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Best Practices in Teaching Unit Ops: the ”Field Session” Lab Experience at the Colorado School of Mines

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The results of a 2017 comprehensive survey of 70 programs [1] revealed that the unit ops laboratory course offered during a 6-week summer "Field Session" at the Colorado School of Mines is an outlier from other U.S. programs in many ways. The biggest differences between this course and the typical unit ops course run concurrently with other courses are *the immersive experience* and *the extent and nature of the real-time formative and summative assessments provided.* Students and faculty work full- or close to full-time (students ~40-60+ and faculty ~30-40+ hours per week) exclusively on this course. This level of personal interaction & feedback, *and the ways in which they are conducted*, build connections and community amongst all involved and motivate student engagement and cooperation. This in turn leads to students achieving significant technical and non-technical learning outcomes and the course is recognized by alumni and recruiters as highly effective at preparing students for the workplace. Furthermore, despite the intense pace and depth and breadth of skills covered and assessed in the course, the fail rate is effectively zero.

The course is offered twice each summer, each 6-week session currently accommodating up to 84 students, with a Student-to-Professor ratio of up to 12:1 (yes, 7 faculty per session!). There are also writing instructors, a lab manager, and at least two TA's working full- to nearly full-time to help manage the course. There is 1 experiment per 6 students and each professor is in charge of 2 experiments. Each student runs 8 of the experiments and repeats the second one as their 9^{th} with additional objectives that their group designs. During week 1 students run one and during weeks 2-5 they run two experiments per week, each with different teams, delivering one oral presentation and one written report per week. Hence, students complete a total of nine summative communication reports, placing this program in the $\leq$ 11% category of all programs surveyed in 2017 whose students do 9 or more experiments.

In addition to running and reporting on the experiments, students attend workshops on Safety, Graphics, Statistical Analysis, Technical Writing, and Higher-Order-Thinking Skills. For three of the four written reports, students attend separate writing-focused and technical draft reviews. For both reviews the faculty members have read and commented the draft in advance. These 20-45 minutes-long review sessions offer the students a plethora of useful *timely* feedback prior to summative assessment. This significant and coordinated time investment by both instructors and students is *one of* the key elements of this format that is difficult to duplicate in a more typically-timed course.

The decades-running highly effective structure and delivery method of this course will be presented along with results from course evaluations, student assessments, and alumni & recruiter surveys. Comparative assessments of a variation of the course in which it was framed in a more creative and inviting friendly-competition manner will also be presented. Many "best practice" elements of this course will be discussed in terms of their portability to the typical semester or quarter timeframe.

Introduction

The unit operations laboratory course is a central part of the undergraduate chemical engineering curriculum, as it is most often one (or both) of only two lab courses required of all students for graduation [1-2]. While there is growing interest in using virtual laboratory experiences [3-4], the same authors who have shown evidence that these are valuable learning opportunities simultaneously advocate for continuing to use tactile, in-person laboratory experiences [5-6] whenever practicable and affordable. In addition, a comprehensive survey of seventy undergraduate chemical engineering programs in the US in 2017 revealed that the majority of virtual labs were experiments on process control, followed by reactor experiments, with very few on the more traditional transport-related unit operation experiments in Fluids and Heat and Mass Transfer [1-2].

A comprehensive dataset of 148 undergraduate chemical engineering programs listed in a public directory analyzed in 2016 showed an average of 4.5 semester credits (or equivalent) of lab courses were required for graduation [2]. The unit operations laboratory course or "Field Session" offered exclusively during the summer at the Colorado School of Mines, at 6 semester credits, is an outlier from most US programs in this and other metrics accounted for in a more detailed, lab-focused 2017 survey of 70 programs [1]. These survey results prompted the writing of this paper.

While many of these differences can be highlighted as great successes of this course, one of the most important aspects of Field Session could not have been captured by this survey: the student-faculty interactions promoted consistently throughout the course. From individual group pre-lab and draft report meetings to Friday whole-group debriefing meetings and combined faculty and student lunches where more informal technical and even social conversations take place, the amount and quality of student-to-faculty interactions are unparalleled. We believe these are two of the most important keys to the success of this course in terms of student learning *and* alumni perceptions.

Program Description

The chemical engineering program at the Colorado School of Mines is one of the twenty largest undergraduate programs in the country, graduating over 150 students per year [7]. While this might otherwise suggest a possible reason for our being an outlier in other ways in the 2017 survey, rather, programs graduating over 120 students were slightly over-represented in this survey [1]. Despite having doubled and redoubled in enrollment multiple times since this course was first implemented at Mines, it is still centered around principles developed decades earlier for a much smaller program: the cultivation of higher-order thinking (HOT) in a fast-paced laboratory course [8-9]. In fact, the course still adheres to the same structure described in 2016 [10], only now accommodates up to 84 students per session and 14 different experiments running simultaneously. This paper focuses on comparing this course against the national survey results but will also highlight the more unique aspects of the course as well as recent developments to this course and the changes made since the previous paper was presented in 2016.

Field Session aligns with other unit ops courses across the country in several ways. The categories of course objectives (learning outcomes) that are represented in more than 50% of the 2017 respondents are also represented here, with the exception of "Practice engineering design" [1] (which is product-, not process-focused [11]). Students do engage in design of *experiments* in Field Session. Furthermore, all of the experiments in this course may be classified as Fluids-, Heat-, or Mass-related, with some experiments also emphasizing concepts of property measurement, chemical reactions, and biology or bio-engineering. Finally, safety is presented in a HAZOP module including a lecture and assignment, the two most common means of approaching safety in chemical engineering laboratory courses [1].

As mentioned above, the most profound way in which this course differs from the common practices amongst Chemical Engineering unit ops courses nationwide is that it takes place in six weeks in the summer. Each six-week session accommodates two schedule groups, currently of up to 42 students. A typical schedule for weeks 1 through 5 for a student in a "Monday/Wednesday schedule" group is provided in Table 1.

Table 1. Example schedule for a student following a Monday/Wednesday experiment pattern.

		M	T	W	Th	F
Week 1	Due	Orientation/Tour & Safety Lectures	Statistics & Graphics Lectures			Debrief + Writing & Stats Workshops
	Do			Lab 1		
Week 2	Due	Draft 1 Due	Draft Rvw 1		Final Report 1 Due	Debrief + HOT & Stats Exam
	Do	Lab 2	Oral Report 2	Lab 3		
Week 3	Due	Draft 3 Due	Draft Rvw 3		Final Report 3 Due	Debrief + Writing Workshop
	Do	Lab 4	Oral Report 4	Lab 5		
Week 4	Due	Draft 5 Due	Draft Rvw 5	s	Final Report 5 Due	
	Do	Lab 6	Oral Report 6	Lab 7		Debrief
Week 5	Due	Final Report 7 Due				
	Do	Lab 8	Oral Report 8	Lab 9	Oral Briefing 9	

Students are further divided into sub-groups or "houses", two of which follow the Monday/Wednesday schedule and two of which follow a Tuesday/Thursday schedule in which the experiment-related activities and due dates are simply shifted later by one day. This schedule shows the quick turnaround times students must meet with their even-numbered experiments (2, 4, 6, and 8) and experiment 9, for which they give an oral presentation or oral briefing *the day after they performed that experiment*. It should be noted that, of the approximately nine hours the lab is available to them each lab day, the amount of time students spend performing the experiments and collecting data varies by experiment. However, it is uncommon for students to complete *any* experiment more than one hour early during the first week and expected only for a few select experiments in the following week. For some experiments, particularly for most of the mass transfer experiments, students rarely finish early even by the last week of the course. Some experimental setups (e.g., staged distillation on total reflux) are powered on as early as 7:00 AM by the teaching assistants and the lab is shut down around 5:00 PM, at which point students may no longer access the experimental equipment.

For experiments 1, 3, and 5, drafts of the written reports are due five days after the experiment is run (including weekend days) and students receive feedback from the writing instructor and from the supervising professor in separate meetings *the day after the draft is turned in*. Final drafts of those reports are then due two days later. Experiment 7 is also a written report, but without the writing and technical reviews since students will have already had 3 rounds of draft reviews by then. The timing of analyzing data and finalizing presentations & reports for past labs, preparing to run the next lab, and attending the workshops & doing the associated assignments all overlap such that students must manage their time very well to be successful. This requirement of such a high level of coordinated time management is another element of the course (along with the intense timely feedback mentioned earlier) that cannot be easily replicated when the course is offered during a normal academic semester or quarter.

While this schedule is intense for students, it can be just as demanding for the instructors running the course. Table 2 shows a sample week 2-6 schedule (excluding some more trivial or variable tasks) of the major grading responsibilities a professor supervising two different experiments.

Table 2. Schedule of a Professors grading responsibilities (excluding lectures, pre-labs, etc.).

		M	T	W	Th	F
Week 2	Due	Feedback 1 (MW)	Feedback 1 (TR)		Final Report 1 (MW)	Final Report 1 (TR)
	Do		Oral Report 2 (MW)	Oral Report 2 (TR)		
Week 3	Due	Feedback 3 (MW)	Feedback 3 (TR)		Final Report 3 (MW)	Final Report 3 (TR)
	Do		Oral Report 4 (MW)	Oral Report 4 (TR)		
Week 4	Due	Feedback 5 (MW)	Feedback 5 (TR)		Final Report 5 (MW)	Final Report 5 (TR)
	Do		Oral Report 6 (MW)	Oral Report 6 (TR)		
Week 5	Due	Final Report 7 (MW)	Final Report 7 (TR)			
	Do		Oral Report 8 (MW)	Oral Report 8 (TR)	Oral Briefing 9 (MW)	Oral Briefing 9 (TR)
Week 6	Due					
	Do		Final Grading Meeting			

The tight turnaround times for written feedback that are so helpful to students are equally demanding for professors. Each lab day (4 days per week most weeks) we have pre-lab meetings with teams of 3 students running each of "our" two experiments. During these pre-lab meetings we make sure the students have prepared well for their lab day focusing on 1) safety, 2) the efficacy of their experimental approach (which they design based on some minimum experimental objectives, increasing in number and complexity as the weeks go on), and 3) their analysis plan. These pre-lab meetings are run in a Socratic manner where we ask questions to guide rather than give answers. We read and provide feedback on two drafts on Monday, go over those commented drafts in meetings with students on Tuesday, then comment the Group B drafts that same day for the Wednesday draft reviews. On top of this, professors attend two oral presentations on Tuesday and two on Wednesday, providing summative assessments to students completing even numbered experiments. Professors provide feedback on drafts within 24 hours and then grade final reports within 3 days of when they are turned in. Finally, in addition to conducting one of the workshops (equally divided among professors), we must be available while our students are in the lab and we try to visit the lab at least once (if not twice) per day to assist students running the experiments and answer any questions they might have.

There are two aspects to this schedule which may not immediately appear portable, but which are nevertheless important elements of the success of this course. Assigning a given professor the responsibility of overseeing *no more than two* experiments allows her or him to specialize and therefore to more deeply probe students' understanding of key concepts in a given experiment.

While this ratio of 12:1 students-to-professors may seem difficult to meet, if the course is offered over a quarter or semester time period instead the impact may be lessened as faculty could potentially have more time between assessments. On the other hand, one of the main advantages of the quick turnaround times and significant professor-student interaction is that students tend to retain more when they get timely and detailed feedback. Therefore, someone considering adapting a unit ops course to incorporate these elements during a typical quarter or semester timeframe might *condense* elements of the course to keep these advantages.

Alluded to briefly above, another important aspect of the schedule is the stage-gate nature of the pre-lab meetings on the mornings of experiment days, for which every student must be a “group leader” 2-3 times per session (depending on total enrollment numbers). Although not explicitly mentioned in the previous paper on this course, professors can tell a student group that has not properly prepared for the lab that they need to go study the material and retry the pre-lab before they can enter the lab. While this is only really done in practice for a small number of groups per session, and only based on the group missing crucial information (such as safety or operational/procedural information), this check helps to prevent not only safety hazards and unnecessary risks in the lab but also fruitless days of improper or unusable data collection. Furthermore, the dynamics of having a leader “drop the ball” and having a group member “pick up the slack” (or otherwise exactly the opposite and “leave them hanging”) can be a valuable learning experience for all types of students, especially when the stakes are low enough to recover with only the loss of an hour or two. This is certainly a best practice which is highly portable and should be applied to most (if not all) laboratory courses, in general. Furthermore, the pre-lab meetings are often fantastic opportunities for students to learn more before they go into the lab. They are typically run by the professor asking questions; probing for conceptual and data analysis understanding in addition to making sure students will be safe and collect reasonable data. This allows for differentiated learning where more prepared students spend less time on the lower level skills such as remembering and calculating and get deeper into the higher order learning levels such as analysis and experimental design. Pre-lab meetings, similar to draft reviews, can run 30 minutes or longer – that’s *a lot* of one-on-three time between professors and students where significant learning occurs!

As described previously [10], students rotate continuously through 3-person groups and only occasionally have a repeated lab partner from within their own “house”. This can be problematic in some ways, potentially lowering average class grades and/or leading to more harsh peer evaluations than when students choose their own groups [12]. Nevertheless, the authors believe this method is important not only because it more accurately represents the “real-world” (in which students will not, generally, be able to select their own co-workers) but also because students must work with individuals with a diverse set of skills, thereby forcing them to *rapidly* adapt to new group dynamics. Students often succeed at this, but sometimes they do not; nevertheless, survey results indicate that many of them seem to take valuable lessons away from this experience.

One prominent way in which this course deviates from the national survey results is the total number of experiments the students perform. While over half of the programs who responded (most of which offer the unit operations lab during a regular term instead of summer) collect a total of only five or fewer summative communication products, this summer course requires nine: four oral presentations, four written reports, and one memo combined with an oral briefing, placing us within a small minority (≤ 11%) of all programs surveyed [1]. This broad range of experiments, combined with a repeat of their second experiment but with emphasis on new, student-designed objectives and procedures, allows students to become familiar with a wider range of equipment and theories and allows students with *different skill sets* to shine at different moments. Furthermore, the rotating group assignment problems are ameliorated somewhat simply by increasing the number of rotations—this makes it easier to spot trends like the "albatross" (a student who consistently "weighs down" the performance of their groups) or the "keystone" (a student who takes on more than their share of the work and "pulls up" the grades of their groups).

Another way the faculty are able to keep an eye on group dynamics is through regular meetings such as the draft reviews and pre-lab meetings. As mentioned above, students meet as a group with a writing instructor as well as the supervising professor. Employing only two writing instructors to complete up to seven drafts each overnight may seem like a lot, but these instructors are able to focus only on form while the experiment professor focuses on the content. This is not to understate the responsibility and importance of the writing instructors – they are vital to the success of our Field Session! The writing instructors provide writing workshops twice each session, in addition to editing and reviewing all draft reports. Furthermore, their feedback on grammar, spelling, formatting, voice, style, etc. allow the professors to focus their feedback on experimental methods, data analysis, and higher order thinking in the reports.

Much has been published on the development of high-order-thinking skills in this course [8-10], and little has changed about this aspect of the course despite enrollment numbers growing *significantly* since this method was first applied. The professors for each experiment have increasing expectations of the students over the duration of the course—that is, a paper which earns an A for Report #1 would only receive a B or C for Report #7—and this is clearly explained to the students during the first lecture and reinforced during class meetings.

The weekly class debriefing is another highly portable best practice. All students meet in one classroom every Friday of Field Session for a general meeting where the faculty and staff make any announcements to the entire class at once. Also, students are encouraged to make any course relevant announcements they'd like to make. This has proven to be highly valuable for maintaining a well-functioning lab environment because many students take this opportunity to explain quirks and idiosyncrasies about the equipment to their classmates and common questions about both experimentation and analysis are addressed for everyone all at once. It also provides an opportunity for and feeling of cooperation, friendliness, and community amongst students, faculty, and staff. Students comment on this community aspect, frequently and positively, in the course evaluations!

One of the most loved-by-the-students elements of Field Session is the Friday lunches. The department furnishes lunch for the students, faculty, and staff on Fridays for three of the five weeks, with strategically increasing quality of food vendor as the weeks go on[1]. The informal nature of the students and faculty sitting together sharing a meal is invaluable for class morale and community building. Students also use this time to ask specific questions of those who have just performed the experiments they will perform on Monday or Tuesday, adding further to the cooperative nature of the course. In addition to this, the department furnishes popsicles to the students on warm days (the lab building can get especially hot with all the steam-related experiments, particularly in July and August!). These are tried-and-true methods of motivating the students, and the social interactions they stimulate provide great benefits to both the students and the faculty. Additional ways to motivate students are discussed below in the Recent Innovations section.

Recent Innovations

The two primary innovations to the delivery of this course over the past three years are the addition of themes & teams and the introduction of pre-lab videos covering operational procedures. Since the second half of the summer of 2017, Field Session students have been divided into teams based on a theme, such as Harry Potter or Game of Thrones. Instead of being grouped into teams A1, A2, B1, and B2, students were members of houses such as Hufflepuff & Slytherin or Baratheon & Targaryen. This "theming" of Field Session has succeeded in its intended purpose of bringing a feeling of comradery between students grouped together, and an air of healthy competition throughout the course. It has had additional side benefits, such as the development of fun and interesting nicknames and memes (used in presentations or sometimes in reports) as well as the opportunity to integrate popular culture into some of the lectures and weekly class debriefings, which has proven effective in some active learning situations [13-14].

The second major innovation to this course is the introduction of pre-lab videos. These videos are a mix of first-person and third-person clips of experimental operation, with particular focus on frequently occurring mistakes (e.g., turning on a pump upstream of a fully open rotameter), potentially major problems (e.g., draining the reboiler of a distillation column), and particularly confusing or less obvious aspects to the procedures (e.g., the location of a hard-to-find switch or how to depressurize a non-relieving gas regulator). Since their introduction for only a few select experiments, these videos have been increasingly requested by the students and reviewed positively. While detailed results will be presented in a future paper, this innovation has already led to fewer incidents of minor equipment damage and less frequent "experimental failure". Preliminary data on lab performance point to potentially greater long-term gains (from the second to the fifth week) on report grades for labs which had pre-lab videos compared to those without.

Program Outcomes & Recommendations

One important metric for any core course is the percentage of students who successfully complete the course on their first attempt. Field Session has an incredibly low recidivism rate, with *the only (incredibly rare) failures in recent decades originating from either plagiarism or non-completion/-attendance*. The average (mean) course GPA is slightly higher than other

[1] We typically have pizza in week 2, sandwiches in week 3, and barbecue in week 4.

courses, ranging from 3.08 to 3.32 in recent years, and varies less from year to year than other courses within the core.

When surveyed at the end of the course, student perceptions fall in line with these outcomes. Ninety-three percent of students surveyed from 2012-15 agreed or strongly agreed with the statement "instructors helped me to develop my 'higher-order thinking' skills" [10], while more recent surveys have shown that students value the critical thinking workshops. These surveys asked students to rate the value of various aspects of the course, from 1 to 5 (with 5 being highly valuable), and the only aspects to receive an average score of lower than 3.1 in 2018 were the Graphics (3.07), Writing (3.01), and HAZOP/Safety workshops (2.92). The highest rated aspect of the course besides the Friday lunch (4.66) was the opportunity for technical draft reviews with professor supervising that experiment (4.50). A portion of these data is presented in Figure 1.

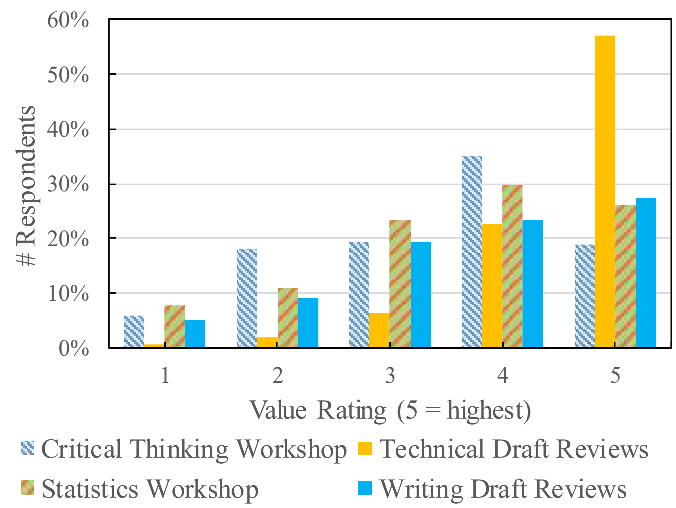

Figure 1. Student ratings (1=lowest, 5=highest) of a selection of aspects of the course in a 2018 survey.

In addition to these quantitative results, qualitative data has been gleaned from student comments on the surveys to open-ended questions such as "What did you like most about field session?" and "What did you like least…?". Some common, negatively oriented answers to the former question include "That it's over", or "The end meeting" while corresponding answers to the latter question might include "Literally everything else". Nevertheless, there are a number of common positive and *constructive* answers to these questions as well, including the following representative sample responding to "What did you like most":

— "Hands-on, similar to industry"
— "Getting to design our own experiments and being held to a high standard"
— "the people I met, the professors, the communication & team skills"
— "the professors make you think"
— "I learned a lot even if I didn't want to"
— "… working with my peers. I met a lot of people who I probably never would have outside this class"
— "I liked being forced to work hard and apply what I have learned. Working through higher order thinking objectives helped me learn more than I had in normal classes"
— "Honestly the grind and time management skills"
— "Orals. Quick turnaround time left less time for stupidity & messing around"

These last two comments, while constructive, were in fact a bit more commonly found in answers to the second question, “What did you like least about field session?”, as in the following sample:

- “working on 3 labs at a time”
- “the late nights till 2 am”
- “the long nights preparing reports”
- “24-hour turnaround”
- “Monday night preparing orals”
- “so time intensive and I was always tired”
- “the way we had to work 12+ hour days for most of the week”
- “Some of the turnaround times were rough and a lot was expected from us right off the bat but nothing was too horrible”

Clearly the students who have just completed field session have a good deal of complaints, yet the vast majority of it focused on the intense schedule and high demands (as well as about the climate conditions inside the lab on hot days). Yet even more important than perceptions of students who’ve just completed the course are those of alumni. The CBE department surveys alumni regularly with a reasonable response rate (at least around 25%) and field session always filters to the top as the most valuable experience of students’ time at Mines [10].

> Alumni from the Chemical and Biological Engineering Department at the Colorado School of Mines have long indicated that the unit operations Laboratory was invaluable, with many indicating that it was the most important course in terms of preparing them for an industrial or consulting job. Annual alumni surveys include the question (which does not specifically mention the unit operations Laboratory): “Which aspects of your education at Mines were most valuable to you in your current career?” Selected responses from the most recent survey appear below:
>
> > “Without a doubt, the unit ops lab. The ability to write a report that doesn’t need extensive editing or give a talk that doesn’t embarrass my boss goes a long way towards building job security.”
> >
> > “Professors could relate class material to real world experience. Field session was a great class which gave me a dose of what to expect as a professional in the field, presentation, and thinking about exactly what it is that we are doing.”
> >
> > “It pains me to say this, but the unit ops lab gave a great model of a real world working situation – fast paced, heavy loads, and a focus on professional communication.”[2]

[2] One can only speculate that the pained alumnus who wrote the penultimate quote in the above list may have initially given the course a poor evaluation when they took it!

> "My job is very similar to the way field session was run. The teamwork aspect was maybe the most valuable learning experience to me – I need those skills daily." [10]

These data reveal that this unit ops course is one of the most highly valued among alumni (as it likely is of many chemical engineering programs), but also that this is so *not despite* the fact but precisely *because* it is so uniquely rigorous and fast-paced, with increasingly high expectations both of students' communication skills as well as analysis, higher-order-thinking, and experimental design.

The feasibility of moving a unit ops course to a summer schedule, or even to a more condensed (and thus shorter turnaround time) schedule within a normal semester, depends on the program and institution resources, limitations, etc. Although this is explained as a part of the source of benefit from this unique course at the Colorado School of Mines, it is by far not the only aspect of this course that is highly beneficial. The following is a summary of the recommendations based on our best practices, in order of decreasing estimated importance and/or portability (with a briefly described motivation):

- Motivate students with things like team competitions, themes, and snacks or meals (stimulates friendly competition and cooperation improving morale);
- Use a rotation of 6-8 experiments, with at least 3-4 different instructors attached (to allow for focus and depth into each experiment);
- Add a writing instructor, or otherwise a teaching assistant (to provide feedback *exclusively* on writing and formatting issues, not on content);
- Provide students with pre-lab videos or at least a FAQ page (to assist them with procedural tasks only and to help prevent frequent errors or sources of equipment failure/damage);
- Provide students clear information about how they will be assessed, including grading rubrics if applicable (clarifying expectations is crucial in a fast-paced course); and
- Rotate individuals through different teams for every experiment (this point is arguable, but the authors feel that the benefits outweigh the downsides to this method of team formation for unit ops labs, especially with over 5 *different* groups throughout the course).

Program Risks and Potential Disadvantages

The way this course is organized has many positive outcomes, yet there are nevertheless risks and drawbacks associated with the structure of Field Session. For example, conflicts with internship opportunities, financial burdens, and student complaints on course evaluations do arise. Taking place only in summer sessions often requires students to ask for accommodation with (or otherwise potentially give up) summer internships. This means that many of the seniors take this final course only *after* having participated in their May graduation ceremony! One advantage of this, however, is that these particular students have hands-on experience from internships performed during the prior summer(s). This can be a benefit to other students, but it can also lead to frustration for many of themselves, which emerges in critical peer evaluations of some 'inexperienced' juniors.

Maintaining all of the faculty support, from the Writing Center to the experiment-to-professor & student-to-professor ratios, on top of expert technical support for a process laboratory, all conspire to make this course relatively expensive to deliver. This expense is partially offset with laboratory fees and summer tuition (which is higher than for a regular semester, contributing to some student complaints as mentioned above), but this could be a deal-breaker for smaller programs. It is possible that teaching assistants may be used to fill some gaps, but likely there will be a corresponding drop in quality of guidance as compared with having faculty instructors in these roles.

Finally, and at least historically, many students can be quick to complain about the difficult and intense schedule and can then express this discomfit in excruciating detail in course evaluations. Expectations for course evaluations around a unit ops course should always be managed, especially when making any significant changes to course structure. A better measure will be alumni opinions, with a bit more perspective. Course evaluations will necessarily suffer from providing the students with an uncomfortable, albeit highly effective, learning experience. However, we also have experienced significantly improved course evaluations during 2018's first summer session simply by promoting positive voices! A few students were commenting that they were having fun and learning a lot. When that was announced in a general meeting and the whole group was asked who else felt the same, a significant majority of the students raised their hands. This led to a noticeable improvement in student attitudes, better than historical course evaluations, and arguably even a higher overall course performance of the students in that particular session relative to past years. This indicates that student attitudes can both be managed to some extent and can also predict course performance.

Conclusions

These methods are most applicable to programs of considerable size, as they have demonstrated scalability over the decades and utility at the current large size of the program. Nevertheless, the authors feel that there are aspects of this model for a unit operations lab course which could be useful to any Chemical Engineering program in the United States. The support of other parts of the university, like a writing center or English department, should be leveraged whenever possible.

Finally, the authors would like to point out that that the Field Session course should be in operation during the time that the Chemical Engineering Summer School program will be taking place at the Colorado School of Mines in 2021 and we look forward to providing visits or tours to interested attendees, guests, and speakers.

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