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Physics Exams that Promote Collaborative Learning

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The two-stage exam is a relatively simple way to introduce collaborative learning and formative assessment into an exam. Their use is rapidly growing in the physics department at the University of British Columbia, as both students and faculty find them rewarding. In a two-stage exam students first complete and turn in the exam individually, and then, working in small groups, answer the exam questions again. During the second stage, the room is filled with spirited and effective debate with nearly every student participating. This provides students with immediate targeted feedback supplied by discussions with their peers. Furthermore, we see indications that the use of this exam format not only ensures consistency across interactive course components, but it also positively impacts how students approach the other collaborative course components. This is accomplished without losing the summative assessment of individual performance that is the expectation of exams for most instructors. In this paper we describe how to implement two-stage exams and provide arguments why they should be part of physics courses that use interactive engagement and social/collaborative learning methods.

Why two-stage exams?

Two-stage exams are not new. They have been discussed and used in multiple contexts,[1] but they are still relatively rare in physics courses[2] despite some of the clear advantages they offer. Exams are typically individual problem solving in isolation, in stark contrast to problem solving in the real world and in courses that stress collaborative learning activities. As cognitive psychologist Dan Schwartz puts it, "If you ask someone else for help on a problem in an exam, you are cheating, but if you don't ask someone for help on a problem in the real world, you are a fool." Individual exams miss an excellent opportunity for formative assessment that has been shown to be strongly linked to learning.[3] Students are more intensely engaged with the material during an exam than at any other time during the course. However this opportunity for formative assessment is lost, because the feedback on exams is typically very limited—mostly "right/wrong" and coming a substantial time after completion of the exam. Both of these factors reduce the value of feedback to learning. Also, as many instructors have observed, and we have confirmed by monitoring website use, most students only review midterm exam solutions when they are studying for the final exam. During the second stage of the two-stage exam, students receive immediate, targeted feedback on their solutions from their fellow students. Gilley and Clarkson have shown that essentially all members of the group take away from the exam nearly the mastery achieved by the group as a whole during the second stage, a level that is well above that shown by most individuals during the first stage.[4]

How to implement two-stage exams

The particular format of a two-stage exam that we use is relatively easy to implement and has worked well in numerous UBC physics courses. The second-stage "group portion" begins after all individual exams are collected. Students work in groups of three or four students on (mostly) the same problems as in the individual portion. They must come to a consensus on the answers and hand in one copy with the names and student ID numbers of all group members. Since the students have already carefully thought about each problem individually during stage 1, the discussions and agreeing on a solution during stage 2 usually takes less time. In our large introductory courses we allot 55 minutes for the individual effort (stage 1) and 30 minutes for the group effort (stage 2), with five minutes for making the switch from stage 1 to stage 2. Some instructors use two-stage exams in a one-hour timeslot, but it is more challenging. Although there usually is sufficient time to redo the entire exam, to save time when there are many long problems, we often repeat only the conceptual questions of the individual part in the group portion and/or turn short answer questions of the individual part into multiple choice or ranking tasks in the group portion. Box 1 shows two examples of questions that were modified for the group portion.

In determining the exam grades, we have used weightings of the individual to group portions of the exams of both 75/25% and 85/15%, and did not see any difference in the student behavior for the two cases. With either weighting, the impact of the group exam is typically a few percent on a student's total exam score, and less than one percent on his or her overall course grade. Students are told on the first day of classes how two-stage exams work and why examinations will be conducted in this format. They are also told about the stated policy that if the group score is lower than the individual exam grade, the group exam will not reduce their exam grade. In practice, this is relevant to only a few students because the groups nearly always perform as well or better than the best individual students. Overall grading time increases only slightly due to the group exam since a large fraction of the solutions are entirely correct, which makes grading easy and quick.

Students' reactions to two-stage exams

Witnessing the intense productive discussions in which nearly all students are engaged during the second stage has been the most convincing reason for most faculty for using

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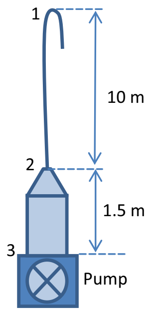
Box 1. Examples of questions taken from a two-stage exam for physics.

Most questions will be the same for the individual and the group part. If questions are modified, it is usually to reduce the number of detailed calculations, which do not promote discussions, and replace with prompts to "explain your reasoning." Additionally, one or two more challenging questions may be added.

Question

Assume you want to design a water fountain for your local park. The fountain is supposed to shoot water up to a height of 10.0 m above the exit nozzle, which is located 1.5 m above a pump that pumps water into a vertical tube of 5.0 cm diameter. The pump has a gauge pressure of 100 kPa.



Individual Part	Group Part
a) Rank the pressures at points 1 (at the top), 2 (at the exit of the nozzle), and 3 (at the exit of the pump). b) What is the diameter of the exit nozzle?	Part b changed to ranking: b) Rank the velocities at points 1, 2, and 3.

Question

You and your little sister are out in the snow on a sled that has a mass of 11 kg. Your sister, who weighs 29 kg, is sitting on the sled and you want to push her along. You start applying a horizontal force and initially the sled doesn't move but you slowly increase your force until, suddenly, the sled does move. You maintain the same force that you were applying when the sled started moving for the next 5.0 s after which you let go.

(Assume that the kinetic friction coefficient is $\mu_k = 0.02$ and the static friction coefficient is $\mu_s = 0.08$ in this case.)

Individual Part	Group Part
a) How far do you have to run if you apply the force for 5.0 s? b) What is your sister's speed at $t = 5.0$ s? c) After letting go, how far do your sister and her sled move until she is stationary again? (In case you could not solve part b, assume that her speed is $v = 2.5$ m/s at $t = 5.0$ s.)	(Converting calculation to reasoning and representation with graphs.) a) Draw a qualitative diagram that roughly shows the net force acting on the sled as a function of time. (Qualitative means that it explains the overall behavior without using exact numbers.) b) Draw a second qualitative graph of the acceleration of the sled as a function of time. c) Draw a third qualitative graph of the velocity of the sled as a function of time.

the two-stage format. Students also see the benefits of these discussions. We rarely have to discourage students from working individually during the group portion, and students that are usually too shy to speak up during in-class activities will defend their answers vigorously during the second stage of the exam. As confirmed through both observations and student self-reports,[5] a large fraction of the groups discuss the questions until all members agree on an answer, or they take a vote in cases where an agreement cannot be achieved. The high stakes context of an exam combined with the fact that all students are well prepared to participate in the discussion, because (a) they have studied for the exam and (b) they thought carefully about the questions and committed to an answer just moments ago during the individual portion, produce the perfect environment for rich discussion. Although we introduce collaborative learning activities into the course before the exams and explain the benefits, for many students the value becomes more readily apparent during the two-stage exam.

We see this on survey responses and in the behavior of the class after the first two-stage exam. Students' response to the use of two-stage exams is overwhelmingly positive, with 87% of the students recommending continued use of two-stage midterm exams and only a few percent recommending against their use. Examples of typical positive comments are:

> ***Student A:*** "I was able to instantly learn from my mistakes."
>
> ***Student B:*** "It was good to compare methods and answers with others, and it allowed us to be more confident."
>
> ***Student C:*** "Interesting. All had different ways [of] approaching the question. Very helpful to understand everyone's response and why they thought their answer was correct."

An interesting subset of the comments were those that indicated that the students found the experience emotionally unpleasant because they immediately recognized what they had done wrong, but for that same reason, clearly supported learning by the students.

> ***Student D:*** "The group exam was useful because I was able to see what I did wrong and what I did correct. The only negative part to it was [that] I realized all the mistakes I made."

Summary

Two-stage exams are an easy way to turn exams into learning experiences. This exam format is very popular with students because they recognize the value of the immediate feedback provided and the learning that results from it. The two-stage exams also provide a consistent message to students in any course that uses group work and collaborative learning.

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