortunately, some of the students during their senior year simply have an attitude that they will only do what may be necessary to barely pass the course, which can eventually become reflected as poor performance for the entire design group [6]. When these types of conflicts arise, the end result for the entire group or individual members is either frustration or perhaps anger with the offending group member, or other group members making up for the work not completed and then scoring the offending group member low on the group contribution that is submitted with major project deliverables.

Table 2. Common Issues Leading to Group Tension

Tension Causing Issues	Group Conflict Manifestations
Lack of availability for meetings due to long commute	Requirement for task rework
Lack of availability for meetings due to off-campus job	Frustration between group members regarding unequal contributions
Poor performance on assigned project tasks	Late project submittals
Personality conflicts	Low group contribution score for one member

Evidence for the effectiveness of the instructor's management of group discord is presented in Table 3, which provides a tally, based on the instructors' observations, of the instances of significant group discord that was brought to his attention in previous Design III course offerings. Significant group discord was identified as any instance when the instructor called a special meeting of group members solely to discuss an issue of disagreement. In some cases, this discord became an issue at the time of grading a major submittal, while in other cases, it was brought to light by one or more group members discussing the general group progress with the instructor. In the former situation, the discord sometimes arose when the contents of each member's group contribution score sheet came to light during grading, and one member indicated disagreement with others' scoring of his contribution. The instructor usually brought together the entire group for a special discussion on the topics cited earlier, when discord of this nature arises. The data in Table 3 indicate a fairly consistent incidence rate of actionable group discord of roughly 10 % of the total number of groups in a course. The incidence rate for the first year listed in Table 3 is higher, and this is attributed to it being the first year of full-time teaching experience for the primary instructor. In another small study of capstone design groups [3], the incidence rate of dysfunctional teams was 20% (1 in 5 teams) for teams formed based on personality matching rather than self-selection [3]. In the current year instruction (spring 2019), the primary instructor has noticed a trend towards group discord being brought to the attention of both instructors earlier in the semester than previous years, which is, of course, helpful with respect to making corrections prior to the end of the project period.

Table 3. Incidence Rate of Senior Design Group Issues

Design III Course Offering	No. of Design Groups	Number of Groups with Observed Group Discord	Incidence Rate
Spring 2016	12	2	17%
Spring 2017	11	1	9%
Summer 2017	4	0	0%
Spring 2018	12	1	8%
Spring 2019*	18	2	11%

* -- preliminary data for current (in progress) semester

The instructors have thus used the following best practices developed from the experiences and observations described above, in an attempt to minimize occurrences of group discord in the capstone senior design experience:

a. Explain to all students in the class at the beginning of the course that working in a team for an extended period of time requires one to cooperate with others, in particular when the other persons may not be one's friends. For engineering projects in industry, team members are almost always appointed, rather than self-selected from friends. This brief discussion in the class environment sometimes falls on deaf ears. As well, sometimes students express that the senior design capstone project is the first time he or she has had to work for an extended time period (more than one or two weeks) in a team environment, and so the instructor should use the opportunity to set appropriate expectations of each team in this new learning environment [2]

b. Institute a required weekly meeting of each senior design project group with the instructor, outside of regularly scheduled class time, which allows for a regular and frequent check on the climate of each group. This appears to work well in preventing any group discord from escalating as the semester progresses.
c. If potential discord is recognized by instructors, the responsible instructor talks to all group members together about the importance and need for cooperation, and how a lack of cooperation may affect their group project grades [5, 2]. If the discord appears to have risen to the level of outright anger between parties, then the instructor will commonly attempt to talk to the two parties individually to be sure he understands all sides of the issue, prior to discussing the issues with the entire team present.

Conclusions and Future Work

The best practices that instructors of the Design II / Design III course sequence in chemical engineering at TAMUK have developed includes the following elements:

- Hold scheduled weekly meetings with each project team, for review of team progress and discussion of issues that may be hindering progress;
- Include ancillary topics to capstone design project objectives, to engender a more real-to-industry feel for the experience, and more opportunity for all members to contribute to the overall project success;
- Emphasize that good communication is a key to both effective group operation and to effectively conveying the group's results to instructor faculty and other students;
- Deal with any project discord that comes to the attention of the course instructor by discussing the issues with the entire team membership, and proposing ideas to resolve the conflict. Additionally, the possibility of changing (dropping) team members is not presented as an option, since this type of an option is usually not available in the industrial setting.

This last point appears to have the greatest effectiveness if it is implemented earlier in the semester rather than later. Based on the work of others [5, 6, 10], the instructors will consider implementing a lecture and exercise on proper team functioning and team conflict resolution skills at the beginning of future Design III course offerings. Additionally, the instructors intend to continue observing the incidences of group discord for comparison to other capstone design programs implemented with different approaches.

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