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Chemical Engineering Senior Design at Colorado School of Mines: Recent Innovations & Achievements

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The one-semester Senior Design course at Colorado School of Mines has seen a large number of changes & developments over the past several years. The evolution of assessments, upgraded from general checklists to detailed checklists and ultimately to detailed rubrics for all assignments, along with structuring the course to be more front-loaded enables more consistency between different professors grading the same assignments (for different students or student groups). Introducing active learning methods has made students more enthusiastic about attending class. Anecdotally, highly detailed rubrics also helped in reducing clarifying questions from students and active learning reduced the need for clarification (office hours or email questions). Professors who had little or no prior experience with active learning methods found the detailed rubrics highly effective as well and continued introducing more activities during lecture in successive years. Introducing reading guides & quizzes (the latter for participation points, due before the accompanying lecture) allowed us to eliminate several lectures in the first few weeks of the course, as these were previously simply rehashing information in the textbook. In addition, the introduction of peer-grading of a follow-up assignment (after students have received feedback on the first assignment) has reduced the workload for the professors while simultaneously enriching the amount and quality of feedback most students receive.

Students had long requested the addition of industrial or other externally sponsored projects. While this was relatively labor-intensive in the first year (making contacts, writing contracts), it has been a highly rewarding exercise for everyone—nevertheless, the authors recommend keeping a professor responsible for grading, as industrial sponsors can have less of an understanding of course design and assessment standards than academics and/or have trouble delineating course learning objectives from project goals. Finally, it is strongly recommended to teach Aspen in the form of tutorials (either in-class or via videos) as students appreciate this learning mode (it is consistently mentioned positively in mid- and end-of-course evaluations) and benefit from it very well. The authors have also had a positive experience after dividing the expectations for progress reports and meetings with a bright line: progress reports focus on schedule, tasks, an updated draft report, and a summary of the latest results; meetings and presentations focus on actual content of the design (e.g., design decisions, stream tables & flow diagrams, etc.). Many of these suggestions are already known best practices, as identified and discussed in literature, while some are merely suggestions the authors found useful in this incarnation of the course.

Since 2016, this core team of instructors has invested considerable time and effort in improving this course, soliciting various modes of student feedback and applying new pedagogical principles and techniques from the literature and from professional development activities. This paper describes these efforts, some of the newly developed tools and instruments used in the course, and some anecdotal results of these efforts from both students and instructors. The authors invite any interested faculty to seek direct contact by email with any questions or requests for materials, such as grading rubrics or reading guides.

Introduction & Background

The most recent survey of (primarily U.S.) chemical engineering programs in the "How We Teach" series which focused on the Senior Design course took place in 2013 and revealed that: a plurality (46.8%) of respondents offered a single course (semester or quarter), a similar percentage of lead instructors are full professors, most draw projects from a combination of sources including industrial or faculty sponsorship and the AIChE design challenge, and a large plurality use Turton, et al. for their textbook and Excel & Aspen Plus for software applications in the course [1]. The course at Colorado School of Mines is similar to the typical program respondent in all of the above-mentioned respects with the exception of the lead instructor: since 2016, this course has been co-led by an Assistant Professor and Assistant *Teaching* Professor, with significant support in course design and implementation from a Professor *of Practice*. This is also the way in which this course differed most significantly from the typical respondent to a more recent survey of senior design faculty in engineering more broadly [2].

Course Description

Along with the growth of the program at Mines, the capstone Senior Design course had seen increasing student numbers through the academic year ending in 2018, at which point the program size has begun to level off. Table 1 provides the number of students who completed the course in each academic year (listed by the calendar year in which that academic year ended).

The course has been co-led by the authors since 2016, with significant planning support from an additional Professor of Practice. Primary coordination responsibilities have been transferred from one author to the other, from year to year, but all major course planning has been closely coordinated within this core group during this time. In addition, there are usually adjunct faculty (from industry and/or emeritus professors) who provide the economics lectures and supply a project and advise & assess student groups during the course (i.e., function as project advisors).

Table 1. Student enrollment and ratio to professors by year (end of academic year).

Year	# Stdt's	Stdt/Prof
2016	122	24.4
2017	136	22.7
2018	161	26.8
2019	151	30.2
2020	139	27.8

This course focuses exclusively on the design of a chemical *process*, and thus there are no interdisciplinary teams with students from other majors on campus (as most other degree programs at Mines focus on physical *product* design projects and operate over two semesters instead of one). We offered the course in the Spring semester until 2019 when it was moved to the Fall during our most recent curriculum-wide revision. To avoid confusion, the academic year will be referred to in this paper by the calendar year in which it ended (e.g. the course offering in Fall of 2019 is considered Year 2020).

This Senior Design course is the "capstone" course in these students' curriculum, but Mines students are also required to complete a freshman design course, the so-called "cornerstone" [3]. The Senior Design course is now taught concurrently with most seniors taking the kinetics and reaction engineering course as part of our curriculum wide revision. In 2016-2019 it was taught in the spring, after completion of these courses. Coming into the senior year, students have already taken courses necessary for success, including process control (junior year in 2020, concurrent prior years) and training in Aspen Plus (throughout the curriculum, beginning in the sophomore year) and other relevant software (e.g. Microsoft Excel, Polymath). Accordingly, in this course we focus on utilizing these tools towards specifically process design, rather than how to use them or designing single unit operations as done in e.g. unit operations, separations, and heat transfer courses.

Course Structure

The course is delivered in three phases, an overview of which is shown in Table 2. The first, Phase I, includes general lecture periods and individual & small (ad-hoc) group assignments, during which time the student design project groups are formed by the instructors, but the students are only informed of their project topic (not their group members). This enables students to do preliminary research and design on their projects independently (see the Front-Loading section below). The students are informed of their groups before the second phase, Phase II, during which they will also receive two lectures per week (one on Aspen Plus software and the other on design topics such as sizing and costing) and have one period reserved for group work (in addition to the time they arrange outside of the class period). The final phase, Phase III, is composed almost exclusively of group design project work, with occasional lectures on more specialized topics such as economic calculations and forecasting or HAZOP as well as the assignments on Aspen Plus performed in sub-groups (more on this in a later section).

Student performance is assessed by means of a number of individual, sub-group, and group assignments (both project-related and non-project-related), in addition to peer evaluations and professor evaluations. One of the course instructors oversees each project, but industrial advisors and other professors often serve as co-advisors and help advise groups on the technical and business details pertinent to particular projects. While these additional advisors may deliver valuable guidance and advice, the course instructors are solely responsible for assessment and grading. The workload for the course instructor is typical for a 4-credit course (semester system credits), but that for the external advisors is notably less. Each year the course offers a number of projects (anywhere from four to ten different projects, including design competitions such as AIChE and ACS-ESBES), and student groups (of 3-6 students) are formed based on student rankings of project choice and group members to potentially include or exclude from their project groups. Any single project may have from 1-6 student groups working on it, with all groups directly assessed against the same rubrics (see Grading Rubrics, below). This avoids inter-group competition and improves inter-instructor consistency. There are no specific mechanisms to avoid student groups discussing projects, although in our experience the designs and decisions typically diverge rapidly, leading to unique projects. We encourage inter-

Table 2. Overview of the three phases of this semester-long course.

Course phase	Phase I	Phase II	Phase III
Approximate Duration	3 weeks	6 weeks	9 weeks
Format	Regular lecture periods	Rotation: two lectures & one group work session, occasional meetings	Occasional lecture, mostly group work and meetings
Assignments	Individual	Individual & Group	Group & Sub-Group
Group known?	No	Yes	Yes

group collaboration, as some students inevitably feel more comfortable seeking help from peers, but plagiarism is enforced as strictly as in any other course (with automatic scanning and manual checking of all flagged reports). Furthermore, literature has demonstrated that the use of draft reports helps to prevent and reduce plagiarism in final reports [4].

Recent Innovations

After reading literature on senior design (or "capstone") courses, both in chemical engineering and more broadly, and in support of continuous development efforts sponsored by the university and supported by the faculty in Chemical and Biological Engineering, the authors have worked to implement best practices in curricular design when improving this course. Senior Design can often be a more critically reviewed core course in many programs due to its open-ended nature and its reliance on all other core courses [5], as well as the widely varying methods of delivery from institution to institution (and from department to department, within the same institution). Many of the innovations and best practices described below are included in Bullard's "Ideas to Consider for New Chemical Engineering Educators" [6], Felder & Brent's book Teaching & Learning STEM [7], and in Howe & Goldberg's chapter in Design Education Today [2].

Discussed below are the recent (since 2016) changes to the Senior Design course curriculum at Mines, treated longitudinally for analysis as a group but discussed separately: use of student feedback sessions and additional modes of feedback; changes to the broader course structure & alignment; grading rubrics and alignment between instructors; (increased) front-loading and reading guides & quizzes; use of active learning during lecture periods; use of peer grading for an individual assignment; industrial (and other external) projects; the evolution of the Aspen assignments in the course; and semester-long assignment structure (progress reports & meetings). The paper will conclude with a summary of the results and recommendations of best practices when administering this course, or one similar.

Student Feedback

To properly assess student opinions on the course and obtain meaningful and sincere suggestions for improvement, university-wide online end of semester student course evaluations were augmented with three additional modes of feedback for this class in most years discussed in this paper: an online mid-semester survey, an in-person feedback session (with a focus group of a range of different types of students), and an anonymous paper survey administered on the last day of the course. These are discussed separately below. The first day of class the instructors detail prior survey responses to the incoming class, and changes made based on that feedback. This has resulted in more student buy in for constructive feedback throughout the course.

The mid-semester survey is an online (anonymous) form not coupled to the Learning Management System (LMS), but instead administered through google forms. A link is emailed to the students around the third week of the course (near the end of Phase I). The survey remains open all semester, with reminder emails sent to the students a few times throughout the semester recapitulating the internet link. The form consists of four basic questions ("What aspects of the course, and its instruction, are helping you learn?" "… are hindering your learning?" "What can you do to improve your performance? What can the instructor do?"), plus a question about the supporting videos in the course and a free-response comment section. This form enables instructors to make changes "on the fly", in the middle of delivering the course. One example was a suggestion made in 2017 that the Aspen Plus instructor slow down or otherwise provide "helping moments" during the lectures to ensure students keep up with the tutorial or example models. Students responded well to this change, both in the mid-semester survey and in course evaluations, leading the instructor to adopt this teaching method permanently.

The in-person feedback session was a lunch-time meeting (with pizza provided by the department) including the coordinators of the course and a panel of students selected from a group of volunteers. The student panel was chosen to reflect the full range of academic performers in the class as well as the diversity of experiences from working on different projects (with different advisors). These sessions often provided the most valuable information that could be used to improve the class, as nearly all of the major issues raised by other modes of feedback were discussed and the faculty could easily poll the group on any one of them as they arose. The sessions were started by one of the coordinators summarizing recent changes to the course (both from the previous year and during the semester) and continued in a more free-form discussion after students responded to the two primary questions: What went well? and What needs improvement?

Course Structure & Alignment Changes

Because of the summative nature of Senior Design courses, it is a best practice to consider the curriculum as a whole when (re-)designing any aspect of this course or its contents. Being aware of what information students have covered in their other classes, including the required courses taken *outside* of their major department (e.g., math, physics, chemistry, but especially courses like freshman design) can help the instructors reduce the amount of duplication in the curriculum and also reinforce those principles with which students may be out of practice. Howe and Goldberg suggest using a "design map" to summarize all of the experience students should have with design problems in their previous classes [2], thereby more optimally scaffolding the students learning up to the senior design course.

Even without mapping the curriculum, instructors should remain vigilant about the mismatch between expectations (e.g., of prior knowledge) and students' preparation in other courses. One example the authors recently identified was a difficulty that many students had in designing control structures in P&ID's. Identifying this weakness allowed the instructors of this course to consult with those of the Process Dynamics & Control course and ultimately put the students' first instruction on these concepts in this earlier course. This is expected improve the quality of the P&ID's the students generate in the future, which will subsequently enhance the productivity of their HAZOP sessions.

Consulting with the instructors of cornerstone design, the authors procured some lecture materials from this freshman course which focused on things like completing a Decision Matrix such that they were familiar to the students when they were presented again this senior design course. Utilizing such materials not only reinforces these principles and skills but also provides students with a bigger picture of their major & curriculum and connects their earlier courses with this, one of their last required core courses.

It has been suggested in the literature that providing the students with more control over their project (e.g., brainstorming the project topic(s) or defining their goals) is a best practice, both to generate and encourage student motivation and enthusiasm about the project as well as to improve student perceptions of the course as a whole [8], [9]. Nevertheless, for this single-semester course, it is essential to have clearly defined projects at the beginning of the semester, in order to afford the students enough time to learn and develop their projects into a well-formulated final report before the end of the course. The authors allow for (and actively encourage) student-defined projects, but these must be fully articulated to faculty by the end of the first week of the semester and are subject to faculty approval as they must satisfy certain pre-conditions. This is to ensure that all student generated projects are capable of demonstrating all learning objectives, align with the overall course goals, and that student groups realize that these projects may entail more work. Examples of some that have worked well are projects that were generated through prior student work experience (see Industrial Projects below). Poor projects that were not approved include simple designs that require little exploration of alternative designs or single unit operations. One risk of student projects is also that the goals may change mid-semester, as happened to one group using this for a competition. Their initial project met all necessary objectives, but mid-semester they changed goals to a product design which necessitated them now completing two independent designs in order to demonstrate the learning objectives (a risk that they were aware of and accepted when starting the project). Overall, the student projects require more up-front work for the students and instructors but can be both valuable and motivating for the students.

The key aspect of student self-definition in the course is that each student (first individually, then within their design project groups—see Assignment Structure below) defines a set of their own Design Objectives for their assigned project. In 2016, lecture material was augmented to include a brief discussion of "SMART" characteristics [10] and these objectives were required as a part of the second individual design assignment (defining a block diagram and establishing a design basis) as well as several group assignments. The grading rubric for these Design Objectives includes an assessment against SMART criteria. In 2017 and 2018, this lecture was modified to include in-class activities defining a Design Objective and assessing those of their classmates (see the Active Learning section below). The students' individual design objectives are combined and refined when they first form their groups, and are continuously improved throughout the semester, with regular feedback from project advisors. These are generally finalized at an acceptable level (in the eyes of both advisor and student) at some point during Phase II. Since its introduction, the instructors have seen steadily improving quality of student-defined Design Objectives in successive years.

Design Project Assignment Structure

Many of the major course assignments (including *all* of the group project assignments) are described in the syllabus, which is presented to students on day one, and available on the LMS even earlier. All grading rubrics (or checklists) are published to the LMS and are published simultaneously with the assignment—this gives students a clear picture of how they will be assessed and what instructors will expect [7]. The major group project assignments are composed largely of four meetings (1st pass Conceptual Process Design, 2nd pass Technical Design

Meeting, Final Technical Presentation, and Final Economics Meeting) and three or four progress reports, due in alternating weeks. The third meeting is the only formal PowerPoint presentation, in which students will present to the other student groups working on the same project, but some project advisors encourage their students to prepare informal slides for the other three meetings. The progress reports are delivered in memo format and provide instructors with opportunities to provide timely feedback on various steps and components all throughout the process.

In the most recent offering of this course in 2020, the authors revamped this structure with a focus on reducing workload for students while also improving the quality of the final reports through elimination or condensation of duplicated writing efforts (e.g. overlap between progress reports and the final design report). In this year, the requirements for the progress reports were pared down significantly and students were required to deliver a draft report with each one. Each progress report had specific requirements of certain portions of the final report (beginning with things like introduction and basis of design, moving on to diagrams and process descriptions, and ending with sections like economics and conclusions). Despite the volume of additional material, the instructors mostly appreciated this new format as it led to greater student confidence and higher quality final reports at the end of the semester. The extra structure also minimized the amount of last-minute writing by the student groups – a challenging problem for many courses. By submission of the final report most sections had been edited by the students at least once in response to instructor feedback. Students responded positively to the survey question specifically asking, "do you think having the draft final reports made preparing the actual final report easier", with 83 student responses including "Yes" and 31 including "No".

Many responses suggested that the continuous and early feedback on report sections was helpful in tailoring their writing and formatting to their advisor's preferences. One complete response to the draft question stated "Yes it made it much easier. We had a great starting block on the final report." Another comment, in the free response section, read "[t]he amount of progress reports and passes [meetings] felt like a good amount to keep things focused and moving."

Grading Rubrics & Instructor Alignment

One consistent complaint in student evaluations from prior offerings of this course (through 2016) was poor alignment between instructors: it was perceived (and confirmed later by quantitative analysis) that some project advisors were "easy graders", with nearly a whole letter grade discrepancy spread between some instructors (normalized against all individual and group assignments graded by a single grader, either instructor or TA). As a result, standardized grading checklists were generated before 2018. These were expanded to more detailed instructor grading rubrics in 2019 (although the student-rubrics were a reduced version of this) and these were further refined and improved upon in 2019 and 2020, with full transparency (i.e., no more differences between instructor and student rubrics). The evolution of these assessment tools can be seen in Appendix figures A2-A4, and with the most recent version in A1. Over this period the discrepancy between instructors decreased significantly, to less than a half of a letter grade (normalized as before) with variability in which professors were above and below the mean. In other words, this solved the "easy grader" aspects of the instructor alignment.

The authors would encourage the reader eager to implement this strategy to start small and work toward gradual improvements—creating detailed rubrics for all assignments in the course before one offering can be a major investment of time and work. Establishing checklists first is an easy way to start with rubrics without investing too much work all at once. It is also very important to distribute these instruments to instructors early (preferably before the course begins, but necessarily before the assignment is distributed to the students), not only to receive constructive feedback from those who will use it but also to receive and respond to any questions they may have on the rubrics. This helps to establish a common understanding of the expectations for the assignment and improves alignment among instructors significantly.

Front-loading the Course: Reading Guides, Quizzes, etc.

Another common difficulty in senior design courses (not only in Chemical Engineering but also more broadly) is that the group-project nature of the course enables the possibility of "freeloading" students who contribute little to no work to the group yet receive the same grade on most assignments or even for the course [11]. The literature suggests several preventative measures for this issue, including team selection procedures, peer evaluations, individual instructor evaluations, and regular meetings [6], [12], and further prescribes that "low performing students should be identified by the instructor" [6].

The authors have added to the methodology of front-loading the course (see section below) by assigning projects right away but postponing the group formation until Phase II and requiring several individual assignments in Phase I. The first assignment is most commonly an annotated bibliography on the project, and the two subsequent assignments focus on establishing a "base case" and "alternative" design to address the project needs. Students are informed on the first day that they must receive a minimum of 70% on these individual assignments (combined with participation points received from submitting in-class work and online reading quizzes, as described below) in order to be placed in a design project group. Thus, instructors may perform a check at the outset of Phase II (at which point more than half of the individual assignments have been submitted), immediately before publishing the groups. At this point, students at risk of not meeting this 70% threshold are invited in for an individual meeting with the project advisor and/or the course (co-)coordinator to discuss how they will rectify the situation. Some of these students choose to unregister from the course (and enroll in a later offering), some are spun out into their own single-person "group", and some get back on track and become productive members of their groups. While this methodology has not completely eliminated the "freeloader" problem (as there are usually 2-3 cases per year), it has reduced it significantly and has all but eliminated the withdrawal and failure rate in this course—students are far more likely to unregister from the course (before the deadline for a listed withdrawal) than to fail it or withdraw late in the semester. Since 2017, there have only been two students who were spun out into their own individual groups (at later points in the semester, usually Phase III) and more than five who have unregistered for the course, while zero have received a failing grade.

Front-loading the course with (the majority of) these individual assignments assists in early identification of potentially problematic group members but also supports student motivation and discipline more broadly in the course. Similar to the assignment front-loading, the lectures on design principles also fall largely in Phase I. It was found that earlier versions of this course (offered prior to 2017) included a large amount of lecture material which simply recapitulated the textbook. This is poor curricular design and squanders the precious contact time available between instructor and students [7], [8]. Consequently, the instructors for each lecture generated corresponding reading guides and quizzes for the chapters covered in that lecture. The reading guides include questions intended to probe students understanding of the concepts the instructor intended for them to glean from the reading; the quizzes, usually composed of 2-5 multiple-choice, multiple-answer, or matching-type questions for a total of 7-20 points, reinforce these concepts and help students assess their own level of understanding. Since this is treated as a formative assessment, students are awarded full participation points for all quizzes with a score of at least one point. Students are advised to use the reading guides on their own: instructors suggest that students read through the guides and answer the questions mentally, and any questions which they find difficult to answer should be used as guides for the content that the student should go back and re-read. The authors have observed that simply posting reading guides was insufficient to stimulate students to come to class prepared (having read and comprehended the related sections of the textbook). The addition of the quizzes for "easy" participation points helped the instructors consistently realize these goals, as the most recent offering of this course enjoyed 96.6% participation rate in the online quizzes, with five of the fifteen quizzes seeing 100% participation and the lowest rate on any one quiz was above 90%—this, despite the fact that any one quiz would only contribute less than 0.5% to the students' final grades. Introducing reading guides and quizzes is a well-established practice to support the flipped classroom and other active learning techniques [7].

Active Learning during Lectures

Owing to the use of reading guides and quizzes described above, the instructors were able to eliminate three lecture periods from the schedule (enabling further front-loading) and to introduce commonly used active learning methods and events into the remaining periods. Examples include: Kahoot! quizzes; Think-Pair-Share exercises; generating a category-weighted Decision Matrix; and performing sizing, costing, or economics calculations in class (on a computer), using pair-programming [7], [13].

While nothing can surpass the popularity among students of the Kahoot! quizzes in class, these active learning moments were positively reviewed by both instructor and student alike. The students appreciate being able to practice their activities (brainstorming, writing, calculating) in class, with the guidance and support of an instructor if needed. Some of the relevant comments in student feedback from 2020 include: "I liked that they gave us a chance to practice" and "keep the lectures --> they are very helpful". This last comment was especially encouraging as the authors had seen the opposite suggestion in evaluations of prior course offerings (before applying active learning strategies).

The instructors also appreciated the opportunity to help students on an individual level, thereby better understanding the status of the class and the ability level of the students more broadly. Even emeritus and adjunct professors who had little to no prior experience with active learning techniques were impressed with their effects and were highly appreciative of this teaching mode.

Peer Graded Assignment

Re-developing this course and implementing the above strategies over these several years led to some unintended consequences and stumbling blocks. One of the first years after increasing the front-loading of the course saw many instructors unable to provide timely feedback on the individual "base case" and "alternative case" assignments because of the number of individual submissions (about 20-40 per instructor) and the rapidity with which the course transitioned into group work in Phase II (two weeks after the base case assignment and several days after the alternative assignment). Consequently, much of the feedback on this assignment came too late to be of use to the students, and the grading load weighed heavily on the instructors. Consequently, and because this assignment is essentially a follow-up to the "base case" assignment (with very few changes to the requirements and grading rubric), feedback on this assignment was transitioned to peer grading in 2019. Students were randomly assigned two different submissions from other students working on the same project to grade using the rubric published on the LMS and were given a week to complete their grading. Instructors ensure that they provided timely feedback on the first "base case" assignment so that students knew their instructors' expectations for the assignment. It was found that, while the students were perhaps slightly more lenient in grading (average grades were slightly higher than the instructor-graded assignment), they provided detailed and copious feedback which was very helpful to the class as a whole. Some examples of such feedback include comments like: "Says that corn steep is purged but BFD shows all liquid waste being recycled" and "I just don't see the point of feeding cells into a batch reactor. I liked your first design for batch into batch, but for this one I'm just not convinced". By using multiple graders for each student submission, the instructors were able to screen for assignments with a wide distribution of grades, potentially highlighting issues with grading. This included <~5% of the submission in 2020.

Implementing a peer-graded assignment in such a large-enrollment course is not without challenges. Nevertheless, the reader who uses Canvas as their LMS should consult the Canvas Community site for a video guide on how to download and collate the data [14]—Canvas' API enables a great deal of access to data, but some work (and additional free software) is required to access it.

Industrial (and other external) Projects

One of the most common suggestions for improvement to this course in previous years was a request for more real-life problems, preferably with industrial sponsorship. While the university has long offered other (multi-disciplinary) senior design courses that include industry-sponsored projects, this course has focused on internally developed project prompts until 2019. In 2018 and prior, the course included projects sponsored by professors both within the department and from other departments, but it was believed that external projects would be difficult and time-consuming to manage.

To support the redesign efforts of this course, the authors took the initiative to contact alumni and local research institutions in the summer and early fall of 2018. Over half of those contacted were receptive. In addition to these efforts, the instructors informed students enrolled in the pre-requisite courses for senior design that any student-initiated projects would be considered if they were submitted well in advance of the first day of the course. This ultimately led to three external projects in the spring of 2019: one sponsored by two alumni in industry, one sponsored by an alum at a nearby research institute, one sponsored by a nearby private company, in addition to one sponsored by a Physics department professor. These last two projects were suggested by students who had previously worked for the company and professor, respectively. The latest offering of the course included still another, new industrial project.

Overall this process was highly rewarding and encouraging. Response from alumni contacted was typically positive and showing interest and the execution was smooth and efficient. In cases where there wasn't current interest, many were open to future projects. Some key things to remember include: solicit project suggestions early (preferably a full semester in advance) and provide clear guidelines for the project descriptions (e.g., define a scale or range of production rate and specify some aspect of product quality, such as purity, define the battery limits); inform (and remind) project sponsors of the schedule of meetings for the entire semester and ensure sufficient space is reserved for these meetings with students; and clear any and all contracts with your university's legal department. This last note can be time consuming, especially in the first year of establishing such a program. It is essential that the instructors require co-sponsors to sign an indemnification contract with the university, releasing the university from liability; in addition, many companies will appreciate a standard non-disclosure agreement (NDA) they can have signed by the students who will work on their projects, if necessary. Drafting these contracts from scratch can be a time-consuming endeavor, so it is strongly recommended that the authors start with a similar document (e.g., one created by a different senior design program within the same university, or one used at a separate university, see Appendix A5 & A6 for examples from Colorado School of Mines).

Aspen Assignments

The requirement of this course that students learn (and be assessed on) the use of design software such as Aspen Plus is a treacherous one to implement, and the authors have oscillated on the details of this point several times in the years in question. The reason for oscillation was to attempt to balance the assessment of the use of Aspen Plus (or other simulation software) with the desire to have most (if not all) coursework be directly applicable to the student project. All of the Aspen assignments described below were assigned to small groups of 2-3 students (until 2017 these groups were decoupled from project groups since 2018 these have been sub-groups of the larger project group). In 2017, students were required to complete one Aspen assignment modeling a plug-flow reactor & a pair of distillation columns and improving their efficiency by applying design principles (including variables such as column sequence and feed stage, in addition to the more traditional reflux ratio, number of stages, etc.). At the end of the semester, course evaluations included several complaints that the Aspen assignment was a distraction, as it had nothing to do with their actual project.

In 2018, the authors replaced the existing Aspen assignment with a more complete one (including more than two unit operations and implementing both reaction *and* separation) and added a second Aspen assignment in which students must document and explain the development of a single unit *in their project*. While this second assignment addressed the previous complaints (as it was now directly related to their project), new complaints arose from students in groups which *did not* use Aspen to model their processes (e.g., solids-handling processes, some bio-related projects), as these students were forced to use the software to model an aspect of their process that they have already modeled in Excel or using a different software package. These students considered the assignment unfair because it required extra work from them (beyond just reporting and documentation) compared to the students who were already modeling their projects in Aspen anyway. Even worse, the original complaints (about the first Aspen assignment) persisted, alongside the new ones.

In 2019, the authors determined it would be best to focus the Aspen assignment on the project itself, and therefore eliminated the first assignment. The second assignment, focused on their group project, was expanded beyond just the development of the model of a unit (e.g., from a simplified, ideal model such as DSTWU into a more rigorous model such as RadFrac) to include the exploration of the unit's response to changes (i.e., sensitivity analysis) and the group's improvements to the unit (e.g., heat integration, optimization of purge/recycle). While this reduced the number of complaints of the original type (that the Aspen assignment was irrelevant), those of the second type (that it was extra work for those projects not requiring Aspen) grew in number and intensity.

Consequently, the most recent version of the course in the 2019-20 school year saw an entirely new pair of Aspen assignments. The first assignment requires the students to model a process described in the textbook (which includes fifteen complete models of chemical engineering processes relying on traditional unit ops which may be modeled in most software programs). The assignment requires that students report on any discrepancies between their results and those in the textbook and to defend their design choices. The second, follow-up assignment, requests that the students find at least three opportunities to improve upon their modeled process by increasing its economic efficiency (e.g., through heat integration, recycling, purge minimization, etc.), and report on this.

While the volume and intensity of complaints about the Aspen assignments has been reduced in this most recent course offering, there are nonetheless mixed responses to this newest incarnation found in student course evaluations. One student commented "I thought the Aspen assignments were HARD" while another wrote "The Aspen assignments sucked but they were very useful." Some more constructive feedback suggested moving the Aspen assignments to even earlier in the semester—instructors will be looking into flipping many of the Aspen tutorial sessions such that the work may be assigned (and due) earlier.

Course Evaluations & Feedback Survey Results

While there are numerous interesting insights to be gleaned from a closer examination of the data, a quick and quantitative keyword search of certain question has revealed crucial outcomes in the most recent offering in 2020. As mentioned above, a majority of students (54%) agreed that the regular drafts of their report due with each progress report were helpful, while only 20% suggested they were not. On the question asking whether the individual work requirement (prior to group formation) worked out well, 67% included words like "well", "good", or "help" while only 24% of responses included words like "bad", "not", or "poor".

A much more diverse set of answers is seen in the general feedback section. But in response the question "What worked well?", some common keywords were analyzed and the results are given in Table 3. These data (and further reading of some comments) reveal that group formation and/or dynamics were among the highest valued aspects of the course. Following this closely were the use of the draft reports with progress reports, and the individual meetings with professors & stakeholders.

Table 3. A selection of keywords (or word-stems) & their frequency found in the 137 student responses to the question "What worked well in this course?" in 2020.

Keyword	Responses
Group	41
Progress/Draft	28
Meeting	27
Econ	14
Lecture	13
Feedback	12
Aspen	8

Course evaluations for individual instructors of this course have improved since introducing these changes as well.

Summary of Course Changes

Table 4 summarizes the key changes discussed above, along with advantages and disadvantages determined from each one. While all of these changes require at least some non-trivial initial investment of work hours and planning, a majority do not require continued work hours after the first year or two of implementation. The advantages of each of these changes includes not only the achievement of its original purpose but also usually several additional side-benefits.

Conclusions & Recommendations

The innovations and developments made to this course represent the collective effort of a number of instructors, but these efforts have paid off significantly.

Table 4. Summary of the key changes to this course and their results.

Key Change	Purpose	Advantages	Disadvantages
Feedback (mid-semester & focus group sessions)	Improve student experience & course evaluations	Targeted improvements Reinforces other modes Specific insights otherwise not seen	Self-selection bias Cost of pizza Some extra hours for analysis
Course Alignment	Connect to cornerstone design experience	Reinforces design thinking Vertical connection of curriculum	Planning
Structure: Student-driven projects & Design Objectives	Provide self-determination aspects to design	Improves student motivation Focuses students on outcomes, not deliverables/steps	Planning, work hours
Assignment structure: Individual first	Prevent "free-loading" in groups	Enables early identification of poor-performing students Instructs group formation	Some student complaints about later group formation
Assignments: Draft report with each PR	Motivate students to start working on the report earlier	Higher quality reports Reports tailored to advisor/grader Students have less work at end	More feedback (work hours)
Assignments: Peer Review	Save instructor time in assessment	Greater volume of feedback No drop in quality Inspires self-criticism	Initial time investment (accessing the data)
Detailed Grading Rubrics	Standardize grading across different advisors	Provides greater transparency Fewer questions from students More fair & smoother grading	Large initial time investment Work hours (maintenance)
Front-loading the course	Saving time for group work	Students read the book Students learn more quickly	Planning Initial time investment

While the evaluation scores of the instructors have only improved slightly over this period, the gains in student learning and improvement in final report quality noticed by the instructors is immense. This of course feeds back into maintaining good relationships with external sources of design projects, since they will be encouraged to return when the quality of the reports they receive is very high. Furthermore, since senior design is often used as a source of data for ABET accreditation, it is one of the most effective ways to highlight improvements to the program as a whole. Finally, and also due to its summative nature, a thorough redesign of this course requires the instructor to become intimately familiar with the curriculum as a whole, including courses outside of the instructor's own department, which has many additional benefits to the course and to the students.

Many of the pitfalls and stumbling blocks in this course (which can stand in the way of receiving positive course evaluations) can be removed or mitigated by an "inoculation" during the first lecture period of the class. The authors include in the first lecture a list of recent changes made to the course (and the motivation behind them, which was usually student feedback), before describing a list of the most common complaints about the course (e.g., "make it two-semester", "allow us design a product") and why we cannot or will not do anything about these. Since introducing this strategy in 2019, the authors have noticed that complaints about the relevance of the Aspen assignments (when they are not directly related to the group projects, or when particular projects do not use Aspen for modeling), for example, have been reduced significantly.

The authors recommend selecting those practices listed in this paper that best fit your institution and student population, and also urge patience and a (relatively) slow pace of change. The interventions listed in this paper represent four years of concerted effort by at least five different instructors on a single course. Senior design is the capstone course in most students' undergraduate careers, and it deserves continual attention and continuous improvement from the faculty entrusted to deliver it.

Acknowledgements

The authors would like to thank the Trefny Center at Colorado School of Mines for their support during the summer of 2018, when Prof. Barankin took part in the third cohort of their intensive course redesign program. The authors are also grateful for the helpful resources (and prompt communication!) provided by Prof. Leslie Light, coordinator of the freshman design course at Colorado School of Mines. In addition, the authors are grateful to Kim Luzeckyj and Savannah Rodgers for enlisting and managing a team of student workers to enter and code all of the paper surveys.

Finally, the authors would also like to thank Professor Ron Miller for his work managing this course before these recent innovations. Improving a course is always much easier when there is a strong basis on which to build, and while this course has seen many evolutions over the past several decades (from two-semester, interdisciplinary projects to the current incarnation) it has always been helmed with vision and stability [15], [16]. In addition, the authors would like to thank professors John Jechura and Bruce Palmer for their continued work in supporting and improving this course. This team of reliable instructors has enabled the volume of changes (and rapid rate of implementation) in recent years.

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Appendix

A1. Most recent (2020) grading rubric for the 2nd pass technical design assessment (also made available to students prior to deadline).

GR2

You've already rated students with this rubric. Any major changes could affect their assessment results.

Criteria	Ratings				Pts
Cases-1	10.0 pts 2-3 full working models, in Aspen or Excel, of the cases selected previously	8.0 pts 1 model is non-functional (fail MEB) or contains unapproved "cheat" units	6.0 pts cheats	0.0 pts No working models	10.0 pts
Cases-2	10.0 pts Demonstrate good understanding of all cases (every unit, global issues) and future work (efficiency improvements)	8.0 pts Demonstrate good undersanding of most cases/units	6.0 pts Demonstrate good understanding of only one of the cases	0.0 pts Demonstrate poor understanding of all cases	10.0 pts
Cases-3	10.0 pts Major utility connections (type/duty) for all cases ID'd and included in OPEX calcs	8.0 pts Several major utility connections, or their details, are missing from one case (or across cases)	6.0 pts Many major utility connections details are missing from one or more cases	0.0 pts No major utility connections are ID'd for any of the cases	10.0 pts
Cases-4	10.0 pts Economic calculations (operating profit) based on stream prices/rates & utilities	8.0 pts Econ calcs are missing for a case or have a few errors	6.0 pts Econ calcs are missing for more than one case, or have several errors	0.0 pts No econ calcs for any of the cases	10.0 pts
Cases-5	5.0 pts Benefits & drawbacks of each case ID'd and discussed (near matrix)	4.0 pts Benefits & drawbacks of one case missing	3.0 pts Benefits & drawbacks of 1-2 cases missing	0.0 pts No benefits or drawbacks identified for any of the cases	5.0 pts
App-1	5.0 pts Stream tables provided for all 2-3 full working models are complete, match PFD's	4.0 pts Stream tables partially incomplete or do not match PFD for one case	3.0 pts Stream table missing for one case or do not match PFD's for all	0.0 pts No stream tables	5.0 pts
App-2	10.0 pts All attempts at sizing have been explained, at least for key units	8.0 pts One or two sizing attempts is incorrect or inappropriate for key units	6.0 pts Several key units were sized incorrectly or not at all	0.0 pts No sizing methods explained	10.0 pts

A1. *<cont'd>*

GR2

You've already rated students with this rubric. Any major changes could affect their assessment results.

Criteria	Ratings				Pts
Eff-1	5.0 pts Group is aware of potential efficiency improvements (e.g., heat integration)	4.0 pts Group is aware of some potential for some processes, but misses key opportunities	3.0 pts Group misses several key opportunities for improvement	0.0 pts Group is unaware of any potential efficiency improvements	5.0 pts
DO-1	10.0 pts All cases are reasonably assessed against DO's (updated matrix & explanation)	8.0 pts Some cases not assessed/explained reasonably against some DO's (but complete matrix)	6.0 pts Only about half of the cases are assessed, or all cases against half of the DO's (or no matrix)	0.0 pts Cases are not assessed against DO's	10.0 pts
Meet-1	5.0 pts Everyone participated in (work and) discussion	4.0 pts 1-2 members are less- or in-active during discussion	3.0 pts 2 members did not participate in discussion at all	0.0 pts Only 1 person spoke for the group during the entire meeting	5.0 pts
Meet-2	10.0 pts Organized & logical discussion with a clear purpose & direction	8.0 pts Slightly disorganized and/or unclear purpose	6.0 pts Disorganized discussion and/or no clear purpose & direction	0.0 pts Incoherent discussion	10.0 pts
Meet-3	10.0 pts Good use of handouts or presentation (figures, tables)	8.0 pts Some key figures/tables confusing or poorly formatted	6.0 pts Some key figures/tables missing from handout/presentation	0.0 pts No handout/presentation (zero figures & tables)	10.0 pts
Bonus/Penalty	0.0 pts Net Difference of Bonus & Penalty points	0.0 pts No Marks			0.0 pts
					Total Points: 100.0

A2. Broad checklist for the Technical Detailed Design presentation assessment (2017 and prior).

Content:
~3 unique processing schemes described in detail (complete PFD, operating conditions, material & energy balances, utilities used, necessary waste processing, etc.), depending on the project.

Grade: ________/4

Content:
- Reasons for why these designs were chosen.
- Concise evaluation of each process in meeting overall design objectives.
- Substantiate all information and/or calculations with references.

Grade: ________/2

Presentation:
Talk organized logically, purpose clear, clearly spoken, infrequent use of notes, good mechanics, minimal jargon, professional and well-balanced visual aids, clear conclusion.

Grade: ________/3

Timing
Completed within the allotted time.

Grade: ________/1

Evaluator: ________________________________ Total Grade: ________/10

A3. Student-view grading checklist for the 2nd pass technical design assessment (used in 2018).

Technical Detailed Design Presentation

Criteria	Ratings		Pts
Content Working models (Excel or Aspen), MEB closes, All Utilities calculated/appropriate, Waste processing present, all design choices explained/well-justified	40.0 pts Full Marks	0.0 pts No Marks	40.0 pts
Analysis Each process is evaluated against the D.O.'s; Analysis shows insight/forethought/creativity; Pros/Cons of each process are well explained; Identification of sites for potential improvement (e.g., efficiency/productivity like heat integration)	35.0 pts Full Marks	0.0 pts No Marks	35.0 pts
Presentation/Logistics Organized/logical ppt; references; quality of figures, et al.; Well-rehearsed (and minimal jargon); Good mechanics, infrequent use of notes; Responds effectively to questions; completed within time allotted by Prof.	25.0 pts Full Marks	0.0 pts No Marks	25.0 pts
			Total Points: 100.0

A4. Instructor-view grading checklist for the 2nd pass technical design assessment (used in 2018).

Prof:		
Criterion	**Key Issues**	Max
1. Content	Two to three (2-3) working models, in Aspen or Excel, ***all units*** accounted for (cheat units modeled in Excel for utilities)	10
	Material & Energy Balances close (stream sheets/values provided)	5
	ALL utilities accounted for, presented rate ***and*** costs in table, reported per utility (H/M/LP Steam, CW, Air, NG, etc.)	5
	All waste is sufficiently processed before crossing battery limits (into environment)	5
	All major design choices (e.g., reactor type, separation train, recycle/purge) explained	5
	All major design choices well-justified/defended	10
		40
2. Analysis	Each process is evaluated (fairly) against ***each Design Objective***	10
	Analysis shows insight/forethought/creativity (additional info/techniques from outside of 402)	10
	Pros/Cons of each process (relative to base case) are well explained	10
	Identification of potential sites for efficiency/productivity improvement(s), e.g., heat integration	5
		35
3. Presentation/ Logistics	Organized & logical presentation with a clear purpose	5
	All information properly referenced, either on-slide or parenthetical notation (up to -5, if not)	*0*
	Quality of figures, tables, slides, and images (style)	5
	Clearly spoken, minimal jargon, good delivery (sounds rehearsed), all members participate	5
	Good mechanics (body language, use of hands), infrequent/no use of notes	5
	Responded effectively to questions	5
	Completed within instructor-determined allotment (plus 5 min for questions/interruptions)? (if not, up to -10 pts)	*0*
		25
	Total:	100

A5. Example of an Industrial Sponsorship agreement for a Senior Design project.

Student Design Sponsorship Agreement

This is an Agreement ("Agreement") between ______________________________ ("SPONSOR") and the Board of Trustees of the Colorado School of Mines, for and on behalf of the Colorado School of Mines ("Mines"), a public institution of higher education in the State of Colorado, 1500 Illinois Street, Golden, CO 80401.

WHEREAS Mines Chemical and Biological Engineering department ("CBEN") desires to collaborate with a broad group of industrial partners in order to enhance the educational experience available to its undergraduate students participating in the Chemical Engineering Design course ("Senior Design") and further the educational mission of the University; and

WHEREAS SPONSOR desires to cooperate with Mines by supporting a student design project and provide non-financial sponsorship for CBEN Senior Design; and

WHEREAS this Agreement is intended to set forth the primary responsibilities of the SPONSOR and Mines for a successful collaboration;

NOW, THEREFORE, in consideration of the mutual agreements, conditions, and covenants set forth herein, the parties hereby agree as follows:

<u>Article 1 - Development of Student Project</u>

Mines and SPONSOR agree to work closely to develop a student design project ("Project") for the __________ academic year that will provide an important "real world" educational experience for an undergraduate student team. The scope of the Project will be defined by conversations between CBEN Faculty and/or Staff and the SPONSOR technical liaison. The project work and project management will be conducted by a student team comprised of four or more undergraduate students ("Student Team"), who will have access to Colorado School of Mines facilities and the support of Mines faculty, including a faculty advisor (FA). The Student Team will provide the SPONSOR with a copy of any Final Design Report ("Report") submitted by the Student Team at the end of the course sequence. The Report will contain a detailed synopsis of all the engineering work executed during the course of the Project, at a deep enough level of technical detail to allow SPONSOR to utilize the information as defined below. To the extent approved by the CBEN Faculty, a Student Team may, but is not required to, provide demonstration hardware, software, and system technology to the SPONSOR.

<u>Article 2 - SPONSOR Fees</u>

Mines shall waive any fees due from SPONSOR for the Fall 2019 semester.

It is understood that members of the Student Team will not receive any direct compensation or remuneration in any form in connection with their work on the Project. SPONSOR further acknowledges that the members of the Student Team working on the Project are doing so for academic credit only and are not officers, agents or employees of Mines or SPONSOR.

A5. *<cont'd>*

Article 3 - Intellectual Property and Proprietary Information

"Intellectual Property" includes all inventions, discoveries, copyrightable materials, and improvements to existing processes, methods, compositions, devices, designs or programs which are created, conceived, or first reduced to practice during the performance of this Agreement by the student(s) working on the Project.

SPONSOR may elect whether it desires to own any Intellectual Property developed by the students during the performance of the Project, or share proprietary or confidential information with the members of the Student Team, and SPONSOR will indicate its preference by selecting one option below:

__ OPTION **1** (preferred): Intellectual Property is owned by the inventors and authors who created it, as determined by United States patent and copyright law. Undergraduate students at Mines are entitled to own and use Intellectual Property they develop as part of an academic course. Mines and SPONSOR agree that all Intellectual Property developed during the performance of this Project belongs to 1) the students involved in the project and/or 2) Mines, if faculty were materially involved in the creation the Intellectual Property.

SPONSOR shall not disclose or deliver any proprietary or confidential information, or information subject to U.S. export control laws and regulations, to CBEN Faculty or Staff, FAs and/or members of the Student Team in connection with the Project.

__ OPTION **2:** Under this OPTION 2, SPONSOR may disclose or deliver proprietary or confidential information and will own any Intellectual Property developed during the performance of the Project. Prior to commencing any work on a Project, Mines shall obtain from each member of the Student Team an agreement to assign to SPONSOR all right, title and interest in and to any inventions, discoveries, copyrightable materials, and improvements to existing processes, methods, compositions, devices, designs or programs (hereafter "intellectual property") which are created, conceived or first reduced to practice as a result of their participation in the Project.

If, after consultation with CBEN Faculty and/or Staff and prior to commencement of work on the Project, SPONSOR determines that confidential or propriety information must be delivered or disclosed to members of the Student Team, such disclosures shall be clearly marked as "Confidential" and will be subject to the terms of the standard confidentiality agreement attached as Exhibit B. The confidentiality agreement will be between SPONSOR and the students directly, and must be executed before work on the Project begins. **Mines does not and cannot warrant any student's compliance with such confidentiality agreement**. Mines recommends that projects largely dependent upon disclosure of confidential or proprietary information are not appropriate student design projects.

Mines agrees that it shall not, without first receiving SPONSOR's written permission, disclose to third-parties any of SPONSOR's Confidential I Information (as defined below)

A5. *<cont'd>*

for a period of two (2) years from the date of receipt of such Confidential Information. Confidential Information may be shared among multiple receiving parties who have executed a non-disclosure agreement with respect to the Project identified herein. At the earlier date of either conclusion of the Project, or termination of this Agreement, the receiving party will deliver all copies or records of Confidential Information in its possession or control to SPONSOR or will verify to SPONSOR that such Confidential Information has been destroyed. SPONSOR acknowledges that Mines is a public institution of higher education in the State of Colorado and subject to the Colorado Open Records Act. All written information marked "Confidential" shall be treated by Mines as proprietary to the extent permitted by C.R.S. § 24-72-204.

"Confidential Information" means any non-public information which is maintained by SPONSOR as confidential, and when disclosed in writing is clearly marked "Confidential," or if disclosed orally will be reduced to writing by SPONSOR, clearly marked "Confidential" and transmitted to receiving party within thirty (30) days of the oral disclosure. Excluded from this definition of Confidential Information is any information that: (a) was in the public domain as of the date this Agreement was fully executed, or comes into the public domain during the term of the Agreement through no fault of the receiving party; (b) was known to the receiving party prior to the date this Agreement was fully executed and was not acquired, directly or indirectly, from SPONSOR or from a third party under a continuing obligation of confidentiality or limited use; (c) was independently developed by the receiving party without use of the Confidential Information; (d) was lawfully disclosed to the receiving party from a third party who did not require the receiving party to hold it in confidence or limit its use and who did not acquire it, directly or indirectly, from SPONSOR under a continuing obligation of confidentiality; or (e) was approved for disclosure by prior written permission of SPONSOR.

Student Team members will be advised of their non-disclosure and assignment obligations prior to beginning any work on the Project. Any Student Team members that decline to assume these obligations will be reassigned to another project. In the event of insufficient student interest in SPONSOR'S Project, the CBEN Faculty and/or Staff will not assign a Student Team to the Project. Mines will notify SPONSOR of this decision and shall reimburse SPONSOR for any fees paid pursuant to Article 2.

SPONSOR shall not disclose or deliver any information subject to U.S. export control laws and regulations to Project Staff, FAs and/or members of the Student Team in connection with the Project.

<u>Article 4 - Publication</u>

SPONSOR agrees and understands that Mines reserves the right to have the Student Team make presentations and publications for campus events during the academic year in which the Project is underway, which are an integral part of the educational program. If information that is clearly marked and identified as "Confidential" is delivered or disclosed to members of the Student Team during the course of the Project, pursuant to OPTION 2 as defined above, SPONSOR shall be provided the opportunity to review any such presentations and publications two-weeks prior to the date of the presentation or publication

A5. *<cont'd>*

for the purpose of ensuring compliance with the obligations set forth in the standard confidentiality agreement. This stipulation shall not in any way limit the ability of members of the Student Team to summarize the Project in resumes, job interviews, advanced degree applications and the like.

Article 5 - Student Work

It is understood that Mines is engaging in this collaboration in furtherance of its educational role and mission, and that the activities of Mines or its students are not of a type ordinarily carried on as incident to commercial or industrial operations. In this regard, the SPONSOR agrees that neither Mines, its faculty, students nor its employees make any warranties, express or implied, as to the condition, accuracy, originality, merchantability, fitness for any purpose, non-infringement or otherwise of any work product or intellectual property developed as a result of the faculty or student's work on the Project, all of which is provided "as is." The use thereof, in all respects, is at the sole risk of the SPONSOR.

Article 6 – Compliance and Governing Law

Each Party agrees to comply with all applicable laws and regulations in the performance of this Agreement. This Agreement shall be interpreted in accordance with the laws of the State of Colorado, and nothing herein shall be construed as an express or implied waiver of any terms or provisions set forth in the Colorado Governmental Immunity Act, C.R.S. 24-10-101, *et seq.*, as now or hereafter amended.

Article 7 - Entire Agreement

This Agreement sets forth the entire agreement and understanding among the parties as to the subject matter hereof, and this Agreement supersedes all previous communications, proposals, representations and agreements, whether oral or written, relating thereto. Any purported modification or termination of this Agreement must be in writing and executed by the parties in order to be effective.

If the foregoing meets with your approval, we would appreciate your signing and returning two originals of this SPONSOR Agreement to:

CBEN Senior Design
Chemical & Biological Engineering
Colorado School of Mines
1500 Illinois St.
Golden, CO 80401

(signature page not included)

A6. Example of a Non-Disclosure Agreement for a Senior Design Project.

Exhibit B

Non-Disclosure Agreement
For Confidential Information in Senior Design Projects

This Non-Disclosure Agreement for Confidential Information ("Agreement") is made and entered into by and between the undersigned SPONSOR and ________________________________ ("Student" or "receiving party"), with respect to the following Senior Design Project ___________________________ ("Project").

Student desires to participate in the Project and obtain access to SPONSOR's confidential and proprietary information. In consideration for Student's education and experience gained from participation in the Project, Student and SPONSOR agree as follows:

1. **Confidential Information**. "Confidential Information" means any nonpublic information which is maintained by SPONSOR as confidential, and when disclosed in writing is clearly marked "Confidential," or if disclosed orally will be reduced to writing by SPONSOR, clearly marked "Confidential" and transmitted to receiving party within thirty (30) days of the oral disclosure. Excluded from this definition of Confidential Information is any information that: (a) was in the public domain as of the date this Agreement was fully executed, or comes into the public domain during the term of the Agreement through no fault of the receiving party; (b) was known to the receiving party prior to the date this Agreement was fully executed and was not acquired, directly or indirectly, from SPONSOR or from a third party under a continuing obligation of confidentiality or limited use; (c) was independently developed by the receiving party without use of the Confidential Information; (d) was lawfully disclosed to the receiving party from a third party who did not require the receiving party to hold it in confidence or limit its use and who did not acquire it, directly or indirectly, from SPONSOR under a continuing obligation of confidentiality; or (e) was approved for disclosure by prior written permission of SPONSOR.

2. **Non-Disclosure.** Receiving party will not disclose the Confidential Information of SPONSOR except as expressly authorized by this Agreement. In no event shall receiving party disclose Confidential Information to third parties without written permission from SPONSOR; however, Confidential Information may be shared among multiple receiving parties who have executed a non-disclosure agreement with respect to the Project identified herein.

3. **Senior Design Course Requirements.** SPONSOR understands that the Confidential Information will be used as part of the Project identified above in an undergraduate design course. As part of the course requirements, Student may be required to make presentations at campus events during the academic year in which the Project is underway. SPONSOR may request in writing to preview any presentation materials or publications (including the final design report) two weeks prior to the date of the presentation or publication for the purpose of ensuring compliance with the obligations set forth herein. In addition, nothing herein shall be construed to prevent student from

A6. *<cont'd>*

mentioning the Project by name during job interviews or on resumes, provided no Confidential Information is disclosed.

4. **Copies**. Confidential Information shall remain the property of SPONSOR and at the earlier date of either conclusion of the Project, or termination of this Agreement, the receiving party will deliver all copies or records of Confidential Information in its possession or control to SPONSOR or will verify to SPONSOR that such Confidential Information has been destroyed.

5. **Term and Termination.** The Non-Disclosure obligation in this Agreement shall expire two (2) years from the date the Agreement is fully executed, and all Confidential Information disclosures made hereunder shall be completed no later than one (1) year from the date the Agreement is fully executed. This Agreement may be terminated by any party by giving thirty days written notice to the other party, however the Non-Disclosure obligation will survive termination of the Agreement and will continue until the end of the two (2) year term set forth above.

6. **Governing Law, Severability and Venue.** This Agreement shall be construed in accordance with the laws of the State of Colorado. If any terms or provision of this Agreement shall be held illegal, unenforceable, or in conflict with any law governing this Agreement, the validity of the remaining portions shall not be affected thereby.

I state that I am at least eighteen (18) years of age and fully competent to sign this Agreement. I understand and execute this Agreement for full, adequate, and complete consideration, fully intending to be bound by the same.

Student:	**SPONSOR**:
By: ______________________________	By: ______________________________
Name:	Name: Title:
Date: ____________________________	Date: ____________________________