

Using Collaborative Group Exams to Investigate Students' Ability to Learn

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Abstract. One of our primary learning goals for our students is: we would like them to be able to learn physics on their own. Unfortunately few existing assessments can assess students' ability to learn without being taught. We are developing a new format of exam which challenges students to work together as a class to tackle a difficult problem that requires them to learn new physics. Rather than restrict their activities, we offer them a resource-rich environment of textbooks and internet access. Students are required to transfer their knowledge by answering a related question on a more standard "individual exam" two days later. In this paper we will discuss the format of the exams, background theory, and present evidence of how students are able to learn new physics on their own. Our results show that although students struggle at first, they do surprisingly well once they get used to the format.

Keywords: Physics education, learning, assessment, preparation for future learning

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INTRODUCTION

Our 30-student introductory calculus-based physics course is a studio format course implementing the Investigative Science Learning Environment (ISLE) [1]. In previous papers [2, 3], we have suggested that for students to "buy in" to the learning goals of a reformed physics curriculum, classroom assessment needs to be aligned with those goals. One of the primary goals of ISLE is to get students to think like physicists by developing scientific habits of mind. We already have ways to assess this with scientific abilities rubrics [4]. However, we wondered if we could go one step further. We see the primary goal of our physics course is to help students develop meaningful scientific habits of mind that are useful to them after they have left our physics course. More specifically, can students apply the scientific abilities they have acquired to learn on their own without intervention from the instructors? In reality, everything in our course is centered around the goal of having students learn how to learn on their own. We ask students to work in groups to design and conduct scientific investigations, and we expect students to hold whole-class meetings to discuss their ideas together. These are just two of many activities students engage in while they learn physics together in mutual collaboration with the instructors [5]. The instructors are always present, moderating the discussions, scaffolding the investigations, and facilitating group dynamics to name but a few roles. The key question we wanted to ask was: What happens if that scaffolding is completely removed? Can our students learn on their own? In order to answer this question, we needed to develop a method

to assess our students' ability to learn. It is the new assessment method which is the subject of this paper. Our research question was simple: Can it work? Can we train students to learn physics on their own, and then be able to reliably measure what they learned?

THEORY

The education community has long been interested in transfer. Transfer is traditionally defined as students' ability to apply knowledge they learned in the classroom to new and/or novel situations. The accumulated literature on human ability to transfer knowledge has revealed only limited success. See, for example, [6]. Experts are relatively unsuccessful at transferring their knowledge when removed from their domain of expertise [7]. Motivated by the litany of transfer failures, Bransford and Schwartz [8] proposed a new construct which they called "preparation for future learning" (PFL) as an alternative way to conceptualize the idea of transfer. Their idea is that transfer fails because a) we expect too much (complete, wholesale transfer) and b) it is often measured in situations that are restrictive in terms of both time and resources offered to the participants. They argue that transfer is better conceptualized in terms of the ability of the participant to learn about the target situation which they are being asked to transfer to. Applied to the context of physics, we interpret their idea as follows: Traditionally we give students novel problems to solve on a closed book, time-restricted exam. This is very much like the old model of transfer failure. The question is, how can we measure our students' ability to learn (the PFL model)?

Our response to this question was to ask students to learn a new physics topic in an examination setting. To facilitate learning, we provided students with a resource-rich environment and the opportunity to collaborate with and learn from each other. When students were learning without the intervention of an instructor, we expected them to put into practice the various scientific abilities [4] that they had been acquiring throughout the class. For example, thinking about and evaluating *assumptions* they are making, *evaluating* a result to see if it is reasonable, and *communicating* scientific ideas with each other through *multiple representations* such as equations, pictures, and diagrams etc. . .

METHOD AND MATERIALS

We decided to modify our traditional exam format by turning each exam into two exams. Students first took a group exam, followed two days later by an individual exam. In the group exam we posed a problem for students that needed to be solved using physics they had not yet learned. For example, measure the height of a building using a barometer. In this case, the problem was posed before students had learned anything about pressure or fluid statics. In the group exam, students were allowed to work together as a whole class to answer the question. They were given unrestricted access to all resources at their disposal including a collection of different textbooks and the internet. (They could, in theory, have called a physics professor from the physics department to come in and explain the physics to them although no student ever tried to implement this idea.) Students were expected to hand in one write-up per group of 3 for grading. In the group exams, students were given a time of 2 hours and 15 minutes to complete their write-ups, however additional time was given as needed. In our class, students worked in groups of three the whole semester and those groups remained unchanged. Write-ups were graded using the scientific abilities rubrics [4]. Students were also informed that there would be a question embedded in the individual exam which would specifically test what they learned during the group exam. That question was carefully designed to see if the students could apply what they had learned in the group exam to a new situation.

Below we provide two examples of group exams and the accompanying questions that were embedded in the following individual exams:

Group exam question 1. Niels Bohr decides to measure height of a building by measuring the pressure at the top of the building and at the bottom of the building with a barometer (a pressure gauge that measures absolute pressure). He measures the difference in pres-

sure between the top and the bottom of the building to be 400 Pa. (I.e., $P_{\text{bottom}} - P_{\text{top}} = 400\text{Pa}$.) Then he drops the barometer from the top of the building and (with a stopwatch) times how long it takes for it to fall and smash on the ground below. The time he measures is 2.5 seconds. a) Use the barometer readings to estimate the height of the building. Also list the assumptions you made to make this estimate. (The density of air is 1.23 kg/m^3 at a temperature of 15°C and pressure of $1.01 \times 10^5\text{Pa}$, if you need it.) b) Use the time of the fall of the barometer to estimate the height of the building. Also list the assumptions you made to make this estimate. c) If the smallest unit that the barometer reads is 100 Pa, estimate the uncertainty in the height estimate in part a). Also estimate the uncertainty in the height estimate for part b). You might want to estimate a reasonable reaction time uncertainty for the time measurement to do this. Based on your calculations, which method do you think will give the better result? Why?

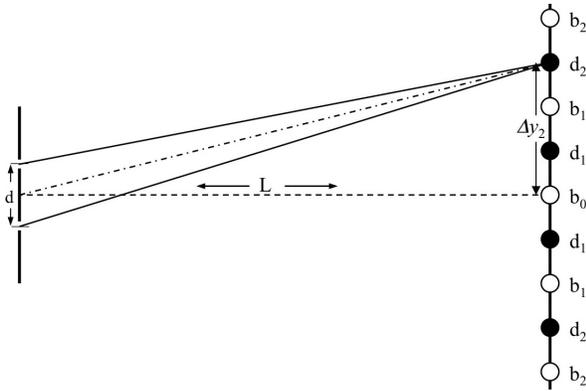
Individual exam question 1. A fancy 35 m tall hotel has a roof-top pool. To monitor the pressure in the pool, a pressure gauge (a barometer) is placed at the bottom of the pool where the depth of the water is 2 m. If the air pressure on the surface of the water is 101 kPa, what will be the reading of the pressure gauge at the bottom of the pool? Assume density of air is 1.29 kg/m^3 , density of water is 1000 kg/m^3 .

Group exam question 2. Figure out how to measure the wavelength of the light from the laser using the optics bench and double slit interference apparatus. Use all the resources at your disposal.

Individual exam question 2. Consider the second dark spot (d_2) formed from a double slit interference experiment with 530 nm light $530\text{ nm} = 5.30 \times 10^{-7}\text{ m}$ as shown in the diagram. $L = 80.0\text{ cm}$, $\Delta y_2 = 0.254\text{ cm}$, and $d = 0.25\text{ mm}$. What is the difference in distance traveled by the wave from each of the two slits to this dark spot? Explain why there is a dark spot there. Clearly represent your reasoning.

We introduced the novel exam format to our class on the final exam of December 2010, giving them the group exam question 1. At the time we doubted whether students would be capable of learning on their own. Thus we did not inform students that there was an embedded question (individual exam question 1) on the individual exam and included the question for bonus credit only. Pressure, gases, and fluid statics/dynamics were not covered in our class because of time constraints.

We administered the second group exam (group exam question 2) to the same group of students on the second mid-term of the Spring semester in March 2011. This time we were confident in our students' abilities and in-



formed them that there would be an embedded question (individual exam question 2) in the accompanying individual exam. At the time of the exam, students had covered mechanical waves (including standing waves on a string) and had completed geometrical optics. They had seen no wave optics at all, but were aware of the idea that light could be modeled as a wave. Both group exams were video-taped with a single video camera.

RESULTS AND ANALYSIS

Analysis of group exams

In analyzing the videos from the two group exams we looked for evidence of students using the scientific abilities they had learned in the class to learn about a new situation. We were also interested to see how students collaborated and worked together.

Evaluating

The following episode from the first group exam shows students engaged in evaluating their calculation for the height of the building.

Nancy: I get 45.08 meters

Daniel: Does that make sense?

Amanda: That's small.

Nancy: That's...pretty big.

Daniel: Meters?

Amanda: Yeah that is.

Nancy: I'm not sure how big that is.

Sarah: That's like your arm length, 45 times your arm length.

Daniel: 45 meters?

Amanda: How can that make sense?

Daniel: That's pretty high.

(*Scott and Lilly come over from another table, Nancy explains their procedure*)

Amanda: We got 45.08 meters.

Scott: 45.08 meters? They say it's a sky scraper? Because that would be extremely tall. 45.8 meters, that would be 120 feet?

Nancy: I don't know how tall things are (laughs).

After this Nancy and Sarah got onto a computer and used google to search for the possible height of a skyscraper.

Assumptions

Students often engaged in thinking about their assumptions in very short episodes. The example below shows students thinking about whether they can assume air is a fluid and whether air density is affected by temperature.

Sarah: Is it a column of fluid or a column of air, or is it the same thing because air is a type of fluid?

Elizabeth: yes

After a short interlude.

Elizabeth: It's [the difference in pressure] dependent only on density, gravity and its height. And you're assuming its temperature is the same because it [the equation] is density dependent.

Collaboration and information flow

In both group exams students made deliberate efforts to share information. In group exam 1, a student made a general announcement asking others to put their work on the whiteboards surrounding the room. At various points during the exam, groups went up to the board and wrote up their work for others to look at and critique. Groups of students clustered around particular whiteboard to discuss a method on the whiteboard.

Below we present an example of effective collaboration and discussion in a whole-class meeting: Context: A group of 3 students is at the board, presenting their work to the whole class. They found a time interval for the falling barometer using $v_f = v_i + at$ and then (incorrectly) used $d = vt$ to find the height of the building.

William: Hold on, you're doing that. How did you get seconds?

Amanda: From here? We solved for time (points towards $v_f = v_i + at$ equation)

William: Isn't that only if it is falling at a constant rate of 18.03 m/s? (pointing towards the $d = vt$ equation).

Numerous students: No, that's free-fall.
 Daniel: It's constant acceleration - that's an assumption.
 William: Okay, but that would be if it is traveling 18.03m/s from the very start, I guess.

Student collaboration in group exam 2 was even more striking. Two groups from opposite ends of the classroom collaborated to produce a large diagram of the double slit experiment on the board which they then used to instruct the rest of the class. They developed their own method of explaining the equations for double slit interference using similar triangles. Throughout the period of the group exam, different groups of students clustered around the diagram while one or more students explained the equations and how they could be understood in terms of the diagram on the board. With the instructors removed, students collaborated much more intensively than during regular class time.

Performance on individual exam questions

Students' performance on individual exam question 1 was extremely poor with only 3 students out of 30 getting the correct pressure at the bottom of the pool with a clear explanation of their reasoning. It is not clear whether this poor performance was because of unfamiliarity with the format of the group exam, because the individual question only counted for bonus points, or because they were not expecting an embedded question related to the group exam.

Students' performance on individual exam question 2 following the second group exam in the Spring semester was much more encouraging. The average on question 2 was 70% while the overall individual exam average was 65%. Detailed scoring results are shown in Table 1.

TABLE 1. Student performance on embedded question 2.

Adequate (9/10 or 10/10)	Partially correct (5/10 to 8/10)	Poor (less than 5/10)
47 %	33%	20%

DISCUSSION AND CONCLUSION

Our analysis shows that students can learn on their own. The video footage showed students engaged in thinking about their assumptions, constructing new and novel representations to aid their understanding, frequently evaluating their results, and working collaboratively to teach each other and critique each other's work. In summary we observed that students seemed to have appropriated the scientific abilities that they had been learning in the

class and were using them spontaneously to learn about new physics that they had not encountered before. Most importantly, we saw evidence (individual exam question 2) that students were able to apply what they had learned from the group exam to a new question on the individual exam. Students scored equally well on question 2 as compared with the rest of the individual exam. While our evidence is limited to a single transfer question this result is suggestive that students may be able to learn just as well on their own as when an instructor was present.

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