Ungrading in STEM Courses

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One of the greatest misconceptions about courses in the STEM (Science, Technology, Engineering, and Mathematics) disciplines is that *everything has one right answer*: only one correct solution to an equation, only one way to resolve a force into two components, only one correct output to a list-sorting algorithm. We learned this in school because this is how our work was graded: the teacher would look at our answers, compare them against the one right answer, and then assign a numerical grade accordingly.

But the "one right answer" misconception is just that—a misconception. Any sustained study of the STEM disciplines reveals the inaccuracy of this belief. Often, there is not a single right answer to a problem—the "answer" you get is dependent on the information available and the models selected—and often, incomplete information and equally-valid models for problem solving lead to different but defensible solutions. Even when there *is* just one correct answer, there might be different ways of understanding that answer. And in any event, the presence of cheap, ubiquitous technology like the website Wolfram|Alpha or Microsoft's Math Solver has made "the answer" less important than the thought processes that lead to it.

Traditional points-based assessment in the STEM disciplines both arises from this misconception about having "one right answer" and perpetuates it. Because of the multiplicity of ways of knowing in these disciplines, it's worthwhile to think about the role that ungrading can play.

Can **You Ungrade in a STEM Course?**

By "ungrading," I mean the model of evaluating student work in which:

> individual items of student work do not receive any kind of mark;
> instead, those items receive feedback about the quality of the work relative to clearly-stated standards, as well as any other aspects of the work the instructor cares to comment upon;
> students are allowed to re-attempt work to improve it based on the feedback; and

> at the end of the course, the instructor and student collaboratively determine a course grade.

Note that I am not including in this definition any alternative forms of grading in which student work receives a mark, such as specifications grading or standards-based grading. A key characteristic of ungrading is the *absence* of marks, which intends to shift focus off the product and onto the process.

A person still holding onto the "one right answer" belief might look at this definition and say that ungrading in a STEM subject is impossible, or at least that it empties the subject of "rigor." But the possibility of ungrading becomes clear once we distinguish between *procedural* and *conceptual* knowledge.

In a 1997 paper, Robert McCormick describes procedural knowledge as "know how to do it" knowledge, whereas conceptual knowledge is "concerned with relationships among 'items' of knowledge."[1] For example, in a geometry course, procedural knowledge would include such items as the definition of an isosceles triangle and how to find the remaining angle measures in such a triangle if one of the angle measures is known. Conceptual knowledge, on the other hand, would consist in explaining (or "proving") why that method works, or why the sides opposite the equal angles in an isosceles triangle must be of equal length.

The belief in "one right answer" is essentially the belief that all STEM courses are procedural. To be fair, most STEM courses prior to college seem to be entirely procedural. But at the college level, not all STEM courses are procedurally focused. In fact, some of them have no real focus at all on procedural knowledge. An upper-level course on Euclidean Geometry, for example, cares very little about computing the measure of an angle. Such a course is instead entirely focused on developing conjectures about global truths, refining conjectures through rigorous analysis, and eventually writing mathematically sound proofs.

Put this way, a geometry course or any other STEM subject with a significant focus on conceptual knowledge sounds a little like a course in writing or philosophy, where ungrading, with its focus on conversations with the instructor via feedback loops, is easy to conceptualize. This is no accident: at this level, STEM subjects and non-STEM subjects both focus on the classic liberal arts practices of reasoning, communication, and critical thinking. And if ungrading works in one of those subjects, it can work in the other.

Not only do courses like the upper-level geometry course exist, every STEM course at the college level ought similarly to include large helpings of conceptual knowledge in its design and assessment. While we value procedural knowledge, we should value conceptual understanding more, because conceptual understanding is the substrate for lifelong learning and professional success. These values can, and should, be apparent in the work students do and how we evaluate it.

***How* Do You Ungrade in a STEM Course?**

Implementing ungrading can happen on one of two levels: at the level of a single assignment or at the level of an entire course.

I teach a course called "Discrete Structures for Computer Science" that sits in the intersection of mathematics and computer science. In it, the students—almost all of whom are computer science majors—learn a mix of procedural and conceptual knowledge from discrete mathematics. The course has a system of quizzes set up to assess procedural knowledge; conceptual knowledge is assessed by a series of application problems. Here is a typical one:

> You'd like to purchase a dozen doughnuts from your favorite doughnut shop. The shop has five flavors available: plain, chocolate, jelly-filled, strawberry, and blueberry. You can get as many as you want of each kind, but you must get exactly one dozen total. How many different ways are there to do this?

On the surface, this sounds like the usual "word problem" from a math course that should have one right answer. In fact, there is one right answer here: 1820. But we're far more curious about the *method* used to get to that answer than the number itself.

A solution to this problem must not only be mathematically correct (not just the answer, but also the process), it must also be clearly and cogently communicated. With ungrading, both are required. A student may say the answer is $12^5 = 248832$ and explain that this is because there are twelve choices to make and five options per choice. This explanation is clear—but wrong![2] Or the student may arrive at the number 1820 but give an explanation that leaves doubt that they understood the process. (Often, students leave no explanations at all, being used to giving only answers in their prior courses.)

Applying ungrading to student work here is therefore not fundamentally different from ungrading an essay: the instructor looks at the student's work, gives clear and actionable feedback (on both the good and not-as-good parts), and then lets the student try again—and the feedback loop repeats until the instructor has no more comments. In this way, it's possible for ungrading to coexist with work in which there is one right answer, or at least one preferred model or process. Indeed, an ungrading approach to evaluating conceptual understanding imbues the "one right answer" with enhanced validity.

Scaling ungrading up to an entire course involves two steps on the instructor's part: providing a clear and accurate narrative of what a grade of A, B, C, or D looks like in terms of student work, and then setting up a system for having a collaborative conversation with students about course grades at the end. For example, all work in the course might be ungraded as described above, and then students assemble a portfolio of their work to make a case for their course grade. Or, some items of work might be ungraded while others receive marks; course grades might require baseline amounts of marked work (e.g., at least 75 points on the final exam, or 12 out of 16 content standards met through standards-based grading methods), and students then use the ungraded work to make a case for a higher grade.

These are just a few examples of how ungrading might be implemented in a STEM course. But there are other implementation issues that go beyond the "how" to the deeper question of "why."

Should **You Ungrade in a STEM Course?**

The answer to this question is: *not necessarily*. Although saying so might put me out of step with the other essays in this forum, it's important to acknowledge a plain fact: ungrading is not always the best choice for every student in every course. The choice to ungrade should be deliberate, and that choice must make sense for your unique educational, professional, and personal situations.

Making the best choice for your students involves a number of considerations, including:

> **The specific focus of your course**. Some courses are primarily, even entirely procedural, with little to no conceptual knowledge built into them. If you have such a course, and especially if you have little creative control over it, then other approaches to grading are likely to be more helpful to students than ungrading. Although it should be otherwise, many introductory STEM courses can fall into these categories.

Students' abilities to self-assess. Ungrading is only as good as students' abilities to evaluate their own work and the feedback you provide them. Some students excel at this already, and others are in a good position to learn. But many others struggle with this, especially in STEM courses where not only must communication be clear, but technical concepts must also be well-understood. For those students, ungrading might do more harm than good. Marks on the work of these students are not necessarily motivation-killers, but guideposts that can state in clear terms how well they are progressing.

Logistics. For example, course size. It is exceedingly difficult to give meaningful feedback on student work at scale, and if you have a large section of a course—as is often the case in STEM subjects—then ungrading may simply not be possible without other changes that you may not be able to make. Or, if you must give a common final exam (again, as is common in STEM subjects), then ungrading may be off the menu.

Whatever your choice, ungrading is not only possible in a STEM course, it can be a transformative way for students to encounter the STEM disciplines as they truly are: a way of understanding the world that admits multiple ways of knowing, bolstered by iterative conversations among people journeying together toward understanding.

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[1] Robert McCormick, "Conceptual and procedural knowledge," *International Journal of Technology and Design Education* 7/1 (1997): 143.

[2] It's wrong because there is a conceptual misunderstanding: This method counts equal selections as being different: for example, choosing plain first, then eleven blueberries is counted as a different outcome from choosing eleven blueberries first and then a plain one last, even though these are the same overall box of doughnuts. Therefore, the answer is way too large.