EFFICIENT GRADING

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Wankat and Felder suggest instructors, particularly new professors, limit total time in teaching-related activities.[1-4] For example, one to three hours of preparation for each hour of class time is often suggested. [3,5] Yet, determining how to wisely trim teaching-related activities remains challenging. Inspired by their guidance, this article presents specific time-management strategies selected due to their ability to decrease the administrative time burden to both faculty and teaching assistants (TAs), allowing focus on the tasks and interactions that matter most (as Covey suggests, effective time management arranges first things first[6]), while engaging students and providing timely feedback.[7] These strategies, addressed in detail below, include a multiple-answer-multiple-choice interface for free-response exams to accelerate grading, a three-tier grading system that frees TA time to be spent with students and facilitates open-ended problem solving, and a quiz strategy that provides early and frequent engagement with essential content. The net result has been, first and foremost, more time to individually assist struggling students[8,9]; plus additional time to pursue research, grant writing, and service commitments; and better work-life balance as desired.

EXAMS

The exam format governs the grading time required. Oral exams are often the least time-consuming exam format, particularly for small classes (*e.g.*, less than ~10-20 students), because they require the least-detailed exam sheets and grading can be completed during the exam itself. Oral exams are effective in allowing instructors to provide direct and individualized feedback to each student.[10] However, oral exams quickly become unmanageable for larger classes and may be subject to subjective interpretation, although clear grading rubrics help eliminate subjective ambiguity.[11] Alternatively, many faculty choose traditional free-response formats for the exam, because these allow direct examination of each student's work and generous partial credit (see Table 1). However, grading free-response exams represents a significant time commitment. For example, a three to 10 question exam with each question having multiple parts requires approximately 2-8 hours per question for classes of 30-100 students, for total of ~15-40 hours/exam including online posting of results. Altogether, one author (LP) spent slightly less than 200 hours grading free-response questions in the first year. This process requires ~4,000-6,000 grading decisions for each exam, most of which were rote. This is not only time-consuming but ineffective in that, while grading, the door is often shut to the very students who most need individualized help exactly when they pay the most attention. It is possible to reduce the grading time by giving fewer problems or/and by turning grading over to the TAs. Yet, giving fewer problems increases the sampling error in the final grade, and asking TAs to grade content increases the variability (anecdotally a source of complaints on student reviews).

For medium to large courses, one alternative is to use a multiple-answer-multiple-choice with partial credit format, a fundamentally free-response structure that eliminates most of the rote decision making. In this format, the instructor first writes an exam as though it were a traditional free-response exam. Only then does the instructor construct a multiple-choice answer set that reflects the most common answers anticipated in the free-response format. These include one or more correct answers, several answers with systematic errors for partial credit, and several incorrect answers. (Although this exam format most closely mirrors a free-response format instead of a traditional multiple-choice format, new

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TABLE 1
Exam Format Options

	Grading Time	Partial Credit Allowed	Grading Automated or Delegated
Traditional Multiple-Choice	1-3 hr	Not usually	Yes
Free Response*	18-40 hr*	Yes	Introduces variability
Multiple-Choice with Partial Credit	1-3 hr	Yes	Partially
Oral	0.2-0.5 hr/student	Yes	Partially

* *Can be reduced by assigning problems to TAs or graders (e.g., 1-3 graders would reduce faculty grading time to 5-20 hours).*

faculty may find a rich and helpful literature associated with multiple-choice questions.[12-15]) Students are expected to work through the solution and show their work as though it was a free-response exam; a multiple-choice interface only accelerates the grading process. Large answer sets (*e.g.*, a-q with x for none of the above) minimize the potential to guess randomly. If a student marks none of the above, his or her work is individually evaluated as though it were a free-response exam. This way, students retain all the benefits of a free-response exam but get feedback on the time scale of a multiple-choice exam.

Indeed, this format is surprisingly efficient to grade. Immediately following the exam, faculty and TAs divide the tests among themselves and assign points based on a prepared answer key to eliminate grader-to-grader variability (this only requires comparing student written letters to a key instead of content evaluation). When the TAs encounter poor handwriting, a none-of-the-above answer, or any other situation requiring a judgment call, the faculty evaluates the answer and determines the appropriate response. TAs often enjoy this experience because they see who did well and who did not, which motivates them to reach out to struggling students and congratulate top performers. Additionally, this system minimizes TAs' decision making, while simultaneously making a significant contribution to grading the exams. This process takes 1-2 hours for grading and online posting of the grades. Quiz grades and final course grades, for example, can be posted in as little as 40 minutes and 2 hours, respectively. This accelerated test and quiz format allows rapid feedback to dovetail with student post-exam discussions—a time when students are particularly amenable to content instruction.

Admittedly, a multiple-answer-multiple-choice with partial credit format does take additional preparation time over traditional free-response exams (*e.g.*, 3-5 hours to generate multiple-choice answers, obtain TA feedback on the exam, and prepare a thorough review sheet). However, this additional time is more than compensated by the 13-38 hour reduction in grading time (see Table 1). Exam preparation may be accelerated further by requiring students to propose exam problems with written-out solutions as part of their homework, a well-established creativity exercise at the top of Bloom's taxonomy that helps students synthesize course content,[16-20] further reduces preparation time, and builds a powerful reservoir of future exam and homework problems.

With some portion of time saved, one or more exam appeal times may be scheduled. These take ~3-4 hours each approximately 1-2 weeks after presenting exam solutions in class, when students are ready to receive feedback on how to improve. Channeling student appeals not only improves regrade consistency but follows the time-honored time-management technique of grouping like activities together.[21] Although labeled as an appeal time, these interviews quickly become an opportunity to address individually the specific cognitive skills that each student lacked on the exam. To encourage this interaction, points are not subtracted upon appeal (unless academic misconduct is discovered). Although test regrades can be done in a purely written format with substantial time savings, these individual meetings remain more effective because without them many students merely repeat the faulty arguments presented on the exam.

HOMEWORK

Homework grading can also be time consuming. To manage this important commitment, some faculty select one or more problems to grade or allow students to make this selection. Many faculty often delegate grading to designated graders or TAs. However, delegating grading to TAs reduces TA time with students, depriving students of a valuable second vantage into course material (at the authors' institution, TAs are limited to 6-8 hours per week, presenting a direct tradeoff between grading and face time helping students). Another option uses a three-tier grading system (similar to but distinct from published triage strategies[22]) to differentiate correct and excellently articulated assignments from poor, inferior, or incomplete assignments, with a mediocre grouping for those that do not cleanly identify with either category. Identifying the first two groups or tiers is straightforward, so the graders place these assignments into two stacks. When no remaining paper clearly identifies with either of the first two stacks, these become the third stack. TAs have the flexibility to check one or more of the problems or grade on professional presentation as appropriate to the assignment. Posting a rubric delineates the attributes of each of the three tiers and removes student questions about what is required. Since the TAs grade the homework and respond to appeals, they design the rubric. This stacking process requires 1/2 to 1 hour for small (*e.g.*, 30 students) and large (*e.g.*, 100 students) classes, respectively. A three-stack approach is marginally faster than a two-stack approach because less time is spent on judgment calls.

The excellent assignments earn two points (P_i=2), the mediocre grouping one point (P_i=1), and the inferior assignments or those not turned in earn zero points (P_i=0). The homework grade (P_{HW} on a 100% basis) is calculated with

$$P_{HW} = \left(10 - \sum_{i=1}^{15}\left(2 - P_i\right)\right)10\%, \quad (1)$$

where P_{HW} must remain ≥0% and the leading term may be tuned as desired (freshmen courses may need more leeway through a larger term); 10 was selected to signal five late or missing assignments as unacceptable at the collegiate level or in the workplace and works well for junior-level courses. Students may recover half of the points lost on any assignment by revising it or turning it in for the first time (if late), and the lowest score is dropped. Eq. (1) allows immediate posting (on the due date) of the answer key (typically one or more exemplary assignments with names removed; students are informed in syllabi), because students who merely copy the posted key receive no net points via Eq. (1) (P_i≤1 for each late assignment). Admittedly, this system remains less precise than alternatives that differentiate increments of ≤1%, yet over ~15 assignments/semester, this three-tier system produces similar averages. Students retain the right to request a detailed evaluation of their solutions, although not one has in over 7,000 assignments filed by nearly 500 students, and not one student has complained to an instructor that insufficient time was spent grading his or her assignment, although students continue to indicate that even more individual time with TAs and faculty to answer questions would be helpful.

This system provides a natural avenue for students to explore options in homework problems and exercise engineering judgment (skills at the top of the Bloom taxonomy[16, 17])—a critical advantage. Instructors facilitate this by 1) leaving the problems open-ended, 2) leaving off some information so that students have to use their judgment, and 3) not penalizing students for making reasonable assumptions with an overly detailed grading process. Instructors emphasize early in the course that dream jobs do not come with answer keys or faculty advisors; students will have to rely on their own engineering judgment and their social network to find answers—a message that resonates with second-semester juniors. When students visit, instructors help them brainstorm options and ask how they will know when they have found a good answer. The process is initially unsettling, but the quality and vigor of discussion in the department computer lab at the end of the semester, about which solutions are best and why, has a very different quality.

ESSENTIAL QUIZZES

Although all of the information faculty teach has value (otherwise it would not be taught in the first instance), some information remains critical to success in the courses that follow. Similarly, some of the information taught in other classes is critical to ours. If instructors have a syllabus and an A-level student, they know what that student knows to a reasonable degree of certainty and can plan their courses to advance therefrom. However, instructors do not inherently know what a C-level student knows. Do these students know 75% of everything or do they know 75% of some topics perfectly and nothing about the rest? The latter is particularly disastrous if the missing knowledge is critical for the next course, because each course forms the foundation for those that follow. Indeed, some information is so critical to the field that students should not pass without demonstrating full comprehension.

Essential quizzes are a form of mastery learning with single retake, designed both to evaluate what students know and ensure that they are ready to perform at the next level.[23-26] For example, a junior-level mass transfer and separations course might have four essential quizzes. The first reviews mass and energy balances, the second covers distillation column design concepts, the third evaluates mastery of the ASPEN process simulator (see Appendices A and B for an example of the essential quiz and its corresponding objectives[27]), and the fourth covers essential mass transfer topics. To ensure that this information is truly essential for subsequent courses, quiz content has been vetted by faculty who teach at the senior level. Although a wide variety of recommendable grading scales remain available for mastery learning,[23-26] the essential quiz grade (on a 100% basis) is calculated with

$$P_{EQ} = \left(10 - \sum_{i=1}^{4}\mathrm{Min}\left(10 - P_i^A, 10 - P_i^B\right)\right)10\%, \quad (2)$$

where each quiz, P_i^A or P_i^B, is worth 10 points, so that students who master only 75% of the essential material do not receive points (P_{EQ}≥0). Providing two opportunities to take the quiz (P^A and P^B) prevents an abnormally poor performance from adversely affecting student grades, yet subtraction in Eq. (2) with one retake ensures each pair of quizzes (together, including the first) is treated seriously. Essential quizzes comprise 20% of the final grade (*i.e.*, $0.2P_{EQ}$ contributes to the final percentage) to cap it at the C level if mastery of the fundamentals is not demonstrated. Typically half (45.0%) of the juniors (n=112 in separate years per IRB 00067513) earn ≥9 on the first version. After the second essential quiz, 73% earn ≥9. By the end of the semester, juniors retain on average 90.7-91.9% of the points on each essential quiz pair, which is better than typical mid-term exam averages (62.6-88.8%).

This pattern has important advantages for the students. First, juniors review mass and energy balances on their own and are ready to engage with new material. Offering the first essential quiz on the first two Fridays of the semester provides this engagement early in the term. Some students who are not prepared drop the course, but <2% do so. Second, students appreciate the opportunity to retake the quiz and often study harder the second time. This commitment brings a new focus and vibrancy to the class as exemplified by the increase in content-related discussions among students and between students and instructors. Third, students prefer this option with clear learning objectives (see Appendices A and B) over two additional mid-terms (the alternative).[28-30] Learning objectives are discussed in class prior to the quiz so that expectations are clear. Fourth, the exam format described above allows rapid feedback within the first two hours after taking the quiz. Students find the instructors that afternoon to discuss how to improve, often in response to a class email indicating scores. Finally, students have very little concern about the format of mid-terms and finals because they have seen the testing format in the first week when they can still recover because of the retake policy.

From a time-management perspective, grading the eight essential quizzes per semester required one person 40-80 min of grading and posting time per exam for a cumulative time commitment approximately 8 h, whereas two additional mid-terms would have taken 6-18 h total (including TA grading time, see Table 1). Students who require special accommodations are invited to come early or stay late. Currently, special accommodation requests are modest (1- 3/semester), but large increases in their numbers could become prohibitive. Admittedly, administering these quizzes comes at a significant time cost of 2-3 additional lecture days relative to the three-mid-term strategy, but the elevated student engagement counters this cost.

SCHEDULING FOR MAXIMUM ENGAGEMENT

Some courses gradually increase the workload throughout the semester. Alternatively, we can fully engage students in the first week. This may be done by giving a homework assignment, one essential quiz, and a reading quiz in the first week. In the second week of junior-level mass transfer and separations, two more reading quizzes, an essential quiz retake, and also a 10- to 15-hour review of thermodynamics as a homework assignment brings the students to the highest level of time commitment. The homework may then be reduced to the 6-8 hour level for the rest of the semester. This rapid and intense pace has advantages. First, students set reasonable expectations about what the junior-level workload is. By immediately working at this level of intensity, students recalibrate their work and commuting schedules, perhaps working 5-10 h/week instead of 20-40 h/week. Students develop better time-management habits from the beginning of the semester (stimulated in part by a lecture on time management on the first day). The unexpected consequence is that many students report that they do better in their other engineering courses because they reprioritize at the beginning of the semester. Students also appreciate the fact that this strategy flattens their semester workload. Many classes become more intense in the last weeks of the semester, by which time a majority of learning has already been accomplished.

In a typical course, most students seriously synthesize the course material immediately prior to the exams. The 48 hours before the exam are a rush of learning and synthesis. However, with eight essential quizzes, one mid-term, and one final, the students synthesize the course material at least 10 times, echoing the counsel of Wankat and Oreovicz to give more tests.[20] Much like repeated pharmaceutical administration to keep drug concentrations within therapeutic windows, repeated exams and quizzes keep the students within a learning window. Whereas active-learning techniques repeatedly engage students within a class period; this assessment strategy actively engages students several times over the course of the semester.[30-33]

CONCLUSION

Perhaps the most important aspect of these strategies is that they free the faculty and TAs to focus on the students instead of administering a grading system. These strategies allow more time to listen to students, more time to memorize their names, more time to help students figure out their missing cognitive structures or missing time-management skills that make all the difference, more time to draft better examples, and more time to adopt innovative teaching techniques. [7,34,35] Indeed, these strategies allow more time to do the things faculty know they should do, and would do well . . . if they only had more time. The secret is not *knowing* what to do, but rather finding the time to do it well. For example, intervening with C- and D-level students early in the semester may be most effective[36-38]; offering multiple homework assignments in the first 3-4 weeks coupled with Eq. (1) rapidly identifies these students early in the semester by differentiating them from those who have given up (likely Fs) and those who are doing well without intervention (likely As and Bs). Redirecting time from administering the grading system to helping these struggling students recover, reengage, and eventually succeed is perhaps the most rewarding result of these strategies.

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APPENDIX A: EXEMPLARY EDUCATIONAL OBJECTIVES

Essential Objectives for Essential Quiz 3A & 3B

1. ***Identify the best property package for a given separation.*** *If you were given experimental data, could you identify the best package from a short list? If you know something about the properties of the two fluids to be separated, could you suggest which property packages would be best or select the best from a short list? Remember that high-quality data always trumps hierarchical lists no matter how well-intentioned.*

2. ***Input basic information into ASPEN, get it to return results, and interpret those results.*** *This sort of goes without saying if it is an ASPEN quiz. However, the items below may be a more specific guide.*

3. ***Identify which stage ASPEN uses to identify condenser and reboiler.*** *Is it the same as our McCabe-Thiele convention?*

4. ***Determine the flow rates and composition of each stream.*** *Be sure you know how to use both the long tables that ASPEN generates as well as the plot wizard to obtain flow rates and composition as a function of the stage number. Don't forget that sometimes you need to work out the mass balances by hand to find some of the flow rates or compositions you will enter.*

5. ***Determine which stage is least effective.*** *This is best done using composition versus stage plots to identify where compositions do not change. If there are stages where the composition does not change, do we need them? Can we move a feed stream or shrink the column to eliminate the useless stage? Sometimes both are fixed in the problem statement, but full optimization of the column often requires that we think about both the total*

number of stages and the feed stream location.

6. ***Determine the diameter of each section of the column.*** *Sometimes we want the diameter of the entire column and sometimes we need to determine the diameter section by section. Remember to round up.*
7. ***Input utility streams and determine the heat duties of condensers and reboilers.***
8. ***Determine the column height for a particular separation.*** *Don't forget about entrainment and surge capacity.*
9. ***Evaluate whether the constant molar overflow (CMO) assumption is reasonable for your separation.*** *Hint: how would you use a plot of flow rates versus stage number to determine whether CMO holds? Do you expect to have a change in flow rates around feed and side stream entry and exit points?*
10. ***Know the difference between RADFRAC and DISTWU.*** *Which one is equivalent to the Fenske-Underwood-Gilland shortcut method? Which does not assume constant molar overflow?*
11. ***How do your results compare with what you know from other methods?*** *Do your results agree with McCabe-Thiele? Do they agree with the Fenske shortcut method? If they do not agree, do you know why? Do you have a good split between the heavy and light keys? Many students find that these methods are helpful in finding a good starting reflux ratio or initial number of trays. If you have this information, add a little to the reflux ratio and a few additional trays and then reduce these down sequentially until you have an optimized column profile.*

APPENDIX B: EXEMPLARY ESSENTIAL QUIZ

Mass Transfer and Separations Essential Quiz 3A

This quiz follows a multiple-choice, multiple-answer format; each question may or may not have more than one correct answer. Please mark all correct answers and show your work legibly and clearly. Answers not transferred to the front page will not be graded. Attaching multiple ASPEN printouts is unlikely to be a successful strategy.

1. (1 pt) Name __________________________

2. __________ (use capital letter; 3 pts)

3a. __________ (use capital letter, 2 pts)

3b. __________ (use capital letter, 2 pts)

3c. __________ (use capital letter, 2 pts)

<u>AFTER COMPLETION OF THE QUIZ, PLEASE READ & SIGN THIS CERTIFICATION:</u>

I certify that: (1) I have neither received nor given help on this exam, (2) that all the rules described above have been strictly obeyed, and (3) that I have carefully protected all computer solutions from use by others.

____________________________Signature

--end of front page--

2. (3 pts) Which one of the following property packages is best for the data given? Choose one. Consider the following vapor liquid equilibrium mole fractions extracted from Perry's in your analysis:

x_{EtOH}	x_{water}	y_{EtOH}	y_{water}
0.1661	0.8339	0.5089	0.4911
0.7472	0.2528	0.7815	0.2185

(a) Ideal
(b) Wilson (estimate missing parameters with UNIFAC if needed)
(c) Chou-Seader
(d) Peng-Robinson
(e) SRK

3.[39] (6 pts)The feed consists of 30% ethanol in water entering as a two-phase mixture (50% liquid) at 100 kmol/hr. The bottoms and distillate concentrations are ≤2.0 mol% and ≥79 mole% ethanol, respectively. The column operates at essentially 1 atm (for ASPEN the top tray and feed are at 1 atm). Assume a total condenser, a kettle-type partial reboiler, NRTL as your property package, 16 stages (total), feed at stage 11 (above tray), and a reflux ratio of 2.0. For cooling water assume \$0.16/GJ, 30 BTU/lb, 90 ˚F inlet, and 120 K ˚F outlet. For steam assume \$3.17/GJ and 900 BTU/lb. For tray sizing assume bubble caps, 0.8 flooding ratio, a minimum downcomer area of 0.1, system foaming factor 1, over design factor 1, flooding calc method Fair, and a 2 feet tray separation. Describe your work as much as possible. Consider the possibility that this system may be azeotropic in your selection of simulation strategy.

3a. Which stage is least effective? Printing out a liquid composition versus stage plots may be helpful in awarding partial credit if necessary. Other printouts are unlikely to be helpful.

(a) 1	(b) 2	(c) 3	(d) 4	(e) 5	(f) 6
(g) 7	(h) 8	(i) 9	(j) 10	(k) 11	(l) 12
(m) 13	(n) 14	(o) 15	(p) 16	(x) none of the above	

3b. What is the distillate flow rate?

(a) 100 kmol/h	(b) 30 kmol/h	(c) 64.1 kmol/h	(d) 35.9 kmol/h
(e) 63.6 kmol/h	(f) 36.4 kmol/h	(x) none of the above	

3c. What is the column diameter? Round to the nearest tenth of a meter.

(a) 0.3 m	(b) 0.4 m	(c) 0.5 m	(d) 0.6 m	(e) 0.7 m
(f) 0.8 m	(g) 0.9 m	(h) 1.0 m	(i) 1.1 m	(j) 1.2 m
(k) 1.3 m	(l) 1.4 m	(m) 1.5 m	(n) 1.6 m	(o) 1.7 m
(p) 1.8 m		(x) none of the above		