6-15-2014

Standards-Based Grading in a Fluid Mechanics Course

Scott L. Post
Bradley University

121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014
Paper ID #8417

Standards-Based Grading in a Fluid Mechanics Course

Dr. Scott L Post, Bradley University

Scott Post received his Ph.D. in Mechanical Engineering from Purdue University. He is currently an Associate Professor at Bradley University in Peoria, IL. He has previously worked as an Assistant Professor at Michigan Technological University. He has also been a summer Faculty Fellow at NASA Dryden Flight Research Center, and a Visiting Erskine Fellow at the University of Canterbury in Christchurch, New Zealand.

Standards-Based Grading in a Fluid Mechanics Course

Abstract

Standards based grading is a formal assessment mechanism that tests for student achievement of specified learning objectives, or standards. Standards-Based-Grading has been gaining in popularity in K-12 education, and also has been seeing increased use in higher education. With increased pressure from ABET to measure achievement of student outcomes, Standards-Based Grading provides a method to do that within the traditional course setting without having to generate a separate set of data outside the normal course grading. This paper describes how Standards-Based Grading was implemented in a junior-level fluid mechanics course that included both lecture and laboratory components. A total of nine learning objectives were specified for the course. These learning objectives are: calculate fluid thrust forces, calculate aerodynamic forces, solve pipe flow problems, select a pump for a system, select a flowmeter for a system, write a computer program to solve transient fluids problems, write a professional quality lab report, acquire and analyze laboratory data, and be a valuable member of team that successfully completes a project. The learning objectives can be mapped to ABET student outcomes. In this implementation of Standards-Based Grading, all assessments are done on a pass-fail basis. That is to say, there is no partial credit given. Once a student passes an assessment, usually given in the form of a quiz, on a given learning objective, it is assumed the student has mastered that concept and is not tested on it again. Students are allowed to re-test on particular objectives if they do not pass them on the first try. The final exam serves as a last chance for students to pass any objectives they did not complete earlier in the semester. Student achievement of the learning objectives is compared to that in previous semesters where a traditional grading scheme was used, and grade distributions are also compared.

Introduction

What is the purpose of grading? Is it to motivate, punish, and sort students? Or is it to document student progress, provide feedback to the student, and to inform instructional decisions?[1] As more and more progress is being made towards implementing active learning and cooperative learning in higher education classes, it is worthwhile to re-examine grading procedures to see if they are appropriately supporting active learning strategies. The efficacy of active learning activities[2] and cooperative learning strategies[3-5] has been demonstrated convincingly in the literature.

So how should grading being conducted, in light of the research showing the efficacy of active and cooperative learning? We can broadly divide grading strategies into two types of assessments: formative and summative. Formative assessments can be thought of as a loop, where "students and teachers focus on a learning target, evaluating current student work against the target, act to move the work closer to the target, and repeat."[6] Formative assessments provide feedback not just to the student, but also to the instructor. They inform the instructor of which material the students are having difficulty with and should be covered further. Summative assessments are typically performed only at the end of a particular instructional module.[7] In summative grading, a weighted-average of student scores on a diverse set of assignments is added together to arrive at a final grade that is supposed to assess students' performance in the course. The traditional method to assess student performance in STEM courses is a summative score-based grading system.[8]

In summative grading, it is common to measure student achievement on an assignment based on how many "points" they obtain, but the point is not a well-defined unit of measurement. Its value is not constant (such as a Pascal or a Newton) nor can it be easily linked to other measurements (such as a dollar or euro). The point is an arbitrary unit of measurement. Its value changes from instructor to instructor. Unless an instructor religiously uses rubrics, the value of a point may even change from semester to semester for the same instructor. The use of a 100-point grading system gives the illusion of precision, but grade cut-off scores are not usually linked directly to mastery of specific subject matter or skills.[9] While the 90/80/70 grading scale is popular, it is far from universal, and there is not agreement on how to translate points to grades. In addition there is the issue of how to relate points to learning objectives and measures of student learning. "Validity, sampling adequacy, item quality, marking standards, marking reliability and measurement error generally are all significant variables that produce an underlying softness in the basic data that typically goes unrecognized."[9] In fact, "research indicates that the score a student receives on a test is more dependent on who scores the test and how they score it than it is on what the student knows and understands."[10]

The goal of Standards-Based Grading (SBG) is to measure a student's progress towards achievement of a standard, and thus to show what students are able to do. Students have multiple opportunities to demonstrate their achievement of the standard, and the final grade is based on the student's overall mastery of the standard by the end of the term, not a weighted average of material throughout the term. Standards-Based Grading can also help instructors to more clearly communicate to the students exactly what they will be expected to know and demonstrate on assessments. SBG aims to establish strong connections between assessments (and grades) and course objectives and provide a tool for program assessment.[8,9] The four main challenges facing an instructor who wishes to use SBG are:[9]

- Coming to grips with the concept of a standard
- Determining how to set standards
- Communicating standards to students and colleagues
- Becoming proficient in the use of standards

SBG was first developed in the 90s.[8] Very little information has been published on the use of Standards-Based Grading (SBG) in engineering courses. There was one paper published at a regional ASEE conference on the use of SBG in a materials science course.[11] General publications on SBG include the book by Marzano.[7] Sadler[9] puts forth the arguments for why students should be evaluated using Standards-Based Grading as:

1. "Students deserve to be graded on the basis of the quality of their work alone, uncontaminated by reference to how other students in the course perform on the same or equivalent tasks, and without regard to each student's previous level of performance."
2. "At the point of beginning a course of study, students deserve to know the criteria by which judgments will be made about the quality of their work."

Motivation for Standards-Based Grading

Take for example, a problem to calculate the force necessary to hold a fire hose in place, typical of what might be on a quiz or exam in an undergraduate fluid mechanics course:

> A fires hose of 3" diameter is attached to a nozzle of diameter 1.125". Water flows through the nozzle at 250 GPM, directed to the right. The pressure at the point where the nozzle attaches to the 3" hose is 50 psig. What is the force (in lbf) a fireman would have to exert to hold the nozzle stationary?

Say this problem was given on a quiz and was worth 10 points. How many points should an instructor deduct for each of the following student mistakes?

- Sign error
- Error entering numbers into calculator
- Forgot factor of ½ in the Bernoulli equation for dynamic pressure
- Left out the pressure force entirely
- Used air density instead of water density
- Unit conversion error, involving any of the following – 12 in = 1 ft, 1 min = 60 s, 1 Gal = 231 in^3, 1 psi = 144 psf, 1 lbf = 32.2 lbm ft/s^2
- Incorrect number of significant digits

There would be a wide range of answers from different instructors on how many points to deduct for each mistake. Among other objectives, Standards-Based Grading aims to establish a framework that provides more consistent evaluation of student achievement from instructor to instructor.

Siniawski et al.[11] report on the use standards-based grading in a sophomore mechanics of materials course. Since this was the first published use of SBG in a university engineering course, they had the goals to:

1) obtain insight in how to best implement standards-based grading in an undergraduate STEM course
2) obtain a sense of how students respond to standards-based grading.

A total of 12 specific objectives were used in the Materials course. Example of these objectives include:

1. Understanding the effects of forces and deformations within an elastic body.
2. Analyzing the three fundamental patterns of deformation: axial, torsion, and bending.
3. Determining deflection and the tendency for failure when multiple patterns of deformation occur in combination

For Objective #1, students were tested on their ability to perform the following tasks:

1A. Analyzing the normal stress, strains, and deformations of a body composed of elements
1B. Understanding the elastic properties, stress limits, and stress-strain responses of materials
1C. Analyzing shear stresses and strains of a body composed of elements

Evaluation of student progress level of meeting the standards was done on a 4-point scale:

+ Strong performance
✓ Appropriate development
✓- Approaching appropriate development
N Needs practice and further support

And final grades were determined using the following criteria:
A The student has demonstrated appropriate development on all course objectives and strong development on some objectives.
B The student has demonstrated appropriate development on all course objectives.
C The student has demonstrated appropriate development on the majority of the course objectives.
F The student has failed to demonstrate appropriate development on one-half of the course objectives

Siniawski et al. allow students to request a reevaluation of course objectives by turning in additional homework problems.

Implementation

Since the fluid mechanics course was primarily a calculation-based course, it was decided to use a 2-point, or binary, scale in assessing students' completion of objectives, rather than the 4-point scale used in the material science course[11] that was more concept-oriented. Sadler writes that many "educational outcomes cannot be assessed as dichotomous states, although the competency assessment movement predominantly adopts that perspective."[9] Because most of the objectives for this fluid mechanics course were constructed in terms of students' ability to perform calculations, it was deemed appropriate to use the binary scale for this course. In other words, all objectives were graded on a pass/fail basis, with no partial credit given. An objective is considered to be passed when the student obtains a numerical answer within +/-2% of the instructor's calculated value, reported to 3 significant digits, and a valid solution technique is used. Objectives were typically assessed with 30-minutes quizzes, and on the final exam students could attempt any objectives they had not yet passed. The relationship between student achievement of course objectives and their final grades is as follows:

Completing all 9 course objectives results in a grade of A.
Completing 8 of 9 course objectives results in a grade of B.
Completing 7 of 9 course objectives results in a grade of C.
Completing 6 of 9 course objectives results in a grade of D.
Completing 5 or fewer course objectives results in a grade of F.

Bradley University uses a whole letter grading system. A grading system that allows the assignment of +/- marks to the letter grades would provide more options in relating objectives to grades. The nine Course Objectives are:

You must be able to identify, formulate, and solve engineering problems, including:
1) Calculate fluid thrust forces
2) Calculate aerodynamic drag forces

3) Solve a pipe flow problem
4) Finding the operating point for a pump-pipe system and select a suitable pump
5) Calculate fluid flow rates and select suitable flowmeter instrumentation for a given application
6) Use modern engineering tools (MATLAB) to compute simulation of transient fluids problems

Other course objectives include:

7) Communicate effectively to produce professionally-quality technical reports
    a. Free from spelling & grammar errors and typos
    b. Professionally formatted with clear and consise communication
    c. Figures & Tables are used to convey information effectively
8) Design and Conduct Experiments, and Analyze and Interpret Data
    a. Attend all labs
    b. Complete all necessary measurements
    c. Complete all analysis of data (as shown in Lab Reports)
9) Be a valuable member of a team that successfully completes a group project. This includes:
    a. Providing evidence of your tangible contributions to the team
    b. Receiving an acceptable rating from your teammates (2.5/4.0)
    c. To demonstrate team success, your team must:
        i. Answer at least 70% of the homework problems correctly
        ii. Launch a glider that meets the project design critera (defined on the next page)
        iii. Submit professional-quality reports for your group work

Some of the quiz problems that were given for Objectives 1-6 are:

1. You are designing a jet pack system that uses a high-power air compressor to shoot a jet of air downwards that propels the user upwards into the air for short times. If the total weight of the pilot, compressor, and attachments is 400 lbf, and the outlet nozzle is 4" in diameter, what velocity of air is needed at the exit?
2. A car is going down the highway at 65 mph and has a drag coefficient of 0.35, with an effective height of 52", width of 72", and length of 189". What is the power that goes to overcoming aerodynamic drag?
3. Water flows through a horizontal stainless steel pipe (ε = 0.025 mm) of 8 cm diameter and length 50 m. The pressure differential across the pipe is 75.0 kPa. What is the velocity of water in the pipe?
4. Water flows through a 25 m of a horizontal hydraulically smooth pipe (e ~ 0) of 5 cm diameter at a velocity of 10.4 m/s. Select the pump model from the attached chart that can satisfy these requirements.
5. Air at temperatures from 40 to 100 °F flows through 1/2" tubing at velocities up to 125 mph. Select the flowmeter <u>with the best accuracy</u> to monitor the air flow rate from the attached catalog sheet. What is the expected accuracy of the reading (in SCFM)? Note: SCFM = Standard Cubic Feet per Minute (Flowmeter Selection Guide from Omega.com used).

6. A spherical ball ($C_D = 0.45$) of diameter 35 cm and mass 0.17 kg is thrown downwards, released at an initial height of 20.0 m with an initial downwards velocity of 10.0 m/s. What is its velocity when it hits the ground?

Generally two chances were give to pass each objective. In the case of low student performance, a third opportunity was added, such as for the MATLAB quiz. This is one of the advantages of Standards-Based Grading, as it provides real-time feedback to the instructor. In the past where a point system was used, if a student made a mistake on a 10-point quiz, the author might subtract 1 point for each calculation mistake and 2 points for each conceptual mistake. And so the spreadsheet might show a class average of 80% on a particular quiz, which would like good progress, but the 80% score could mask the fact that only a small number of students in the course were able to complete the problem correctly in its entirety.

Teamwork is an important part of the course. The class is divided into teams of 3-4 students each for the labs, project, and homework. The instructor selects the teams. There is a great deal of literature showing that students learn more effectively in teams than they learn on their own.[4,5,12,13] At the end of the semester students were also allowed to evaluate their teammates to encourage accountability. Among their other findings, Felder and Brent[12] recommend that team sizes are 3-4 students, to collect one assignment per group, to have the instructor select the groups, and not to assign grades on a curve, so that students are given incentive to help each other. The goal is to create positive interdependence and individual accountability.

A group design project to design, build, and fly a foam glider was given to the teams. The glider project was previously described in a conference paper.[14] Each team's glider is built from a 2 ft by 4 ft piece of 2" thick insulating foam. Students must choose an airfoil shape (such as NACA 4-digit series) and build a solid model in AutoCAD or Pro-E, and then generate the g-code to cut the wings from the foam on a 3-axis CNC machine. The glider is hand-launched on a basketball court. In the past the project was graded on a relative basis, with scores proportional to the distance the glider travelled divided by the longest glide distance anyone in the course achieved. This time, to be consistent with the standards-based grading framework, an objective of a glide distance of 32.8 ft (10 m) was selected. All groups whose glider travelled at least that distance would pass the objective. This distance was selected from the median of the glide distances the previous two times the glider project was used. In addition, a prize was offered to the team whose glider went the furthest (typically candy, cookies, or gifts from the $1 store). It was observed that by having all the students trying to meet an absolute, rather than a relative objective, it encouraged more collaboration and cooperation between the teams. In particular, teams were willing to help each other learn to use the CNC machine for making the wings of the gliders.

Objective Results

The final results of student achievement of objectives for the semester are shown in Table 1. It can be seen that on the calculation problems the pass rate was quite high, as desired. On some of the objectives the pass rate on the initial assessment was sometimes quite low, but by the final exam 90% pass rate was typical. For example, for the Thrust force problem, only 20% of the students (11/55) passed on the first try, so the solution to the problem was reviewed in class along with common student mistakes, a second quiz was given, and 68% (30/44) passed, bringing the overall class pass rate to 41/55 = 75%. On the Final Exam 11 of the remaining 14 students passed, bringing the class final pass rate to 52/55 = 95% on the thrust force calculation objective. 13 of the 14 groups (93%) achieved the distance for the glider objective. 11 of the 14 groups (79%) completed at least 70% of the homework problems correctly to pass the homework objective. Homework problems were all calculation problems and also graded on a pass/fail basis. 85% of the students were given an "acceptable" rating by their teammates in the end-of-semester peer evaluations (score of at least 2.5 on a 1-4 scale). The class-averaged GPA of 2.64 was within the range of grades given in previous semesters of the course.

Table 1: Pass rate of individual learning objectives in Fluid Mechanics Course:

Thrust Force	95%
Aerodynamics	93%
Pipe Flow	89%
Flowmeter Selection	87%
Pump Selection	93%
MATLAB 1D transient	87%

Compared to previous semesters, the percentage of students who could correctly work the problems was much higher. The instructor has always asked one of the three classic pipe flow problems on the final exam (find the pressure drop, find the velocity, or select a pipe diameter). Table 2 shows the historical data for how many students could answer the question correctly on the final exam. The data is not perfectly comparable, since a different type of problem is asked each semester, and students generally do better on the find the pressure drop problems, since the other two types of problems require iterative solutions that their programmable calculators cannot solve directly. With the SBG method used in fall 2013, 89% of the students were able to solve a pipe flow problem either on the quiz or the final exam. Also on previous final exams the percentage of students correctly answering an aerodynamics question varied from 30 to 61%, compared to 93% answering correctly with the Standards-Based-Grading method.

Table 2: Percentage of students who could correctly answer a pipe flow problem on the final exam.

Course Semester	Spring 2010	Fall 2010	Spring 2011	Fall 2011	Spring 2012	Fall 2013
% Correct	45%	13%	48%	32%	57%	89%

Survey Results

The same two questions as in the paper on SBG in the materials science course[11] were asked to the students in an end of semester survey. 40 of the 55 students in the class responded. Siniawski's results indicated that the vast majority of the students agreed that Standards-Based Grading is more conducive to learning (89%) and that they prefer standards-based grading (86%). The results of a similar survey in the current work were much less positive. Students were asked the following two questions:

1. Is the standards-based grading system more conducive to learning than traditional, summative score-based grading?
2. Do you prefer standards-based grading to traditional grading?

For question #1 only 38% of the students responded with "Strongly Agree" or "Agree" on a 5-point Likert scale, and on question #2 only 28% responded positively. The student comments that were negative typically focused on their concerns for their grades. Examples are:

- "This system is not fair for when some calculator errors occur. All the work could be correct for the problem but if the answer is wrong there is no credit given."
- "I feel that it pushes students to complete the bare minimum to pass."
- "it's a lot more stressful than traditional grading. An entire letter grade depends on one question so I'm terrified of making a small mistake"
- "Lack of partial credit is very demoralizing, especially when a simple algebra mistake is the difference between a pass and a fail"

There were also some favorable student comments:

- "I think it's a great idea. I wish there were more opportunities to pass them, however."
- "The standards grading system has made me actually study for quizzes pretty hard because they are each worth so much."
- "It makes the goals required much more straightforward. It also eliminates the dependency of your grade on how well everyone else does or the professor's grading practice."

Since this is the first time the students were encountering SBG at Bradley University, it may have been uncomfortable for them to adapt to a grading system to which they were not familiar and unprepared to encounter. An important difference between the current work and that of Siniawski et al. is that they used a 4-point scale to assess student completion of objectives, while students complained primarily about the 2-point scale used in the current work.

Conclusions

This paper presents one of the early attempts at Standards-Based Grading in an undergraduate engineering course. The use of Standards-Based Grading in an engineering course rests on the assumption that "Completion of each task (even after multiple attempts, if necessary) is taken as evidence of achievement of the relevant objective."[9] While there are potential issues with any grading system, it is believed that SBG provides a better assessment of student achievement than traditional summative-score systems that use an arbitrary point system. SBG also provides better feedback to the instructor. Further advantages of SBG are that it can even reduce time in grading compared to traditional score-based systems,[8] and can also be directly used in showing student achievement of performance indicators of Student Outcomes for ABET without the need for extraneous bookkeeping.

Bibliography

1. Wormeli, R. (2006). Fair Isn't Always Equal: Assessing and Grading in the Differentiated Classroom. Stenhouse. Portland, Maine.
2. Prince, M., (2004) "Does Active Learning Work? A Review of the Research," *Journal of Engineering Education*, 93(3), pp. 223-231.

3. Smith, K.A., (1995) "Cooperative Learning: Effective Teamwork for Engineering Classrooms," Frontiers In Education Conference Proceedings. Atlanta, GA.
4. Johnson, D. W., Johnson, R. T., and Smith, K. A. (1991) Cooperative learning: Increasing college faculty instructional productivity." ASHE-ERIC Report on Higher Education. Washington, DC: The George Washington University.
5. Johnson, D. W., Johnson, R. T., and Smith, K. A. (1991) Active learning: Cooperation in the college classroom. Edina, MN: Interaction Book Company.
6. Brookhart, S. and Nitko, A. (2007) Assessment and Grading in Classrooms. Pearson Education.
7. Marzano, R.J. (2010) Formative Assessment and Standards-Based Grading. Marzano Research Library. Bloomington, IN.
8. Carberry, A.R., Siniawski, M.T., and Dionisio, J.D. (2012) Standards-Based Grading: Preliminary Studies to Quantify Changes in Affective and Cognitive Student Behaviors. Proceedings of the 2012 IEEE Frontiers in Education Conference (FIE).
9. Sadler, D. R. (2005) Interpretations of criteria-based assessment and grading in higher education. *Assessment & Evaluation in Higher Education*. Vol. 30, No. 2, pp. 175–194.
10. Marzano, R.J. (2006) Classroom Assessment and Grading that Work. Association for Supervision & Curriculum Development.
11. Siniawski, M.T., Carberry, A.R., and Dionisio, J.D. (2012) Standards-Based Grading: An Alternative to Score-Based Assessment. Proceedings of the ASEE Pacific-Southwest Regional Conference.
12. Felder, R.M., and Brent, R. (1994) "Cooperative Learning in Technical Courses: Procedures, Pitfalls, and Payoffs." Report to the National Science Foundation. ERIC Document Reproduction Service No. ED 377 038.
13. Heller, P., and Hollabaugh, M. (1992) "Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups." *American Journal of Physics,* 60(7), pp. 637-644.
14. Post, S.L., Seetharaman, S., and Abimannan, S. (2009) A Design-Build-Test-Fly Project Involving Modeling, Manufacturing, and Testing. ASEE Annual Conference. AC 2010-233.