Exam as a Positive Experience for Both Students and Teachers

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ABSTRACT

New instructors know that the exams that they give students in their classes should serve many functions, in addition to evaluating the students' performance for the purpose of assigning a letter grade at the end of the term. For example, they know that exams ought to promote learning by stimulating teachers to clarify learning objectives, by motivating students to study, and by providing timely feedback to students as to whether they have or have not accomplished their learning objectives. But, what is usually not obvious to new faculty is *how* to construct exams to serve these additional functions effectively. This paper presents an innovative technique of constructing effective exams that satisfy the multiple functions of exams *and*, at the same time, minimize the frustration often associated with grading. These techniques are based on Bloom's taxonomy of educational objectives, Perry's model of intellectual development, and other pedagogical models. Examples of exam questions from thermodynamics are presented for illustration purpose. Also presented are the techniques and tips which new faculty can use when returning exams in order to emphasize and focus on the constructive aspects of exam. A model exam-feedback-sheet is also introduced. These techniques can improve the overall exam experience for students and teachers.

INTRODUCTION

Making and grading exams are perhaps the most dreaded parts of teaching for teachers. Grading exams for hours can be very boring and even agonizing if the students' solutions to exam questions are either unorganized or only partially legible. Furthermore, when the exam is one of problem solving, which often is the case in engineering courses, it could be extremely frustrating to find a point of divergence of the students' solutions from the model solution. Also, it is taxing to maintain a high degree of consistency in scoring the exam, especially in the case of a class with a high student enrollment. Often the reward of conscientious grading is the endless argument about partial credits from students after the exams are returned. The students dislike taking exams as much as the professors dislike grading them. Consequently, both faculty and students look at exam as a "necessary evil", something to be avoided if at all possible. Some teachers resort to no-partial-credit policy, others to either very hard or very easy exams to facilitate scoring. Some others experiment with group exams and optional exams.

Even an experienced teacher cannot help feeling dejected when the entire exam experience is reduced to a comment "Whadija get?" from students.[1] One can see that these negative perceptions and experiences of exam have not changed much from earlier decades.[2] This may be because teachers may be told about what exams *should* be, but the knowledge of *how* to construct such an exam is not readily available to them. Obviously, a tip about how to construct an exam invariably would involve giving specific examples. Since the examples have to be content specific, such a tip may lack universal significance. Therefore, what I intend to provide in this paper is a theoretical basis for constructing effective exams, and then give several examples from an introductory course in thermodynamics as illustration. It is hoped that the new faculty would be able to create exams in their own fields after reading this paper.

I will review the functions of the exam first. Then, I will analyze the process of the exam in several sequential stages to explain that the different functions of the exam can be satisfied at different stages of exam. Finally, I will focus on the making of effective exams.

THE ANATOMY OF THE EFFECTIVE EXAM

The functions of the exam.

Ebel[3] identifies four learning objectives that exams can accomplish: 1) stimulate teachers to clarify the objective, 2) motivate students, 3) direct efforts of teachers and students toward attainment of essential achievements, and 4) provide effective learning exercises. That is, exams can bring a *focus* to both teaching activities (clarification of learning objectives) and learning activities (the direction of efforts to the stated learning objectives), and *motivate* students to learn by providing them with a suitable challenge (doing exercises). Implied in the functions of these two objectives — focus and motivation — is the function of *evaluation*, which has three customers: evaluation should provide feedback to students, allowing them know how well they are achieving the learning objectives and what weakness exists, if any. It should also provide feedback to teachers, allowing them to gauge how well the class as an aggregate is meeting the learning objectives, with what part of the lecture the class is having difficulty, if any, and which individual student in the class needs special attention. The third customer, who usually receives the evaluation of students in the form of a grade, is the people like a parent, financial aid officer, and potential employer who uses the grade for various purposes. I would like to recapitulate the above functions in five headings: focus, motivation, feedback, evaluation, grade. (I chose these headings for the sake of convenience only: teachers do the *evaluation*, students get *feedback*, and the others only get to see the *grade*). The function of focus needs the learning objectives of the course stated explicitly. The function of motivation needs the element of suitable challenge.[4] The function of evaluation needs the notion of fairness and meaningfulness (in the context of stated learning objectives). The function of feedback needs to be prompt and useful (that leads to accurate assessment and corrective action). And, the function of grade needs to subscribe to a shared notion.[5]

It is my stipulation that an effective exam should and *can* achieve all five functions. It naturally leads to the question "how can one make an exam that would achieve all five functions?" However, this question is ill-posed because it presumes that an exam is an entity, whereas it is important to view an exam as a process and *making an exam* as a step or a stage. It is my second stipulation that one needs to look at the entire process in order to achieve all five functions. If a teacher focuses only on one of the stages, then the discussion on making effective exams would focus around tricks, situation-specific techniques, and other peripheral matters. For example, a debate can be generated ad infinitum on things like whether or not open-book exams are better than closed-book exams.[6], [7] In the next section, the process of exam is briefly reviewed.

The process of exam

The process of exam can be analyzed in seven stages: the planning, writing or making, administering, scoring, returning, following up, and giving the final grade. Each step requires careful considerations. In general, the considerations fall in one of three categories: procedural (how often, when, where, who, and how long), technical content (what, and how), and philosophical (why). Although different considerations dominate at different stages, one should always consider all three categories at all stages of exam. For example, in returning the exam, the following considerations should be entertained: Who should return the exam, when should (if I decide to do it) I do it, how long should it take, what should be discussed or commented during the time, and how should I conduct the process. And, the question "why" should accompany each consideration. One realizes that the above considerations are not as trivial as it first appears. In my opinion, exams should be returned immediately (to effect timely feedback), the discussion about the exam should take a good part of the class time (to effect useful feedback), the atmosphere must be positive (to effect motivation), and the attention placed on content and not on the grade (to effect focus). In the following, the discussion will be limited to the second stage, the making of effective exams.

Typical engineering exam problems

I believe a typical engineering exam problem resembles that of typical problems found in textbooks. Although some textbooks have been adding "design" problems recently, an overwhelming majority of engineering problems in textbooks are still one of the format "Given A, B, C, and D, find E and F," as illustrated in Example 1. It shows an exercise problem from a popular textbook in Thermodynamics. Since the explicit relationships among A, B, C, D, E, and F are usually available somewhere in the textbook, the solution to this type of problem involves three basic steps: identifying the relevant relationships, "plugging" appropriate numerical values, and then "chugging" an answer by performing mathematical manipulations. Some textbook problems are merely complex versions of this format, requiring several such steps to be taken either sequentially or in parallel.

It is appropriate to have this type of problem as exercise problems at the end of a chapter in a textbook, for they serve a legitimate educational purpose. It would also be effective as exam questions, if the sole purpose of the exam is to provide *focus* and *challenge*. However, this type of problem is not effective in serving the other functions of exams, *feedback* and *evaluation*. To understand why this type of problems is inappropriate, it is imperative to appreciate what actually goes on during taking an exam from the students' point of view.

To successfully solve an engineering problem, students must have the knowledge of subject matter, know the necessary background material (usually math, physics, and other prerequisite course material), the good problem solving skills (including being systematic and managing the time wisely), and the ability to perform under stress.[8] It is this multifaceted requirement that makes a proper interpretation of an exam score very difficult for students and teachers alike. Suppose a student scored 17 points out of 25 on an exam question. The score indicates that the student is lacking something, but it is often not clear as to what it is that the student is lacking. The exam may be totally incapable of diagnosing the cause of the poor score. Consequently, teachers often hear a student saying that "I knew the material, but just did not perform well" or "I just made *silly* mistakes" to explain the less than perfect score.

Effective engineering exam problems

In view of the above discussions, I would like to propose making exam problems based on Bloom's taxonomy on educational objectives[9] and Perry's theory of intellectual development.[10] It starts with the realization that there are hierarchical educational objectives, and that the students at different stages of development have different levels of competence. The shortcoming of the typical exam problems, as shown in Example 1, is that students are expected to operate over the entire spectrum of educational objectives: students need to recognize the given information (basic knowledge), realize the meaning of the information (comprehension), apply relevant principles (application), know how to visualize the processes (analysis), integrate all information together (synthesis), and make valid assumptions (judgment and interpretation). This may be an unrealistic expectation either for lower division students or at the early part of the course. I would like to suggest that teachers communicate a clear educational objective to students, and that they construct exam problems appropriate for testing the level of attainment of the stated educational objective.

Example 2 tests the students' mastery of basic knowledge. This problem is straightforward in the sense that it is primarily either you-know-it-and-get-it-right or you-don't-and-get-it-wrong type of question. No assumption needs to be made and no deep appreciation about the nature of thermodynamic state at various points is needed. The same diagram can be used to test the students comprehension of the knowledge as shown in Example 3. In this example, neither knowing the diagram alone nor knowing where to find the property values alone is no longer sufficient to solve the problem. Here, students need to *understand* how the graphical representation of various thermodynamic states are related to the tabular data, and how the states are inter-related.

In Example 4, a higher educational objective of application is tested. This problem is different from the typical exam problems in Thermodynamics only in that the numerical values for the properties (the h's) are given a priori. But, this is an important difference. In the absence of the numerical values, students would take the majority of the exam time in looking up the values in the Thermodynamic Tables. Often students make "silly" errors during either evaluation or transcription. The consequence is that students would be wasting time trying to locate the source of error instead of concentrating on applying concepts to solve the problem. By providing the needed information, the exam tests the ability of students to apply the general concepts to a particular situation and not on their ability to evaluate properties. Certainly, there are situations in which these two abilities are intertwined. However, assuming the students have adequate practice in solving exercise problems from the textbook, the other functions such as feedback should be valued in an exam.

Example 5 deals with the educational objective of synthesis. The figure in the example shows a system with two distinct sub-systems. The sub-system on the right hand side is a typical flow device which the students in Thermodynamics are usually asked to solve several dozen times. The sub-system on the left hand side is a typical cyclic device, again very familiar to students. A new situation emerges when these two systems are integrated, forcing the students to synthesize the knowledge base and understanding which usually are introduced to them linearly and in discrete packets.

Finally, Example 6 deals with the highest level of educational objective, the evaluation. In this example, a solution to the problem is provided and the students are asked to annotate the solution steps with the implied assumptions and their justifications. A student who makes a correct decision either for wrong reasons or based on experience of solving similar problems would have great difficulty in answering this problem. This problem forces the students to be explicitly conscious of every decision they make in solving a problem and to be able to assess their validity critically. Any deficiency in students' ability in these aspects can be quickly identified through this type of problem.

Exam feedback sheet

An integral part of making an exam is the making of an exam feedback sheet. The Example 7 illustrates one for Thermodynamics. This feedback sheet achieves several purposes. First of all, it provide a *focus* for the students to direct their attention to the learning function of exam, after an obligatory initial emphasis on the exam score when the exams are returned. It prevents the students from concentrating their energy on futile debates regarding the appropriateness of exam problems or the fairness of partial credits. Secondly, the sheet provide useful *feedback* to students by explicitly identifying the area of weakness. Thirdly, it *motivates* the students to improve by either suggesting corrective action or requiring them to formulate strategy for improvement.

Once the feedback sheet is constructed, it takes only a few moments to provide customized feedback to individual students. However, their effect is tremendous because the students view the customized feedback sheet to be an example of the teacher being "concerned about student", which is the top core characteristic of effective teacher.[11]

SUMMARY

The functions of an exam are to promote learning by stimulating teachers to clarify learning objectives, to motivate student to study, to provide timely feedback to students as to whether they have or have not accomplished their learning objectives, to evaluate the students' progress, and to assign a letter grade at the end of the term. These functions can be satisfied in the process of exam, which includes planning, making, administering, scoring, returning, following up, and giving grades. This paper focuses on the making stage of the exam and presents an innovative technique of constructing effective exams that satisfy the multiple functions of exams based on Bloom's taxonomy of educational objectives, Perry's model of intellectual development, and other pedagogical models. These techniques can improve the overall exam experience for students and teachers.

REFERENCES

[1] M. McMullen-Pastrick and M. Gleason, "Examinations: Accentuating the Positive," *College Teaching*, Vol. 34, No.4, p.135, 1987.

[2] W. P. Strandberg, "Design of Examinations and Interpretation of Grades," *Higher Education in Engineering and Science*, McGraw Hill, 1963.

[3] "Using Examinations to Promote Learning," in *The Two Ends of the Log*, Ed. R. M. Cooper, p.52, University of Minnesota Press, Minneapolis, 1958.

[4] M. Csikszentmihalyi, *Beyond Boredom and Anxiety*, The Jossey-Bass Publi., San Francisco, 1977.

[5] R. Sprinthall and N. Sprinthall, *Educational Psychology: A Developmental Approach*, 3 ed., Addision-Wesley, 1981.

[6] T. Liska and J. Simonson, "Open-Text and Open-Note Exams," *The Teaching Professor*, Vol. 5, No. 5, p. 1, May 1991.

[7] Open-Text and Open-Notes Exams: More Benefits!" B. Leung, *The Teaching Professor*, Vo. 5, No. 5, p. 6, October 1991.

[8] R. Biehler and J. Snowman, *Psychology Applied to Teaching*, 4 ed., Houghton Mifflin, Boston, 1982.

[9] N. Gronlund, *Stating Objectives for Classroom Instruction*, 2 ed., Macmillan Publ., N. Y., 1978.

[10] P. Wankat and Oreovicz, *Teaching Engineering*, MacGraw Hill, N. Y., 1993.

[11] K. Cross, "On College Teaching," *J. of Engg. Ed.*, Vol.82, No.1, p.9, 1993.

BIOGRAPHY

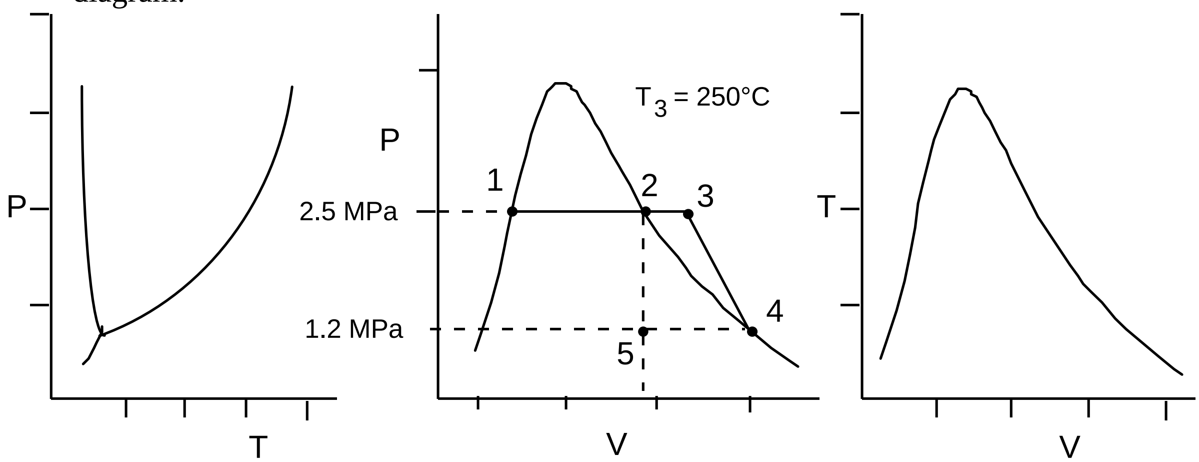
DR. PECK CHO is an Associate Professor in Mechanical Engineering, the Director of Engineering Learning Center, and the Interim Director of the Innovation Center at MTU. His is currently interested in promoting creativity and industry perspective in engineering curriculum. He has received numerous awards from MTU, the State of Michigan, SAE, ASEE, and NSF for his work in teaching and research. He gives workshops on teaching and learning techniques.

Example 1: A typical engineering problem

Steam is contained in a cylinder fitted with a piston at 0.1 MPa and 250°C, at which point the volume is 500 L. The steam is now compressed slowly in an isothermal process until all of the steam condenses. Estimate the work done (in kJ unit) during the process.

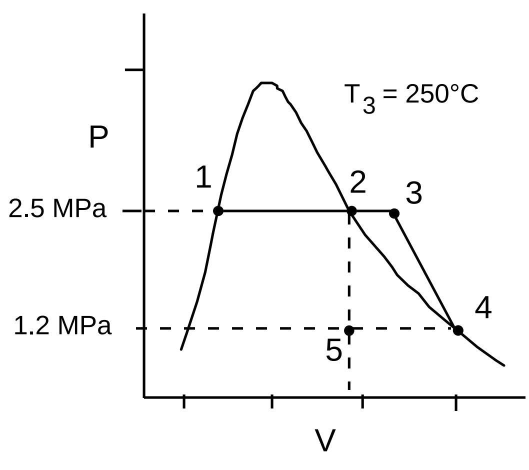
Example 2: Example exam question for testing BASIC KNOWLEDGE

2. Show in p-T and T-v diagrams the processes, 1 through 4, already indicated in the P-v diagram.



Example 3: Example exam question for testing COMPREHENSION

3. Evaluate using Thermodynamic Tables the indicated properties at the points identified in the P-v diagram.



Specific Volume at 3 is ______________   Temperature at 2 is _________________

Specific Volume at 4 is ______________   Quality at 5 is _____________________

Example 4: Example exam question for testing APPLICATION

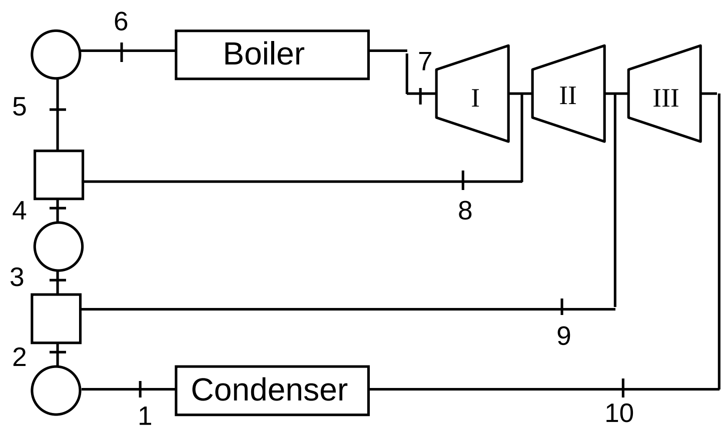
4. An ideal steam regenerative power plant with the water flow rate of 8 kg/s through the boiler is shown below. Steam is extracted from the turbine at 0.8 MPa and also at 0.2 MPa for heating the boiler feedwater in two open feedwater heaters.

   A technician has already evaluated the relevant properties.

enthalpy [kJ/kg]

Water

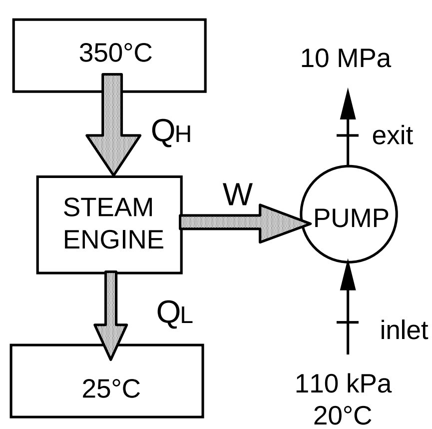
h_1 = 192
h_2 = 193
h_3 = 504.7
h_4 = 505.3
h_5 = 721
h_6 = 724
h_7 = 3104
h_8 = 2767
h_9 = 2522
h_{10} = 2108.7



a. What is the amount of heat rejection from the condenser? Evaluate it per unit mass of the working fluid through the condenser.

Example 5: Example exam question for testing SYNTHESIS

5. A reversible cyclic steam engine is used to drive a reversible water pump in a mine. The steam engine accepts heat from the boiler, which is at 350°C, at the rate of 2.0 MW while rejecting heat to the surroundings, which are at 25°C. The pump has an inlet pressure of 110 kPa and an exit pressure of 10 MPa. Determine the maximum mass flow rate of water through the pump. Explain why your answer is the maximum.



Example 6: Example exam question for testing EVALUATION

Piston-cylinder filled with steam is compressed slowly. An engineer calculated the heat transferred per unit mass of steam during this expansion process as shown below. State what assumptions must have been made for each step outlined below. Are the assumptions valid?

Information:	Initial	Final	process
p [Mpa]	0.2	0.21	$0.20 < p < 0.21$
T [°C]	300	200	
v [m3/kg]	1.32	1.09	

SOLUTION

STEP 1: $Q_{sys} = E_2 - E_1 + W_{sys}$

asssumptions:	validity:

STEP 2: $q_{sys} = u_2 - u_1 + \int_1^2 P\,dv$

asssumptions:	validity:

STEP 3: $q_{sys} = \int_1^2 C_v\,dT + \int_1^2 P\,dv$

asssumptions:	validity:

STEP 4: $q_{sys} = C_v (T_2 - T_1) + P (v_2 - v_1)$

asssumptions:	validity:

STEP 5: $q_{sys} = 1.41\ (300 – 200) + 205\ (1.09 - 1.32)$

asssumptions:	validity:

Example 7: Example exam feedback sheet.

ME 323 THERMODYNAMICS EXAM I FEEDBACK

The following checked items are identified as your weakness from the result of EXAM I.

CONCERNING COURSE MATERIAL (CH 1 ~ 6)

❑	Has difficulty in locating states and/or tracing processes in phase diagrams.	3.2 & 3.6
❑	Has difficulty looking up values in thermodynamic property tables.	3.3~4, 6.3.3~4
❑	Has difficulty with idealized property relationships.	3.3.4~5, 3.5, 6.3~4
❑	Has difficulty evaluating work.	2.2
❑	Has difficulty with the concept of the first law of thermodynamics.	2.3~6
❑	Has difficulty with the application of the first law of thermodynamics.	4.2~4
❑	Has difficulty with Carnot efficiency.	5.6~7
❑	Has difficulty with the concept/application of the second law.	5.1~5, 6.5~9

GENERAL PROBLEM SOLVING TECHNIQUE

❑ Not reading the question carefully.
Result: Irrelevant solution.

❑ Not organized.
Result: Self-inflicted confusion.

❑ Making assumptions without checking their validity.
Result: Failure to make simplification or making over-simplification of problems.

❑ Plugging numbers at an early stage of problem solving.
Result: Unnecessary computations which, in turn, results in either wasted time or silly math errors.

❑ Not checking the units.
Result: Nonsensical or meaningless values.

❑ Not checking the reasonableness of your solution.
Result: Physically unrealistic values.

❑ Serious deficiencies are noted. Please do the following:
Study your exam and evaluation very carefully.
Formulate an action plan to make an improvement.
Then, please see me to discuss your action plan with me.

❑ Some deficiencies are noted: Please take corrective action by, at least, reading the chapters and sections indicated above.

❑ Nothing serious.