Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #47267

# Increasing Student Achievement in ECE Fundamentals Through Standards-Based Grading

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## Abstract

In a traditional STEM course, student work is evaluated using points, allowing students to receive partial credit on the problems attempted. Final grades are then determined by combining the scores on the formative (homework) and summative (tests) assessments using a predetermined formula. In some cases, attendance, class participation, and lab work may factor in the final grade calculation. Although this works reasonably well, the final grade does not accurately reflect student knowledge.

Standards-based Grading is a more authentic way to assess student achievement. In a course using authentic grading, course grades are based on student proficiency in specific topics, called standards. Standards are regularly assessed and opportunities for reassessments are offered periodically. Final grades are assigned based on the number of standards a student has ultimately mastered, resulting in a final grade that more accurately reflects student knowledge.

During the Fall of 2023, two sophomore-level course offerings (Circuits I and Electricity and Magnetism) were modified to use Standards-based Grading to assess student learning. These two courses are required for all engineering students, and as such, approximately one-third of the students were common to both course offerings. Quantitative and qualitative results indicating student performance and student feedback are shared. Lessons learned and future work is also presented.

**Motivation**

Most fundamental Electrical and Computer Engineering (ECE) courses are taught using the traditional recipe for college STEM teaching and learning: lecture → class examples → homework → assessments → rinse→ repeat. See Figure 1.

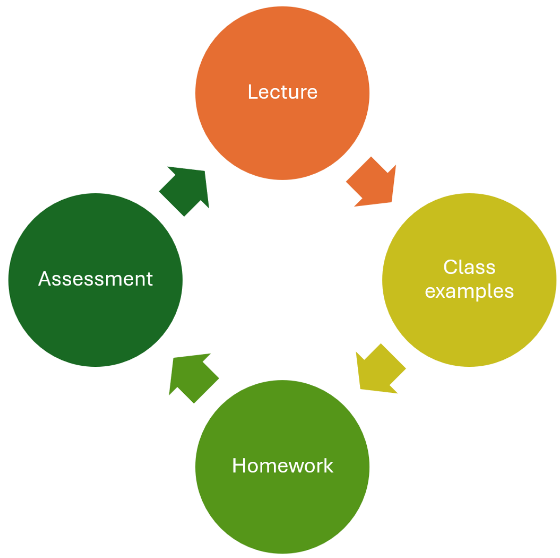


Figure 1: Traditional Recipe for STEM Teaching and Learning

Although this comfortable recipe works well for many students, it does not reliably produce a course grade that accurately represents a student's knowledge of the course material. Consider a first semester circuits course in which the final grade is calculated using some combination of homework, assessments, and lab work. It is possible for a student to pass the course, albeit barely, with very little knowledge of the course material. Unable to set up the correct governing equations on assessments, they earn partial credit for the resulting mathematical solution. Boosted by a reasonable lab grade and a curiously high homework average, they are ultimately able to earn enough points to pass the course. It's just the way the numbers work.

Another type of student who does not fare well with the traditional recipe for STEM teaching and learning is the one who stumbles at the start of the semester and is unable to recover. The fundamental circuit analysis procedures for DC circuits are covered at the start of the semester – circuit reduction followed by current and voltage division, nodal analysis, and mesh analysis. Later material builds on this foundation. Students who are slow to establish a strong foundation early and fail the first assessments are very unlikely to pass the course. With no incentive to return and master the fundamentals, they look forward hoping to do better on the next assessment. But with a weak foundation they are sure to fail.

And finally, there is a third type of student. This student does well on assessments, but occasionally misses a key concept. Rather than turn their sights to the new material, they carefully study their mistakes and ultimately master any concept they missed. This student would finish the course with a B+ or A-, yet their ultimate mastery of the material would more fairly earn an A.

Another issue with the traditional approach to STEM teaching and learning is the overemphasis on points. Students often equate points with learning and grades, leading them to focus more on accumulating points than on truly understanding the material. In courses designed to foster a growth mindset, however, students are encouraged to shift their focus from merely earning high marks to developing a deep comprehension of concepts. This shift promotes greater engagement with subjects like circuits and physics, where mastery takes precedence over rote memorization. As students embrace challenges and put in the effort to improve, their confidence grows, creating a more dynamic, supportive, and rewarding learning environment.

A new approach to teaching and learning is needed - one that is structured enough to ensure all students grasp fundamental course concepts, yet flexible enough to allow them to recover from early setbacks. This revised framework should also cultivate a growth mindset, reinforcing the idea that learning is a continuous process rather than a fixed outcome. By prioritizing mastery over points, educators can help students develop resilience, problem-solving skills, and a genuine passion for STEM disciplines.

**Literature Review**

In a traditionally-graded physics or engineering course, students complete a combination of homework, laboratory work, quizzes, and exams, with each contributing a percentage toward a final grade. Many courses include other activities such as class participation and attendance. For instance, the course grade might be computed using the breakdown shown in Figure 2. At the end of the term, a student's overall percentage is converted into a letter grade (A, B, C, etc.).

Feldman [1] identifies three pillars of equitable grading that are missing in traditional grading - accuracy, resistance to bias, and student motivation. Clark and Talbert [2] point out the following additional shortcomings. Traditional grading systems -

- do not produce grades that necessarily reflect mastery of course material
- misuse statistics by treating categorical data as numerical data
- disproportionately reward students who learn fast, have already learned the material, or know how to "play the game" due to their privilege
- promote unhealthy student-faculty relationships and academic dishonesty

Additionally, the rise in grade inflation in higher education over the past several decades has raised questions about the reliability and meaning of grades as indicators of student performance [3, 4]. We recognize that the current letter grading scheme in the US education system is unlikely to change any time soon but are interested in exploring ways to structure our courses so that the grades more closely reflect student learning, reduce inequity, and promote a growth mindset.

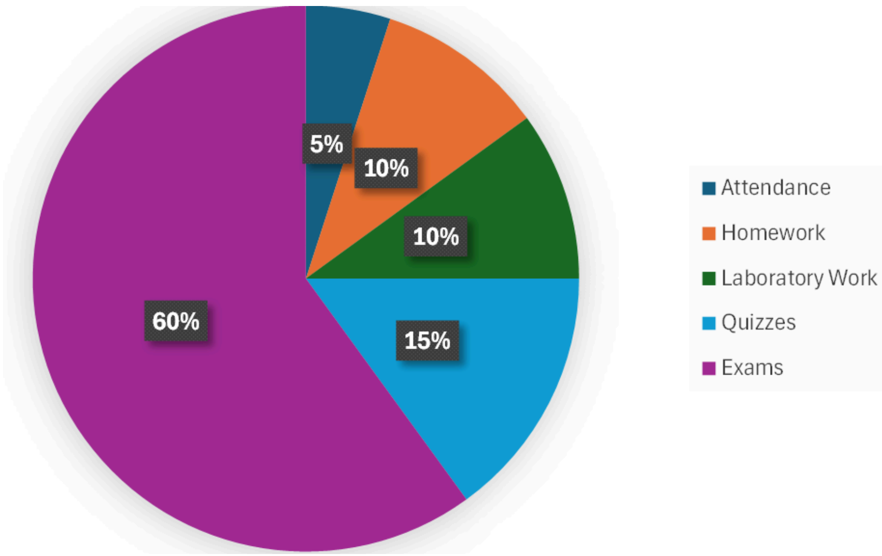


Figure 2: Typical Weighting of Coursework Used with Traditional Grading

Many educators are turning toward alternative grading strategies that more authentically assess student learning. Clark and Talbert [2] describe several alternative grading strategies that are gaining acceptance in education. The Center for Grading Reform [5] maintains a list of resources for alternative grading, including a repository of syllabi in mathematics and the sciences. Hackerson, et al [6] surveyed alternative grading practices in use in STEM education. Of these, Standards-based Grading (SBG) is growing in popularity.

Carberry, et al [7] provide guidance for setting up an engineering course using SBG. Beatty [8] reports on SBG in an introductory physics course. Del Carlo and Strauss [9] propose rubrics that can be used to assess the learning outcomes in a chemistry course.

Understanding the motivation and bolstered by the experience of others, we were left wanting more details, particularly in terms of the logistics of the many assessments. Furthermore, the experience of teaching the same students in different courses provided support and helped build consensus between the relevant departments.

**Defining Success**

We established the following criteria to assess whether SBG mitigates the common challenges of traditional STEM teaching and learning. These criteria will be revisited throughout the paper to evaluate the success of SBG in achieving its intended outcomes.

The proposed metrics for evaluating the effectiveness of SBG include:

- **Authentic Reflection of Learning:** Final grades that more accurately represent student understanding and mastery of course material.
- **Resilience and Recovery:** Students who struggle early in the semester are able to recover and successfully complete the course.
- **Cultural Shift:** A noticeable shift in course culture toward collaboration, persistence, and deeper engagement with the material.
- **Student Well-Being and Perception:** A majority of students report reduced stress and increased learning.
- **Post-Requisite Success:** Students demonstrate continued success in subsequent courses, indicating lasting conceptual understanding.

By tracking these metrics, we aim to build a robust framework for evaluating SBG and guiding future improvements to STEM education.

**General Course Implementation**

During the Fall of 2023, two sophomore-level course offerings were modified to use SBG to assess student learning. Circuits I was taught by Barbara Marino from the Department of Electrical and Computer Engineering, while Electricity and Magnetism (E&M) was taught by David Berube from the Department of Physics. These two faculty members collaborated during the summer prior to the start of the semester but ultimately adopted slightly different approaches. The following subsections describe the specifics of the two offerings.

**Implementation in Circuits I**

A list of 24 standards were identified for the first semester circuits course. These were divided into three categories – basic, intermediate, and advanced. See Figure 3. To ensure all students learned the circuit fundamentals, each student was required to demonstrate proficiency on all twelve basic standards to earn a passing grade. This also encouraged the students to return to the fundamentals before attempting the more difficult standards. Each standard was assessed on a four-point scale indicating the demonstrated mastery. See Figure 4. Final grades were assigned based on the number of standards a student had ultimately mastered. See Figure 5.

| Standard | | Level | | |
|---|---|---|---|---|
| Number | Skill | Basic | Intermediate | Advanced |
| 1 | Circuit reduction | B | | |
| 2 | KVL/KCL to solve for a circuit parameter | B | | |
| 3 | Calculating power | B | | |
| 4 | Nodal analysis | B | | |
| 5 | Nodal analysis - supernodes | | | A |
| 6 | Mesh analysis | B | | |
| 7 | Mesh analysis - super mesh | | I | |
| 8 | Superposition | | I | |
| 9 | Source transformation | | | A |
| 10 | Circuit analysis with dependent sources | | | A |
| 11 | Thevenin/Norton equivalent circuits | B | | |
| 12 | Single stage op-amps | B | | |
| 13 | Multiple-stage op-amps | | I | |
| 14 | Characteristics of capacitors and inductors | B | | |
| 15 | Step response of first order capacitive circuits | | I | |
| 16 | Step response of first order inductive circuits | | I | |
| 17 | First-order active circuits | | | A |
| 18 | Steady state nodal or mesh analysis | B | | |
| 19 | Steady state superposition | | I | |
| 20 | Steady state Thevenin/Norton equivalencies | | | A |
| 21 | Frequency response | B | | |
| 22 | AC power calculations | B | | |
| 23 | Power factor correction | | I | |
| 24 | Lab experimentation | B | | |

Figure 3: Circuits I Standards

| Score | Level of Attainment | Description |
| --- | --- | --- |
| 4 | Exceeding Standard | Solution is complete and demonstrates understanding of concepts; answer is correct; units are included. |
| 3 | Meeting Standard | Solution demonstrates understanding of concepts but contains one or two minor mathematical error or units are not included. |
| 2 | Approaching Standard | Solution demonstrates understanding of concepts, but execution is incomplete or incorrect. |
| 1 | Not meeting Standard | Solution does not demonstrate understanding of concepts. |
| 0 | Insufficient Evidence | There is not enough information in the solutions to assess. |

Figure 4: Circuits I Assessment Rubric

| Course Grade | Minimum number of standards met | Level of attainment |
|---|---|---|
| **A** | 21 | Earn a vast majority of 4s on standards |
| **A-** | 21 | Earn a mix of 3s and 4s on standards |
| **B+** | 18 | Earn a vast majority of 4s on standards |
| **B** | 18 | Earn a mix of 3s and 4s on standards |
| **B-** | 18 | Earn a vast majority of 3s on standards |
| **C+** | 15 | Earn a vast majority of 4s on standards |
| **C** | 15 | Earn a mix of 3s and 4s on standards |
| **C-** | 15 | Earn a vast majority of 3s on standards |
| **D** | 12 | Earn a mix of 3s and 4s on standards |

* A vast majority is defined as ≥ 66%

Figure 5: Assignment of Final Course Grades for Circuits I

Reassessment opportunities were first offered monthly, and then weekly during the second half of the semester. To ensure students were adequately prepared before seeking reassessment, a token system was used. Students could earn a token for each of the following activities, which they in turn "paid" for their reassessment. As can be seen from the following list, some activities are easier than others, requiring the students to plan accordingly.

- Complete *Getting Started* assignment. (one token)
- Complete *Introductions* assignment. (one token)
- Complete *Academic Biography* assignment. (one token)
- Solve a problem similar to the requested assessment. Submit the paper solution showing all steps. (maximum three tokens)
- Create a Multisim simulation of a problem similar to the requested reassessment. Submit the Multisim file along with a pdf document showing the circuit and resulting measurement(s). (maximum three tokens)
- Create a video demonstrating the solution to a problem similar to the requested reassessment. The work can be done on paper, a whiteboard, or an electronic device such as a tablet or iPad. The video must include words describing the solution. (maximum three tokens)
- Build a circuit in lab to test the solution to a problem similar to the requested assessment. (maximum three tokens)

The experiment proved to be quite successful, as the grades more accurately reflected student learning. This contrasted with previous years using traditional methods, where students who had mastered all the concepts might not earn an A, and others could pass the course - supported by high lab and homework scores - despite having limited understanding of circuit analysis.

The experiment was also successful in creating a pathway for students who struggle early to recover and complete the course successfully. Figure 6 shows the grade distribution for the Fall 2022 course offering which used a traditional grading model and the grade distribution for the Fall 2023 offering of the course which used SBG. Most striking, the percentage of students who earned an A in the course increased dramatically with SBG. Armed with the recipe for success, every single student was motivated to earn an A at the start of the semester. Not all students were able to demonstrate mastery of each standard the first time it was assessed, but the reassessment opportunities gave them an opportunity to learn from their mistakes and try again. Most significant though, *the percentage of students who dropped or failed the course decreased to almost zero*. With SBG, students who struggle at the start of the course have an incentive to return and master the fundamentals instead of naively looking forward hoping to do better on the next assessment.

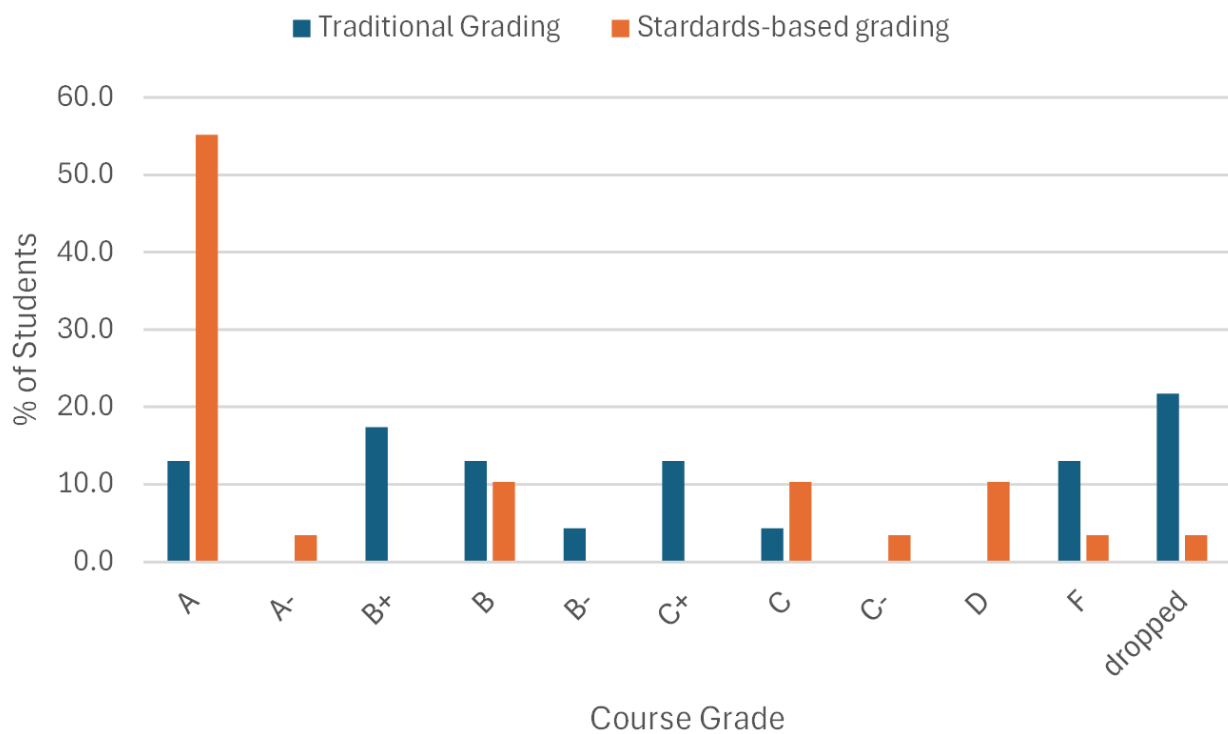


Figure 6: Comparing the Circuits I Grade Distribution Between Traditional and SBG Offerings

The university course evaluation provides an opportunity for students to report what they found most beneficial about a course. More than half of the comments related to the advantages of SBG. Students wrote that SBG "made a difficult course seem more approachable," and "allowed for individual focus on each of the course material every week while providing students the opportunity to draw upon a mix of old and new material to solve each problem." The reassessments were "especially beneficial in how it allowed students who might have not fully understood the topic the first time around, to learn from their mistakes and try again next week."

Of course, SBG made its way into the comments on what students felt could have made the course more effective. One student commented that the frequency of assessments was stressful. Another felt the threshold for a score of 4 on the assessments was too high. The tokens were not very popular. Most students found them to be more time-consuming than their worth.

**Implementation in Electricity and Magnetism**

A total of 20 learning targets were identified for the sophomore-level E&M course. Each target was treated equally, with no distinction between *basic*, *intermediate*, and *advanced*. The targets were statements such as “I can solve for the motion of a charged particle in an electric field.” The targets were grouped into four units corresponding to the general categories of electrostatics, electric potential and circuits, magnetic fields, and electrodynamics. A list of topics associated with each target is shown in Figure 7.

| Target | Description |
|---|---|
| 1.1 | Nature of electric charge |
| 1.2 | Coulomb’s Law |
| 1.3 | Calculating the electric field |
| 1.4 | Motion of charges in an electric field |
| 1.5 | Gauss’s Law |
| 2.1 | Electric potential energy |
| 2.2 | Calculating electric potential |
| 2.3 | The connection between potential and field |
| 2.4 | Capacitance |
| 2.5 | Ohm’s Law, current, and resistance |
| 2.6 | DC circuits |
| 2.7 | RC circuits |
| 3.1 | Motion of charges in a magnetic field |
| 3.2 | Calculating magnetic fields |
| 3.3 | Magnetic force on a current-carrying wire |
| 3.4 | Magnetic field applications |
| 4.1 | Faraday’s Law |
| 4.2 | Lenz’s Law |
| 4.3 | Maxwell’s Equations |
| L.1 | Laboratory experiments |

Figure 7: E&M Learning Targets

The students were given weekly quizzes assessing two or three learning targets. Rather than receiving grades for the quizzes, students were given feedback and a progress marker indicating how close they were to proficiency in each topic. The progress markers are:

S – Starting out. As it says, you're just starting out. You may have some idea of the basic concepts involved but you're still far from being able to fully solve it. You likely need to brush up on some problem-solving skills (the feedback will tell you which ones) before you'll be able to tackle the problem again.

W – Working on it. You're making progress. You have a good idea of which concepts to apply towards solving the problem, but you're still not getting the correct answer. You will need to practice doing more problems of this type. Focus on the setup of the problem, the math, and physics fundamentals. You may need to go back and practice vector arithmetic, some calculus concepts, or be extra careful with executing the algebra required to solve the problem.

A – Almost there. You may or may not have gotten the correct answer, but there's still room for improvement. Your units or significant figures are off, or you may have made some small math errors. Pay close attention to the details and check if your answers are unreasonable.

G – Got it! You arrived at the correct answer with the correct units and significant figures. You've demonstrated that you can solve problems of this type, and you have a solid grasp of the fundamental physics concepts involved. If you saw another problem like this again, you'd be confident you could solve it.

Seven times throughout the semester, students were given the opportunity to reassess any learning targets not yet at "G." Three of these opportunities occurred during normal class times, and one took place during the scheduled final exam period. In addition, three assessment days were offered during which any student could reassess any target at any time throughout the day. For logistical reasons, rather than using tokens, students could decide which problems they wanted to retake on the reassessment days without needing to perform additional tasks. Many students realized after two or three tries that doing nothing between retakes was not a successful strategy, and they would come to office hours or tutoring to ensure they could meet the standard before the next retake.

At the end of the semester, letter grades were assigned based solely on the number of "G's" reached. See Figure 8.

Figure 9 shows the grade distribution for Fall 2021 and Fall 2022 in blue and the distribution for Fall 2023 in orange. Fall 2021 and 2022 were graded in the traditional way and Fall 2023 used SBG. As with Circuits I, the most noticeable difference in the grade distribution is the number of As assigned, with 40% of the students in the standards-based course earning an A compared to less than 20% in the traditionally graded courses.

| Grade Scheme | |
|---|---|
| **Grade** | **G's** |
| **A** | 20 |
| **A-** | 18 |
| **B+** | 17 |
| **B** | 16 |
| **B-** | 15 |
| **C+** | 14 |
| **C** | 13 |
| **C-** | 12 |
| **D** | 11 |

Figure 8: Assignment of Final Course Grades for E&M

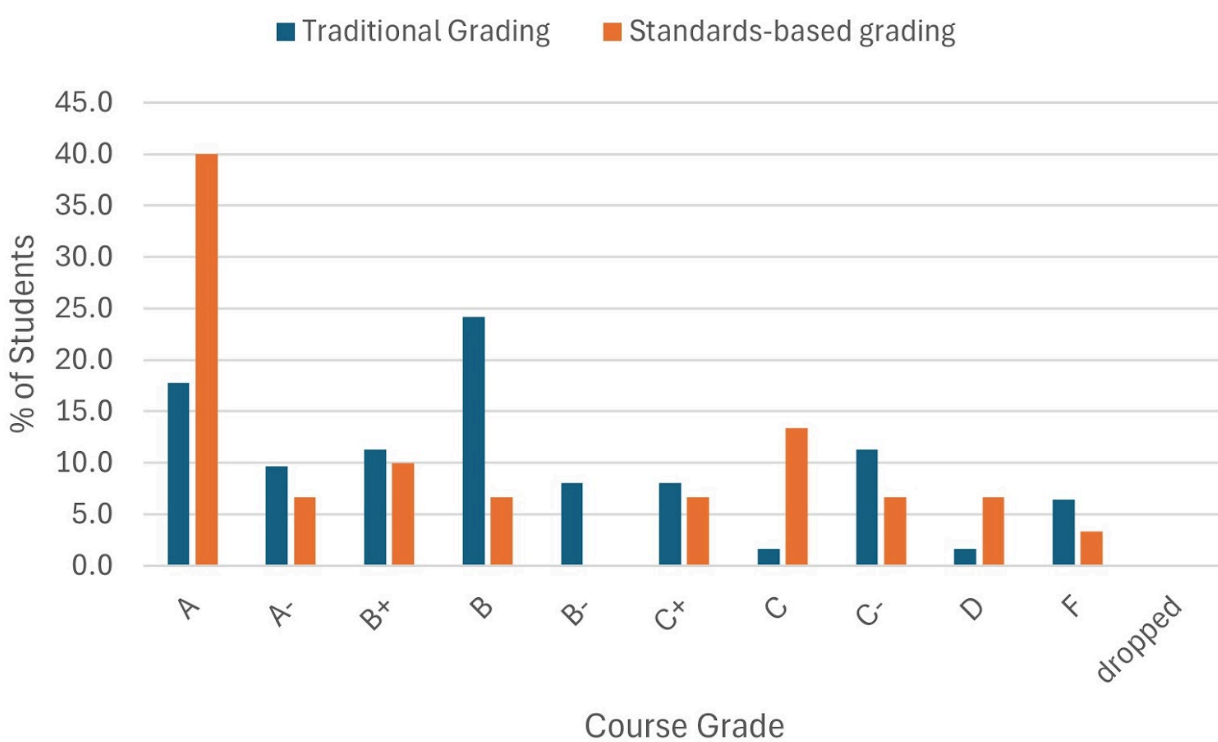


Figure 9: Comparing the E&M Grade Distribution Between Traditional and SBG Offering

The course evaluations for the standards-based course followed a similar pattern to the circuits course. Students commented that they enjoyed “the new grading system and the fact that we can retake any quiz we want” and “the clearly outlined standards and the many opportunities for reassessment.” Some students commented that the quizzes were too frequent or too difficult. One student remarked that they had two standards-based courses that semester and was taking over five quizzes a week, which resulted in assessment fatigue.

A notable impact of the shift to SBG was the nature of the discussions between the instructor and the students. Because students could retake any standard multiple times, they were interested in talking about physics instead of arguing over points. This resulted in more fruitful discussions and the development of a growth mindset.

**Hidden Complexities**

While the conversion to SBG may seem straightforward at first glance, there are hidden complexities that may not be immediately obvious. Here are some things to consider before embarking on the SBG adventure.

It is important to put thought into how the grading strategy is framed on the syllabus and in the introductory lecture to motivate the students and create the necessary buy-in. SBG can be very stressful for a student who does not take full advantage of the reassessments from the start of the semester because they do not fully understand the grading strategy.

Homework is still important when using SBG, even though it does not count toward the final grade. In a perfect world the students would be motivated to complete the homework and faculty would have time to provide feedback. In an imperfect world, compromises must be made. Both authors assigned regular homework assignments. To offset the extra time required to create and evaluate the many assessments and reassessments, homework was not collected or graded. Instead, solutions were made available during office hours or posted on the course website.

In E&M all standards (targets) were weighted equally. This simplified the grading scheme for the students and lightened the grading load for the professor. In Circuits I an emphasis was put on “basic” standards which seemed unnecessarily restrictive to some students, yet provided guidance to the struggling students on where to focus their studies.

One of the most difficult aspects of SBG is scheduling the reassessments. When and how often assessments will be offered should be given careful consideration. A schedule was created for both E&M and Circuits I, setting aside time for periodic in-class assessments and reassessments. This allocated time proved to be woefully insufficient by the middle of the semester. Reassessments in E&M spilled over into office hours. In Circuits I unused time in the corresponding lab course was used for additional reassessments.

Another task that can be easily underestimated is the time it takes to create problems for the assessments and various reassessments. More than 150 problems were created to allow any student to retake any standard during any reassessment. There are also challenges in printing and distributing the right problems to the interested students.

Similarly, the number of standards a student may reassess at any one time must be considered. If a student attempts to reassess too many standards at once, they may fail to demonstrate proficiency in *any* standard because the time they have to study for each standard will be too small. It proved manageable for students to reassess up to four standards at once.

**Conclusions**

The implementation of Standards-Based Grading (SBG) in Circuits I and Electricity and Magnetism during Fall 2023 marked a transformative shift in assessing student achievement. By prioritizing mastery over point accumulation, SBG fostered meaningful learning, persistence, and deeper engagement. A comparison of grade distributions highlighted its success, with higher proportions of students earning A's and a significant reduction in drop and fail rates.

Student feedback reinforced the value of SBG, praising its emphasis on individual progress and opportunities for reassessment. While some complexities emerged, they can be mitigated through thoughtful course design, ultimately creating a more authentic and effective learning environment.

Although we cannot yet measure post-requisite success due to the limited adoption of SBG at our university, our hope is that our experience encourages broader implementation. Widespread adoption would allow for deeper analysis of long-term student outcomes, providing further evidence of SBG's impact.

By shifting the focus from grades to mastery, SBG provides a clearer reflection of students' abilities, measuring success through progress, problem-solving, and resilience. This approach not only reduces dropout rates but also cultivates a classroom culture where effort and growth are celebrated. In doing so, we prepare students not just for academic success, but for the challenges they will face beyond the classroom—equipping them with the skills to adapt, persist, and thrive.

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