Teaching Physics with Physlet®-Based Ranking Task Exercises

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In this paper, we describe how we use a pedagogical tool, Physlets®, in combination with a complementary pedagogical method, Ranking Task (RT) exercises, to enhance students' interactive engagement in introductory physics.

RTs (see Fig. 1) are one of more than a dozen Tasks Inspired by Physics Education Research (TIPERs) conceived by Curtis Hieggelke, David Maloney, and Thomas O'Kuma.[1] RTs are exercises that require students to compare scenarios with slightly different configurations (such as force applied, mass, or instantaneous velocity) and rank-order another attribute (such as acceleration).[2-5]

RTs have a number of pedagogical strengths. Most students, when solving a traditional physics problem, find a formula and simply plug the numbers given into that formula. This approach, which often results in the correct answer, does not require a solid conceptual understanding of the problem. RTs discourage such a plug-and-chug approach because they require students to set up, but not completely solve, a set of similar problems with slightly different configurations. Students must then determine how to efficiently compare different scenarios by ranking different variables and stating whether the rankings of any of these variables are the same. RTs also ask students to give a reason for their rankings. Such reasoning can provide insight into student thinking. In addition, RTs can present students with multiple representations of the same problem by having them rank graphs, vectors, or motion. RTs, then, serve to prepare students for standard textbook problems because "students see that problem solving has a conceptual basis as they learn that they need a concept first, before doing any calculations."[6]

Physlets, Java applets that simulate physics content, are interactive animations that serve as a foundation for a variety of physics exercises.[7-12] Physlet-based exercises share many of the same problem-solving attributes as RTs. With the Physlet approach, students are not given much, if any, data; they must determine and measure meaningful quantities for themselves. Students following a standard plug-and-chug approach will find that, without a concept-first approach, they have either no data or too much data (depending on how many measurements were made) to put into an equation. Once students discover that plug-and-chug methods are not effective, they tend to adapt to a more

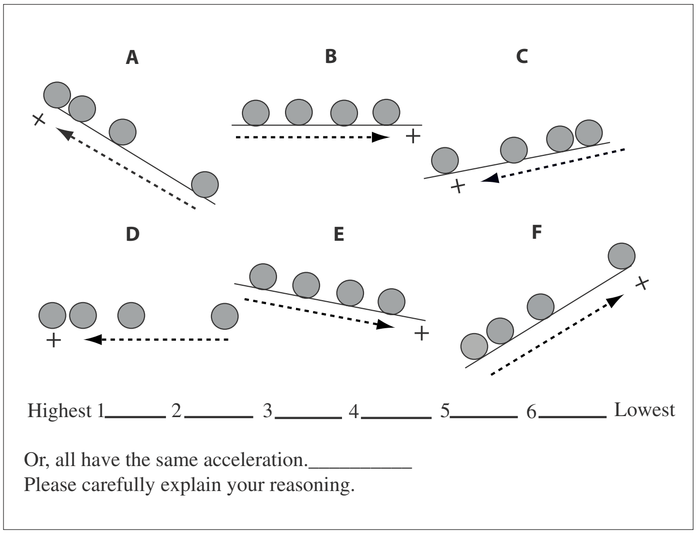

Fig. 1. A Ranking Task on acceleration depicting the motion of six balls using motion diagrams (Ref. 4, Task #5).

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successful concept-first approach to determine what data from the animation are relevant for the problem solution. Like RTs, Physlet-based exercises can also provide multiple representations via animations, graphs, vectors, and tables. Physlet-based exercises provide the additional benefit of visualizing the physical process. This often makes Physlet-based exercises an intermediate step between the abstraction of a static figure in a text and the complicated motion of the physical world. Students regularly cite their ability to interact with and make measurements within the visualization as one of the most helpful qualities of Physlet-based exercises.[13]

Given the complementary strengths of these two types of exercises, it is only natural to combine, where appropriate, the effective pedagogical tool of Physlets with the pedagogical method of RTs. The curricular material developed in this manner generally falls into two categories: 1) paper-and-pencil RTs that we animated or "Physletized" to make it easier for students to visualize the scenario that the original RT presented, and 2) RT exercises based on the animations. The latter, although possible as paper-and-pencil exercises, exploit the power of an animation as students do a ranking based on their direct interactions with the exercise. Many exercises of this second type are unique because converting them from animations to paper-and-pencil exercises is simply not possible.

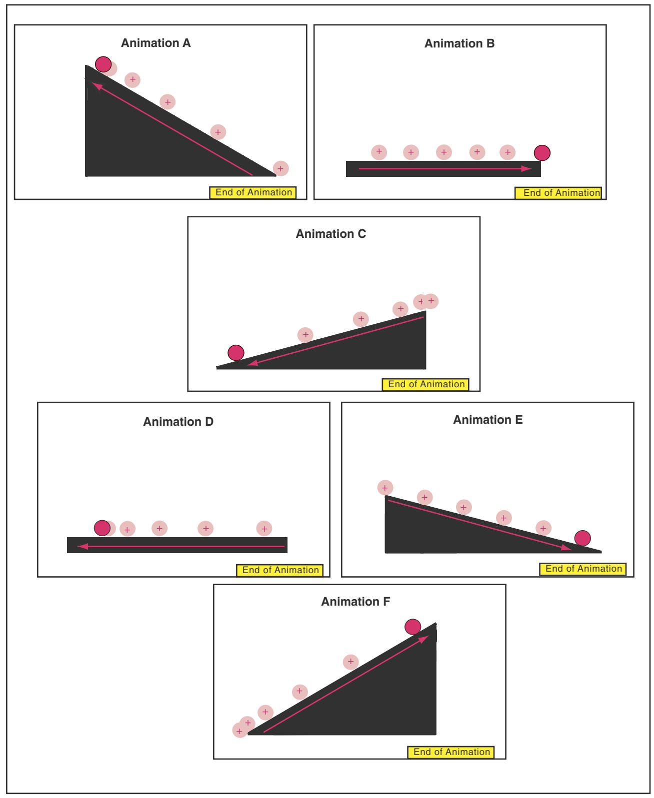


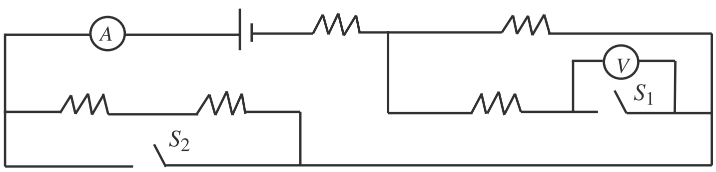
Fig. 2. Physletized version of task shown in Fig. 1. The animations represent the motion of a ball on various surfaces. The "ghost images" are placed at equal time intervals. Students are to rank each animation from highest to lowest acceleration (assume constant acceleration) [Ref. 10, Problem 3.3(c)].

Physletized Ranking Tasks

An example of a Physletized RT is shown in Fig. 2. The red ball moves in the direction of the red arrow and a red ghost image marks its position in 0.2-s intervals. Seeing the "ghost images" (a so-called motion diagram) as the ball rolls provides a visualization of "an image at equal time intervals," which is part of the text explanation of "ghost images" in the original RT shown in Fig. 1. The animation avoids confusion about what the image shows, and therefore students can focus more quickly on the underlying physical concept: acceleration.

RTs are specifically designed to make students think about what parameters are most important in a ranking: Is it the slope of the hill, the spacing between the ghost images, or the distance traveled? To this end, RTs often give students extraneous data not needed to successfully rank the scenarios. Physlet-based exercises are similarly overspecified since students can collect more data from the animation than they need. With Physletized RTs, the problem statement does not need to contain either all the data required or extraneous information to serve as a distracter. Students must therefore try to understand what is happening and what the salient features of the problem are. This is consistent with the underlying philosophy of the original RTs since the key to a correct ranking is identifying the important feature of a problem and using that to drive the ranking of the variables. Thus, a Physletized RT preserves and supports the goals of paper-and-pencil RTs.

Another example of a Physletized RT is taking an original paper-and-pencil RT and providing a Physletized version that asks the converse question. Figure 3(a) shows a RT that asks students to rank ammeter



Configuration	S_1	S_2
A	open	open
B	open	closed
C	closed	open
D	closed	closed

Fig. 3(a): The dc circuit above contains two switches. All of the resistors shown are identical. Assume that the wires, battery, and meters are ideal. The diagram shows both switches open. Below the diagram are four different switch configurations for the circuit. Rank these configurations in terms of the ammeter reading (Ref. 4, Task #184).

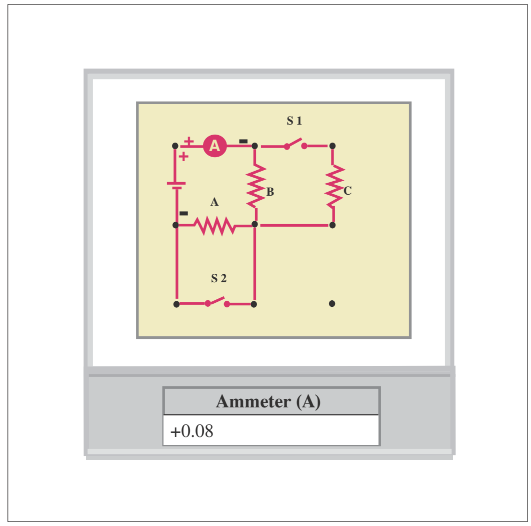


Fig. 3(b): Rank the three resistors (from smallest to largest) in the circuit. The table displays the current as measured by the ammeter. Clicking the open/close buttons shows the current through the ammeter for the configuration selected [Ref. 10, Problem 30.4(b)].

readings for different combinations of opened and closed switches. The Physletized version [Fig. 3(b)] provides the ammeter reading as a student opens and closes the switches and then asks for a ranking of the three resistors. For both versions of the RT, students need to first determine a way to approach the problem conceptually. Only then is it useful for them to consider all four switch configurations. In its Physletized form, the students control the switches and so it is easier for them to visualize the different paths available to the current in the circuit and then use that to connect the ammeter reading with their ranking schema. The Physletized version could, in principle, be turned into a paper-and-pencil version, but it would require a cumbersome data table of ammeter readings associated with various combinations of opened and closed switches. This would also diminish the exercise because it would tell the students that all four switch combinations are important. With the Physlet-based exercise, students must make this connection for themselves.

Despite the convergence of pedagogical philosophies between RTs and Physlets and the fact that many RTs can be Physletized, in many cases animation serves no useful pedagogical purpose (or worse, gives the answer away). The guiding criteria for Physletizing a task are whether an animation would help students understand the question, help them visualize the situation, or help provide an alternate view of a situation. Note that simply having a visual representation available does not mean that students are more likely to rank the scenarios correctly. Visualizations can force students to confront their ideas as they "see" what happens, but that confrontation can either reinforce or discourage correct reasoning.[14] Both of these can be important for the learning process.

Ranking Tasks Requiring Animation

Combining Physlets with RTs need not be limited to simply Physletizing original paper-and-pencil versions. There are a number of Physlet-based RTs that do not have an equivalent paper version. Consider an animation of a mass pulled up via a pulley as shown in Fig. 4. Instead of asking for a calculation of the tension in the rope, a Physlet-based RT shows students the motion for several situations (different velocities and directions of motion) and the task is to rank both the acceleration and the tension in the rope. Although this complements an Atwood's machine RT (Fig. 5), this particular Physlet-based RT only works as an animation because the paper-and-pencil equivalent would need to tell students either the acceleration or the tension. The animated version does not need to explicitly tell the students the acceleration, because they can collect the data or simply watch the animation to rank the acceleration. Ranking the acceleration can then help students rank the tension, a task they find more difficult.

Another type of Physlet problem asks students to identify the hidden object or determine the unknown

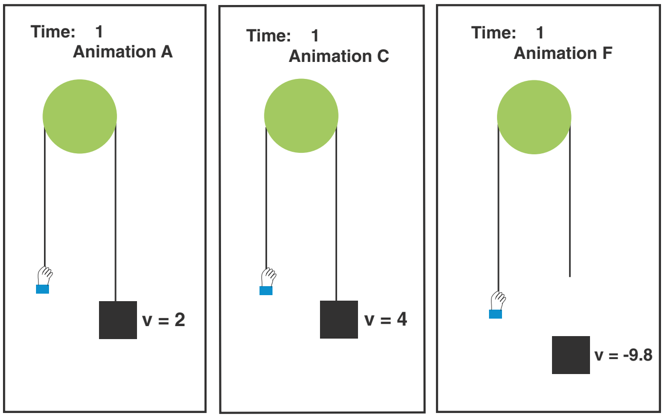


Fig. 4. A hand pulls a massless rope hanging over a massless and frictionless pulley with a 10-kg block at the end. The block moves up, down, or remains stationary depending on the animation. Students are asked to rank the animations by both the acceleration of the mass and the tension in the rope. Only three of the six animations are shown (Ref. 10, Problem 4.9).

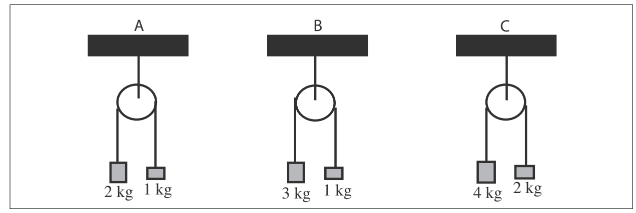


Fig. 5. Each figure shows two blocks hanging from the ends of a massless string that passes over a massless and frictionless pulley. The mass of each block is given in the figures. Rank the figures from greatest to least tension in the string for the system of blocks (Ref. 4, Task #27). Only three of the six options are shown.

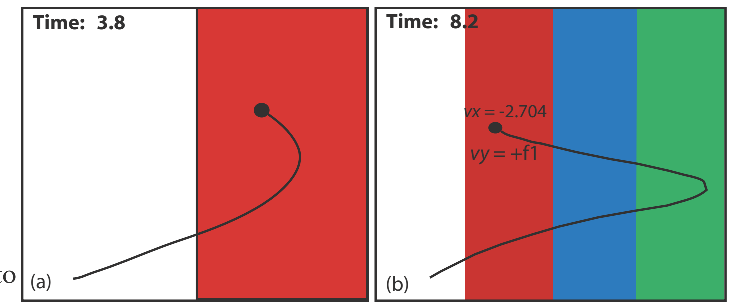


Fig. 6. (a) A "hidden electric field" problem. A charged particle of charge 2 μC and mass 1 mg moves into an unknown electric field. Students are asked to determine the field (direction and magnitude). (b) A positively charged particle fired into regions of unknown electric field. The *x* and *y* components of velocity are given. Students are asked to rank the magnitude of the electric field in each region.

quantity. As shown in Fig. 6(a), students are asked to determine the direction and magnitude of the electric field that a charged particle enters. When this is converted into a RT, as shown in Fig. 6(b), students can still do a calculation as they would for Fig. 6(a), or they can look at the velocity changes or simply compare the trajectories.

Characterizing hidden or unknown objects in a Physlet-based problem also provides RTs in geometric optics, a topic with fewer RTs.[15] For the following Physlet-based RT (Fig. 7), students can change the angle of the light source and move the protractor around to make measurements of the incident and refracted beams of light through the different unknown media. Observing the refracted light provides an easy comparison of media next to each other, but a measurement of the angle of incident and refracted light is required to compare the outermost regions (A and D). This is typical of Physlet-based exercises: They are much closer to laboratory exercises since students must take measurements in conjunction with conceptual understanding.

This type of Physlet-based RT, such as the ones shown above on electric fields and indices of refraction, can also be effective for other topics like forces, potential energies, and magnetic fields.

Case Study of Student Responses: Gauss's Law

One of the strengths of Physlet-based RTs is that they help students learn the material by forcing a concept-first approach. Furthermore, RTs "determine how the students work … and thus provide significant information about their thinking process."[16]

As a case in point, we asked a group of five students in a second-semester calculus-based introductory physics course to do two Physlet-based RTs related to Gauss's law. After a short lecture to introduce Gauss's law, students were instructed to complete two exercises in class, which would then be followed by a group discussion. The two tasks required each student to 1) rank the electric flux through three concentric Gaussian spheres (shown in the *xy* plane as circles) surrounding a single point charge [Fig. 8(a)] and 2) rank the charges in a Physlet where they had different size, spherical, or cubical "electric flux detectors" they

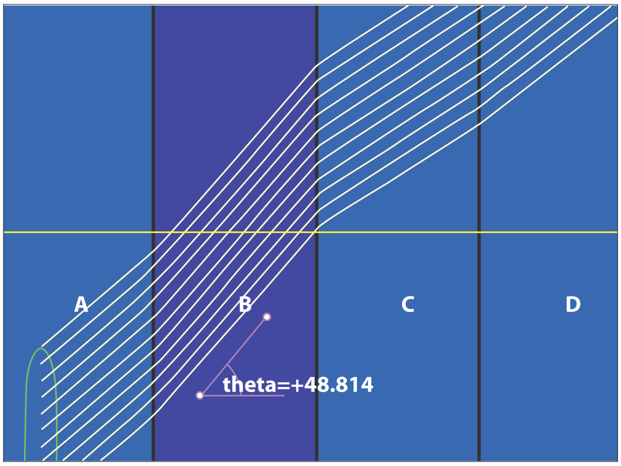


Fig. 7. The animation shows parallel light rays passing through four unknown media. Students move the beam source vertically (only) and change the angle of the beam source. They can also use a moveable protractor to measure angles of interest. Students are asked to rank the media from smallest index of refraction to largest. (Ref. 10, Problem 34.6).

could move around [Fig. 8(b)]. For both tasks, the students had more information than they needed.

For the first RT, a moveable electric field detector provided the electric field values anywhere in the animation; click-dragging the mouse in the animation showed the position coordinates, and the colored arrows showed the direction and relative magnitude of the electric field. Given this information, one student measured the electric field at each surface and then calculated *EA* while two other students claimed (without making careful measurements) that since the electric field decreased as the area of the spherical surface increased, the electric flux should be the same. None of the students said that since the charge enclosed by each surface is the same, the electric flux should be the same. One student who gave an incorrect response ranked them from smallest surface to the largest and gave as his reasoning that the electric flux was related to the number of electric field lines, confusing electric field vectors (shown in the animation) with electric field lines (not shown). One student did not complete either task in time, because he was trying to measure the different size surfaces and relate that to the electric flux in both animations.

The three students who completed the second RT all solved the problem correctly by reasoning that the electric flux was directly related to the charge

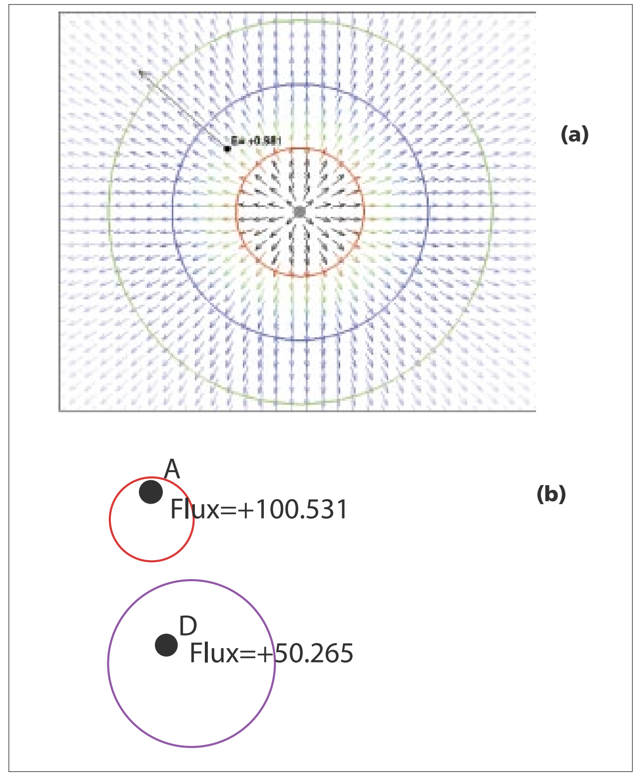


Fig. 8. Physlet-based Ranking Tasks for Gauss's law. (a) Task 1: Rank the electric flux through the three spherical surfaces. (b) Task 2: Rank charge in each animation using a movable "electric flux detector." Only two of the four animations are shown.

enclosed, independent of the electric flux detector size or shape. Students moved the detector and saw that when it did not enclose the charge, the electric flux was zero. This helped students directly connect electric flux with the enclosed charge. These students expressed more confidence in their answers and were quick to provide their reasoning during the group discussion.

Those students who gave the correct reasoning on the second RT did not use the same reasoning for the first task even though the students did the two tasks at the same time (and prior to a discussion of everyone's answers). In fact, it was not until a brief instructor-led discussion following both tasks that a student noted that she could have used the same reasoning for both RTs. It was then an easy matter for the instructor to point out that Gauss's law is what they had essentially "discovered" in using the two Physlet-based RTs: The electric flux through a surface is proportional to the charge enclosed by that surface. The increase in surface area for the larger electric flux detector is exactly offset by the decrease in the electric field at the surface of the detector. The two tasks, then, helped students start to make sense of electric flux as both $\oint \vec{E} \bullet d\vec{A}$ (or EA for "good" symmetry) and $q_{\text{enclosed}}/\varepsilon_0$, from Gauss's law.

Summary

Physlet-based RTs are an effective way to combine two proven pedagogical strategies: Physlets and RTs. Physlet-based versions of RTs can, in some cases, provide advantages where an animation helps clarify the RT or aids in a problem's visualization. Physlet-based RTs also allow for novel problems not possible with only paper-and-pencil versions. Finally, using Physlet-based RTs can allow an instructor to further probe student understanding and aid in concept development. Example Physlet-based RTs in this paper are at http://webphysics.davidson.edu/physlet_resources/.

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