

nTIPERs: Tasks to Help Students “Unpack” Aspects of Newtonian Mechanics

David P. Maloney¹, Curtis Hieggelke², and Stephen Kanim³

¹*Department of Physics, Indiana University Purdue University Fort Wayne*

²*Emeritus, Joliet Junior College*

³*Department of Physics, New Mexico State University*

Abstract. nTIPERs (Newtonian Tasks Inspired by Physics Education Research), are tasks intended to strengthen students’ conceptual understanding of topics in introductory mechanics. These tasks can be used individually as in-class assignments, as homework, or as evaluation instruments, and are especially appropriate for incremental adoption by instructors who wish to strengthen the conceptual focus of their introductory courses. We will present examples of several nTIPER tasks related to common student difficulties with different aspects of the concept of force: Force as proportional to velocity; force as a property of an object; and force calculated from mass times acceleration. We will also present ideas for how to use nTIPERs.

Keywords: Conceptual learning, mechanics, introductory physics, task formats.

PACS: 01.40.-d, 01.40Fk, 01.40.Di, 01.40.gb, 01.40.G-.

INTRODUCTION

Physics education research has shown [1] that instruction that features effectively structured interactive engagement can promote learning. But in order to strengthen conceptual understanding, interactive engagement instruction requires tasks and activities that allow students the opportunity to come to grips with and to make sense of the concepts underlying the physics topics under study.

Students’ tendency to approach physics problems as opportunities to plug numbers into equations has been well documented. Unfortunately, typical end-of-chapter physics problems do not appear to be very effective at promoting the conceptual understanding that most instructors would like to accompany problem solving. It has been found, however [2, 3], that altering the *format* of tasks from the traditional quantitative problems that students expect can be an effective way to engage students in making sense of the material rather than just searching for an answer. The goal of the TIPER (Tasks Inspired by Physics Education Research) project is to develop tasks in a variety of formats that can be used by instructors to promote student conceptual understanding of physics topics. We are currently developing tasks for topics that span the introductory mechanics course. (Previously, we have published a set of TIPER tasks

for introductory electricity and magnetism [4].) Such tasks need to be carefully structured so that they do not intimidate the students, i.e., the students must believe they know how to do the tasks so that the tasks elicit students’ natural ideas to foster active exploration of those ideas and the reasons the students believe them. In this paper we will describe the basic approach of the nTIPER (Newtonian TIPER) project to developing tasks, show several examples of tasks involving the concepts of force and energy, and describe some ways to use the tasks.

We have attempted to design tasks to address issues and ideas that research has shown to be problematic for students. Most tasks require explanations as well as an answer, which promotes a deeper engagement with the topic and strengthens students’ ability to identify and create scientific arguments.

TYPES OF TIPER TASKS

TIPER tasks are designed to allow students to compare their natural or common-sense ideas to those of other students and to physically accepted ideas. Even though many tasks include quantitative information, they are intended to promote conceptual understanding and sense making.

There are ten different TIPER formats:

Bar Chart Tasks—these require student to draw histograms for specified quantities of a situation.

Changing Representation Tasks—given one representation, e.g., a free-body diagram, students generate an alternative representation, e.g., the Newton’s second law equation.

Comparison Tasks—these ask the student to determine which of two situations has a greater value for a quantity, or if the two situations have the same value for quantity.

Conflicting Contentions Tasks—these tasks present two or three (usually natural language) statements about a situation and the goal is to decide which, if any, of the statements is correct.

Linked Multiple-Choice Tasks—in these the same question, with the same set of answer possibilities, is asked about a sequence of variations for a situation.

Qualitative Reasoning Tasks—these tasks ask about how a qualitative variation of a situation affects the behavior of the system.

Ranking Tasks—ask students to rank a set of physical situations based on the magnitude of a single characteristic.

Troubleshooting Tasks—these require the identification of the acknowledged error(s) in a contention, representation or analysis.

What, if Anything, is Wrong Tasks—these are similar to troubleshooting tasks except that there may not be anything wrong.

Working Backwards Tasks—these usually have one or more equations as the starting point with the goal being a description or drawing of a physical situation.

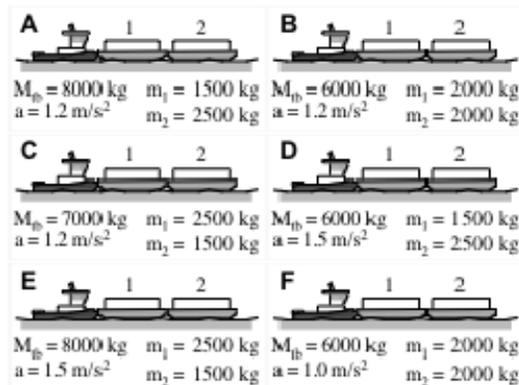
Many of these formats are based on descriptions in the physics education research literature. While we have written tasks in a variety of formats for each mechanics topic, there are some formats that pair particularly well with certain physics topics. For example, bar chart tasks are very well suited to accounting for changes in energy during physical processes, and are strongly featured in that section.

EXAMPLES OF TASKS FOR UNPACKING ASPECTS OF FORCE AND ENERGY

The following tasks address several aspects of force. The first one elicits two aspects of students’ ideas about force: use of Newton’s second law, in the form of $F = ma$, to find force, and the idea that force is a thing that can be transferred from one object to another:

Example 1: Tugboat Pushing Barges

Each of the six figures below shows a system consisting of a tugboat pushing two barges labeled 1 and 2. The masses of the tugboats and the barges and the accelerations of the systems are given for each case. The positive direction is to the right. Ignore the effects of fluid friction.



Rank these six cases (from greatest to least) on the basis of the force the tugboat exerts on barge one.

Greatest 1 _____ 2 _____ 3 _____ 4 _____ 5 _____ 6 _____ Least

OR, The force the tugboats exert on barge one is the same for all six systems.

OR, The tugboat does not exert a force on barge one for any of these six systems.

OR, We cannot determine the ranking for the force the tugboat exerts on barge one for these systems.

Please explain your reasoning.

This task is called a *Ranking Task* for fairly obvious reasons. Notice that although it has numerical values given, because the goal is not to find a specific numerical value students do not tend to just plug numbers into an equation. This task asks students to compare the six variations on the basis of the force the tug exerts on the first barge, which is something students are seldom asked to do. Furthermore, they must decide which pieces of the given information are important, and which are superfluous. Students do not automatically treat this as a “physics” question for which they go into their memorized store of physics answers, but rather tend to think about it using their natural beliefs.

Newton’s third law as an aspect of force is notoriously difficult for students to accept [5] and the next example explores this issue. This format is called a *What, if Anything, is Wrong Task* and was described by Peters [6]:

Example 2: Tennis Ball and Racquet

A tennis player returns a serve. A physics student watching the match makes the following contention:

“While the ball is in contact with the racquet the racquet exerts a larger force on the ball than the ball does on the racquet because the racquet has to stop the ball and then reverse its motion.”

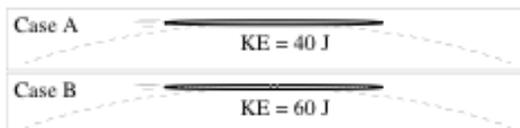
What, if anything, is wrong with this student’s contention? If something is wrong, explain the error and how to correct it. If the contention is correct, explain why.

In responding to this task the students have to first decide whether there is an error or not. If they decide there is no error they have to explain the reasoning behind the contention. If they decide there is an error they have to identify what they believe the difficulty is and then explain how to correct it.

Beside the basic aspects of the force concept there are also issues about its relation to other concepts such as momentum and energy. The following item probes students’ ideas about the relationship between force and kinetic energy in a situation where they are also likely to be wrestling with the issue of the relationship between force and velocity. This format is called a *Comparison Task*:

Example 3: Javelins

Shown below are two javelins (or light spears) that have been thrown at targets. We are viewing the spears when they are in the air about halfway to landing. Both spears have the same mass, but they have different kinetic energies as shown. (Ignore air resistance for this task.)



Is the horizontal force acting on the spear *greater in Case A, greater in Case B, or the same in both cases?* Explain.

Another task exploring students’ ideas about Newton’s third law and the relation between force and work is shown below. This one is in a format called *Conflicting Contentions Tasks*, modeled after curricula developed by the Physics Education Group at the University of Washington [7]:

Example 4: Two Skaters

Three students are discussing a situation

where two skaters—a small girl and a large boy—are initially standing face-to-face but then push off each other. After they are no longer touching, the girl has more kinetic energy than the boy.

The students make the following contentions about the forces the boy and girl exerted on each other:

Alex: *“I think the boy pushed harder on the girl because he is bigger, so she ended up with more kinetic energy than he did.”*

Bonita: *“I disagree. They pushed equally hard on each other: it’s a physics thing. But the girl moved farther while they were pushing on each other, so she ended up with more kinetic energy.”*

Carmen: *“I think that the girl had to push harder to get the boy moving since he is bigger, and that caused her to accelerate more as she recoiled.”*

Which, if any, of these three students do you agree with? Explain.

This task requires the students to consider three statements about a physical situation and decide whether any of the students has the right idea. The three student statements are couched in natural language so they will encourage the students working the tasks to deal with the situation as if they were actually interacting with their peers.

USE of nTIPERs

The tasks are designed to be used in a variety of ways. Many of the tasks are optimally suited for peer instruction, and can be used to initiate discussion among students. The tasks are constructed so that the students feel comfortable responding to them, i.e., they are the right “step size” for students, and so students usually employ their natural ideas rather than memorized physics and active discussions among the students are more likely.

The tasks are also useful as homework assignments, as quizzes, or as test items. In all cases we believe that they are most useful if students are required to write clear coherent explanations as part of their answers; promoting conceptual understanding requires the students to use the concepts in constructing arguments to support and explain answers.

Some of the task formats lend themselves well to tests. For example, the *Comparison Tasks* allow an instructor to quickly gauge whether a student has

understood a physical concept and is able to give a coherent explanation for their reasoning. It is important, however, that students are exposed to the task format in some other context before it is used as a test question.

One feature of the TIPERs is that the same physical situation is often used as a basis for questions posed in different formats. For many students the different formats will appear to be different questions. How someone reasons through a *What, if Anything, is Wrong Task* is different from how they will reason through a *Comparison Task*: The latter has a target quantity that is the focus of the student's comparing the two cases, while for the former task the student has to do a general analysis of the situation without any guidance from the identification of a specific concept or principle. Getting the students to revisit the same situation in these two different ways at two different times (for example, as an in-class activity followed by a homework assignment) promotes a more robust understanding of the relevant physics concepts.

Another aspect of using the TIPERs is that they can often be the source of the development of additional instructional materials or test items. For example, having obtained the following explanation on the tugboat and barge ranking task:

"Force is (mass)(acceleration). Also N3L states that two objects acting on each other have equal but oppositely direct forces acting on them. If this is true then the $F_{\text{tug on 1}} = F_{1 \text{ on tug}}$ which means to find the force you multiply the mass of the tugboat by the acceleration of the system."

One could give this as the contention for a new *What, if Anything, is Wrong Task*, or as one of the student statements in a *Conflicting Contentions Task*. This allows an instructor to generate new items to respond to issues that a class is having difficulty learning.

One goal of the TIPERs project is to facilitate the introduction of PER-based materials to classrooms that are primarily traditional in terms of the kinds of work that is expected of students. Because the tasks are independent of one another and are intended to be solved in a relatively short time (~5 to 15 minutes), they may be adopted by instructors incrementally as they move to increase the conceptual focus of their courses. TIPER tasks can be assigned in addition to or in lieu of more traditional homework problems. They should not require significant alterations in the approach of an instructor interested in trying them. Rather than adopt a new curriculum wholesale, instructors can try a few tasks in a semester as a trial, and then (we hope!) increase the number of tasks assigned as they become comfortable with the different formats.

REFERENCES

1. R. Hake, *Am. J. Phys.* **66**, 64 - 74 (1998).
2. A. Van Heuvelen & D. P. Maloney, *Am. J. Phys.* **67**, 252 - 256 (1999).
3. A. Van Heuvelen & X Zou, *Am. J. Phys.* **69**, 184 -194 (2001).
4. C.J Hieggelke, D.P. Maloney, S.E. Kanim, and T.L. O'Kuma, *E&M TIPERs: Electricity and Magnetism Tasks Inspired by Physics Education Research*, Upper Saddle River, New Jersey: Pearson, Prentice Hall, 2006.
5. R. K. Boyle, and D.P. Maloney, *Journal of Research in Science Teaching*, **28**, 123 - 139, (1991).
6. P. C. Peters, *Am. J. Phys.* **50**, 501 - 508 (1982).
7. L. C. McDermott, P. S. Schaffer, & the Physics Education Group, *Tutorials in Introductory Physics*, Upper Saddle River, New Jersey: Prentice Hall, 1998