Multimedia curricular material informed by physics education research: Physlet®-Based Ranking Task Exercises

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Abstract: Combining a teaching tool based on physics education research (“Ranking Tasks”) with Physlets (java applets with physics content) provides a multimedia learning environment which can enhance student learning. “Ranking Tasks” 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). This paper discusses animated versions of Ranking Tasks using Physlets as well as an example of student concept development that grew out of two Physlet-based Ranking Tasks.

Introduction

Research on teaching a learning shows that interactive techniques are more effective at enhancing student learning than traditional lectures.

Technologies, specifically in the form of computers in the classroom, have been seen by many as a way to enhance interactivity and thereby enhance learning. For example, computer animations can provide students with a more complete picture of the motion in comparison with static text images. Animations can increase interactivity by allowing students to change parameters and observe the outcomes. Students can also make measurements within the animations which can simulate a laboratory-like setting. However, technology alone, even in the form of interactive animations, does not necessarily enhance student learning. Curricular materials that accompany animations are equally important.

Figure 1: A Ranking Task on acceleration depicting the motion of six balls using motion diagrams [Ref 4, Task #5]. The instructions explain that the gray balls indicate the position of the ball at equal time intervals and ask students to rank the scenarios from lowest acceleration (most negative) to highest (most positive), given the sign convention indicated on each diagram.
simply plug the numbers given into that formula. This approach, which often results in the

correct answer, does so without requiring a solid conceptual understanding of the problem.

Ranking Tasks 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. Physlets

similarly discourage a plug-and-chug approach because students are not given much, if any, data;

they must determine and measure meaningful quantities for themselves. In addition, both

Ranking Tasks and Physlets can present students with multiple representations of the same

problem by having them rank graphs, vectors, or motion. Ranking Tasks, 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”\textsuperscript{18} and

the same can be said for Physlets as well.

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.\textsuperscript{19}

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

Ranking Tasks. The curricular material developed in this manner generally falls into two
categories: 1) paper-and-pencil Ranking Tasks that we animated or “Physletized” to make it

easier for students to visualize the scenario that the original Ranking Task presented and 2)

Ranking Task exercises based on the animations.

**Animated compared with Paper-and-Pencil Ranking Tasks**

**Figure 2:** Physletized version of task shown in Figure 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 11, Problem 3.3(c)].
An example of a Physletized Ranking Task is shown in Figure 2. Notice that for the Physletized version, students get to see the “ghost images” (light red balls) put in place as the ball rolls which provides a visualization of “an image at equal time intervals” (part of the text explanation of “ghost images” in the original Ranking Task shown in Figure 1). The animation avoids confusion about what the image shows and therefore students can focus more quickly on the underlying physical concept: acceleration.

Another example of a Physletized Ranking Task is taking an original paper-and-pencil Ranking Task and providing a Physletized version that asks the converse question. Compare the tasks shown in Figure 3a and Figure 3b. In both tasks, the student needs to compare the current flow for different configurations of open and closed switches. In the Physletized version, 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. Notice further that the Physletized version eliminates the need for a cumbersome data table and does not tell students that all four switch configurations are important.

Figure 3a: 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].

Figure 3b: 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 11, Problem 30.4(b)].

Despite the convergence of pedagogical philosophies between Ranking Tasks and Physlets and the fact that many Ranking Tasks 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. Both of these can be important for the learning process.
Physlet Based Ranking Tasks

Combining Physlets with Ranking Tasks need not be limited to simply Physletizing original paper-and-pencil versions. There are a number of Physlet-based Ranking Tasks that do not have an equivalent paper version. Consider an animation of a mass pulled up via a pulley as shown in Figure 4. Instead of asking for a calculation of the tension in the rope, a Physlet-based Ranking Task 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 compliments an Atwood's machine Ranking Task (Figure 5), this particular Physlet-based Ranking Task only works as an animation because the paper-and-pencil equivalent would need to tell students either the acceleration or the tension. Ranking the acceleration can then help students rank the tension, a task they find more difficult.

![Figure 4](image1.png)

**Figure 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 3 of the 6 animations are shown [Ref 11, Problem 4.9].

![Figure 5](image2.png)

**Figure 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].

Another type of unique Physlet-based problem asks students to identify the hidden object or determine the unknown quantity. As shown in Figure 6a, students are asked to determine the direction and magnitude of the electric field that a charged particle enters. When this is converted into a Ranking Task, as shown in Figure 6b, students can still do a calculation as they would for Figure 6a 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 Ranking Tasks in geometric optics (a topic with fewer Ranking Tasks)\textsuperscript{21} as shown in Figure 7 and can be effective for other topics like forces, potential energies, and magnetic fields. In additional, this type of Physlet-based Ranking Task can also be extended to upper-level courses as shown in Figure 8.

\textbf{Figure 6a:} A “hidden electric field” problem. A charged particle of charge 2 $\mu$C and mass 1 mg moves into an unknown electric field. Students are asked to determine the field (direction and magnitude).

\textbf{Figure 6b:} 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.

\textbf{Figure 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 11, Problem 34.6].

\textbf{Figure 8:} Ranking Task for modern physics and/or quantum mechanics. Shown is a right-moving plane wave incident on several different regions of constant potential energy. The color of the wave function indicates its phase (the color bar at the top of the Figure shows the correspondence) while the height of the wave indicates the amplitude. Students are asked to rank the regions by the kinetic energy, the potential energy, and the total energy.
Case Study of Student Responses: Gauss’s law

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

Figure 9: Physlet-based Ranking Tasks for Gauss’s law.

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 ranking tasks 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 were as follows:

1) Rank the electric flux through three concentric Gaussian spheres (shown in the $xy$ plane as circles) surrounding a single point charge (Figure 9a). 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.

2) Rank the charges in a Physlet where they had different size spherical or cubical “electric flux detectors” they could move around (Figure 9b) and see the value of the flux through the detector.

Table 1 shows the student responses. Note that for the first task, although three students had the correct ranking, 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 Ranking Task all solved the problem correctly by reasoning that the electric flux was directly related to the charge 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 Ranking Task 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 Ranking Tasks. 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 Ranking Tasks: 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 $\int \mathbf{E} \cdot d\mathbf{A}$ (or $EA$ for “good” symmetry) and $q_{\text{enclosed}} / \varepsilon_0$, from Gauss’s law.

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

14. For more information about the other TIPERs, please visit: [http://tycphysics.org/tipers.htm](http://tycphysics.org/tipers.htm).
18. Maloney, p 513.
21. *Ranking Task Exercises in Physics* did not include optics Ranking Tasks, but the *Ranking Task Exercises in Physics, Student Edition* does include a small number of geometric optics Ranking Tasks.