Tutorial Instructor's Guide
The meaning of speed

This will be the first tutorial for many students and TAs. Consider doing some pre-tutorial preparation activities in the weeks preceding this tutorial.

All the equipment for all the tutorials is (hopefully) in one of two places: in one of the cabinets near the door of 0220, or with Bill Norwood. Whatever you're looking for, look in the 0220 cabinets first, then if it's not there, ask Bill for it.

<u>Equipment:</u>

This tutorial uses a representation of motion that is probably new to most students and TAs. Prior to the tutorial, a ribbon of paper is attached to a cart so that the ribbon drags behind the cart and through a tapping device. The tapper leaves dots as it taps the ribbon at a constant rate. There are probably envelopes in 0220 containing prepared paper segments for the students and the long ribbon needed for section III. If these are lost or destroyed, you'll need to create new ones, which is not awful but takes a little doing. See below.

For the tutorial sessions themselves, you will need:

- A "tapper" – a little black plastic device, maybe 4"x2"x2, with a metal arm that can tap on a circle of carbon paper, and some of the paper ribbon that goes with it. This is just for demo purposes, to show the students how the paper segments are generated. One for the room.
- Prepared paper segments from one of the envelopes in 0220. It's helpful to use only segments from a single envelope (probably marked A or B) – that means all the segments were part of the same cart motion. One per student (a few more or less is okay).
- A prepared long paper ribbon, marked A or B to match the paper segments. One for the room.
- Small post-it notes. Plenty for each table (these are used up).
- Rulers, one or more for each table.
- Butcher paper or 11x17 paper for each table (a plentiful supply in the room).

At the beginning of tutorial, the tables should have all of the above equipment on them EXCEPT the tapper and the long paper ribbon. The tapper should be available for the TA to show to the students. The long paper ribbon should be withheld until section III.

If the prepared paper ribbons are lost or destroyed: You will need a Pasco cart, the tapper with its carbon paper circle, plenty of paper ribbon, some tape, scissors, a wall outlet, a long hallway with a smooth floor, and a helper. Thread the ribbon through the tapper and tape it to the cart. With the tapper tapping at the faster rate (maybe 40/sec? the slow tap is 10/sec), give the cart a good push so that it rolls about 20 feet down the hall before coming to a stop (due to friction and the gentle drag from the paper ribbon – not you stopping it). The tricky part is feeding the ribbon through the tapper smoothly. It helps if one person feeds the ribbon and the other starts the tapper and gives the cart its

push. It also helps to unroll the ribbon from the roll first. Make one ribbon to leave whole (cut off the part corresponding to the initial push) and one ribbon to cut into segments. *The two ribbons should be for similar cart motions.* Cut the one ribbon into segments so that there are six dots on each segment; this should result in the segments being a convenient length for classroom measurements, ranging from about 1cm to maybe 10cm. Throw out the ones that are much longer or shorter than this. *Ideally, there would be 24 segments in a set (one for each tutorial student in a section).* In practice it's okay if there are more. Label the remaining segments in light pencil on the back so that you know they go together. For the tutorial to work well, *each paper segment should match a string of dots on the long ribbon.* Label the long ribbon so that you know which paper segments it goes with. While you're at it, make another set, so that you have a spare.

I. In this part students interpret the motion represented by segments of paper generated by the tapper. Most students **and TAs** are not familiar with the tapper. Some may want to have the device briefly demonstrated to them, or may misinterpret the representation in a way that will be helped by seeing the device. A demo is optional.

    A. The question, "What kind of motion does each represent?" confuses some students. Ask them, *For example, is the cart speeding up, slowing down, or moving at constant speed?* The dots on each paper segment are equally spaced, indicating uniform motion during that time interval. (If you made the tapes yourself, you know that the overall motion of the cart that generated the tapes was not uniform; keep that to yourself for now.)

        1. Each paper segment has the same number of dots on it and was therefore generated in the same time. This is not as trivial as it may sound. Quite a number of students think that the longer segments must have taken a longer time to generate (because they're longer) or a shorter time to generate (because the cart was going faster). It is easy for students and TAs to miss the fact that they think different things, especially because "longer" and "shorter" can refer to either space or time. Listen carefully.

        2. Students usually do this correctly, which in some cases means implicitly contradicting their answer to the first question. Again, it takes pretty careful listening to know when this is happening.

    B. It doesn't actually matter whether the tapper actually went at 40/sec or not.

        1. Students do fine with this quantitative part, sometimes contradicting their qualitative answers in part A.

        2. Students do fine with the calculations. Some have trouble recognizing the assumptions that go into the calculation: for example, that the motion of the cart was uniform in between the dots, and continued uniformly in the same

way before and after the dots. (Neither of these is true for the cart, actually, but there's no reason to mention that here.)

3. Students should not write on the paper segments, but on sticky notes attached to the paper segments. Each segment should be labeled.

II. In this part students interpret calculated numbers associated with the motion of the cart. This is a new skill for most students **and TAs** and many of them do not see its usefulness at first. This tutorial has not historically been very successful at teaching students to do good interpretations. Stronger instructional support might help.

A. The kind of answer the tutorial is looking for is, "The speed is the number of centimeters that the object moves in each second." This answer tells you the *meaning* of the number in terms of what is happening physically to the cart. Undesirable answers include:
   - "The number is the speed." Speed is the name of the number, but the task here is to say what that number tells you about the physical motion of the cart.
   - "Distance divided by time." This tells how to calculate the number, which is a great thing to know, but does not say what the number means.
   - "It's the number of centimeters per second." For some students "per" indicates a mathematical operation rather than relating to anything physical, so it's worth making everyone avoid it. Ask students to find a way to say it without any math.

   Students may think this is unnecessarily pedantic for a quantity they believe they already understand well. Students may not understand speed as well as they think they do. TAs, meanwhile, may have trouble believing that anyone has any difficulties with speed, and worry about alienating students with such a basic activity. Both of these issues can be addressed by emphasizing that this is practice for interpreting more difficult quantities later on.

Checkpoint: This is primarily to check on their interpretation, above, because almost no one understands what they're being asked for initially. Discussion of this interpretation can lead to checking on the subtleties of part A above (comparing the time to generate each tape).

B. 1. Students sometimes say 40/1.5 is the velocity rather than the speed. You can decide for yourself whether you want to emphasize this distinction or not.

   2. A good answer is, "40 is the number of centimeters that the train moves in each second." All the same issues arise as in part A above. Some students say "40 is the speed" and then complain about the tutorial being repetitive, since they just gave that answer in part 1. The point of asking both questions is to hopefully make the distinction clearer.

3. A good answer is, "If the train moves 40 cm in each second, it moves 80 cm in two seconds, and another 20 cm in half a second; so in 2.5 seconds, it moves 100 cm." Multiplying 2.5 by 40 is also fine *if* students provide an explanation as to why multiplication is appropriate. Arithmetic is fine; what the tutorial wants to avoid is "x=vt=40t=40(2.5)=100." Some students **and many TAs** are really freaked out by being told not to use an equation. **Some TAs are offended** by the idea of steering students away from quantitative representations. Explain to those who are concerned that most students are actually very good at churning through algebraic formalism, and that the more difficult part is to understand what the formalism represents. The emphasis throughout the tutorials is on conceptual understanding of what's happening physically; the rest of the class has quantitative representation aplenty.

C. 1. "No" is a perfectly fine answer. This bugs people; they will ask for the answer. When they do, tell them it's fine to answer "Not that I know of," and ask, *Can you give an interpretation of the quantity even if you don't know a name?* The answer should be yes. The point of the pair of questions is, again, to make the distinction between the name (if any) and the interpretation. (One might call this number the "pace," as in a four-minute mile, but students don't need to know that, and if you tell it to them, they might think that they do.)

2. A good answer is, "0.025 is the number of seconds that it takes the train to move one centimeter." Try to make sure students are not just being formulaic when they say this but are instead really picturing what it means.

3. A good answer is, "If the train takes 0.025 seconds to travel one centimeter, it takes 90 times that amount to move 90 cm; so the time it takes is 90(0.025) = 2.25 seconds." Again, arithmetic is fine, just not equation-pushing.

III. In this part students consider nonuniform motion, and in particular, develop interpretations of instantaneous speed and average speed.

A. Any pattern in which the dots are unequally spaced is fine.

B. For this activity, the TA should lay out the long paper ribbon corresponding to the whole motion of the cart on a long table or on the floor. In 0220, consider putting the tape out in the hallway. Each student should bring her paper segment (labeled with its post-it note) to the long ribbon. TAs give the following instructions/questions:

- *Look over this long ribbon of dots. This was made by the same tapper device that made your short paper segments. Describe the motion of the cart that generated this long ribbon.* (It was speeding up (or slowing down), because the dots get farther apart (or closer together). You can't tell which.)

- *What kind of motion does your short segment represent?* (Constant speed, 30 cm/s or whatever.)
- *Is there a spot on the long ribbon that almost matches your short segment?* (There is, by construction. If there's not a perfect match students might try flipping their segment over (left-right).)
- *Is it possible that your short segment was actually part of an overall motion that looked like this long ribbon?* (Yes, it sure is.)
- *So motion that is overall speeding up or slowing down could be made up of shorter motions that are constant speed? How can that be?* Pause for philosophical conundrum. See what students make of this.
- *Leave your segment here.* As the class period goes on, students' segments will begin to reconstruct the whole long ribbon, which is kind of cool.

An alternative activity is to forgo the long ribbon and have students all stop at once, line up in order of the speed that they calculated, and observe that their paper segments fit together end-to-end like a puzzle. Use similar questions to the above.

C. The answer is "no," because the interpretation of the speed was "the number of centimeters the train moves in each second," and under the assumption that the paper segment is part of a long ribbon like the one in the demo, the cart didn't move in the same way each second. A good new interpretation would be "the number of centimeters the cart *would move* in each second *if it continued to move the way that's shown on the paper segment.*" The name for the speed interpreted this way is the "instantaneous speed." Note that "the speed the cart was going at that time" is not an interpretation; that's just the name again, phrased slightly differently.

D. If you measured the distance between two widely separated dots on the long ribbon, and divided that distance by the time it took the object to move that distance, the resulting number should be interpreted as "the number of centimeters the train would move in each second if it moved at constant speed between making the one dot and the other dot." **This is hard.** Many will recognize that this is the quantity whose name is "average speed," but few students **or TAs** will be able to provide a good interpretation.

Checkpoint: This checkpoint is mainly to check on students' interpretations of instantaneous and average speed (above). Notice that the tutorial holds their hands less and less as it proceeds… sometimes students **and TAs** miss the fact that a question is challenging, because it appears short on the page. Instructors should help participants recognize where the challenges lie.

IV. In this part we try to draw students' attention to what's most important in the tutorial. The multiple-choice questions are really, truly constructed so that a smart student

might agree with more than one of the answers, or have a good answer that's not on the list. The intention is to spark discussion about the issue.

A. It's true that one can do all kinds of meaningless calculations in physics and only a few of the infinite number of possible arithmetic results are physically meaningful (option i). Option ii is also true, and gives a good hint about the use of interpretations. Option iii is perhaps a little less desirable, but we admit that it's sometimes practical: how much interpreting is worthwhile to do might depend on the class you're in and the assignment you're doing.

B. Again, all of the options have at least some merit. However, option i is probably not practical. The other three options are, in my opinion, increasingly sophisticated in the order they're shown, but they're all valid.

Checkpoint: Students will probably look for the "right answer." TAs should try to convince them that there are many issues by engaging in genuine discussion of more than one multiple-choice option.