RELATING REPRESENTATIONS IN KINEMATICS

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ABSTRACT

This article focuses on the importance, development, structure, and delivery of an assessment tool that I created called Relating Representations in Kinematics (RRK). When teaching physics, we constantly remind the students that there are generally four different ways to represent motion—verbally (V), mathematically (M), graphically (G), and diagrammatically (dot diagrams, D). The RRK tests students on their ability to differentiate between the representations and their ability to transfer information from one representation to another. This formative assessment tool can also be used as an activity to help students practice relating between the interpretations of motion.

Introduction:

According to the NYS Physical Setting/Physics Core Curriculum, students are required to be able to distinguish, relate and interpret symbolic, verbal, and mathematical information (Standard 1, Key Idea 1). Research also shows that students must know how to relate one interpretation of motion to another in order to master their understanding of kinematics. "The thinking involved in making the translations to and from graphs help register the concepts [of kinematics]," (Arons, 29). "Apparently students who could correctly translate from one kinematics graph to another also had the best overall understanding of kinematics graphs," (Beichner, 754).

This assessment tool is only 4 questions long, but each question includes a combination of relating interpretations. For example, question 1 has the format "G, V, M, D." Students must analyze a velocity vs. time graph and qualitatively sketch the acceleration and position vs. time graphs to complete the graphing section of the question. They must then take the graphical information and explain the motion verbally. The next step is to use the verbal part of the question to answer a mathematical problem. Finally, they are asked to draw dot diagrams to represent the same motion. Since students must graph something 3 times, there are 5 problems per question. So there are actually 20 problems for this assessment.

Mathematically, there should be 24 different ways to arrange these 4 representations, however, most of the combinations repeat itself—for example:

a) G, V, M, D

b) G, V, D, M

Although the combination is different, students are relating a verbal representation from the graphical for both questions. This route will yield a 120 problem assessment which is very excessive. Therefore, the format for the assessment is:

G, V, M, D

V, D, G, M

D, M, V, G

M, G, D, V

This format ensures that the students will be assessed on every possible way to relate the representations with the minimum amount of questions so that it is possible to use this assessment as a full period exam.

Structure of the RRK:

Question 1: GVMD

The RRK begins with a velocity vs. time graph of a ball in motion. The ball is slowing down while traveling in the positive direction and speeding up while traveling in the negative direction. This is a classical case of a ball being thrown up in the air or rolled up a ramp. I start with this question to reinforce the importance of constant acceleration while slowing down. A similar question has been mentioned in the June 2007 NYS Physics Regents Exam (Question 41).

Students are then asked to draw the position vs. time and acceleration vs. time graphs accordingly. It is important to mention that they must start at the origin for the position graph for ease of grading. Otherwise, students will start at whatever position they want, and the grader must accept multiple answers. This also helps reinstate the idea that an object that slows down does not travel backward until it stops. Students frequently draw a position vs. time graph as an "inverse" curve when they are asked to graphically represent the motion of an object decreasing its speed.

Students are then asked to write a verbal description of the motion. "Students should be led to translate graphs into verbal description. They should also translate verbal description into graphs," (Arons, 35). Students should include enough information as to provide them with a sufficient amount of givens to solve the next part of the question, which is to calculate the acceleration.

Using their calculated acceleration, students must now draw dot diagrams for the motion of the object. Since their first dot will represent t=0, they should have 9 dots for this step. The students must not only figure out the separation of the dots but also the direction and size of the velocity and acceleration vectors for each moment of time. Since they calculated the acceleration for the step before, they get extra practice with the idea that acceleration means the change in velocity for every dot and not velocity itself. "If asked to describe, in simple, everyday words, what "acceleration" means, many students respond 'how fast it goes,' with no very clear antecedent for the pronoun 'it.' If then asked to describe what 'velocity means, they give the same response," (Arons, 32).

Question 2: VDGM

As further practice and proper segue for the concept of acceleration, students must first figure out how many dots they must use in order to correctly draw their dot diagram based on the given verbal information. They are not plugging numbers into an equation but rather thinking conceptually about how long it will take for an object to reach that speed with the given acceleration.

If a student makes a mistake on the dot diagram, then the graph should be graded based on the dot diagram and not the verbal description. The question clearly states that students are to use their dot diagram to answer the next step, not the verbal representation. This ensures 2 things: 1) Students are following the intended order and 2) students can go back to check if all their steps make sense when the steps are compared to each other. At this point, students can quantitatively sketch the velocity and acceleration vs. time graphs but only qualitatively sketch the position vs. time graph.

The next step is a good way to check if the students are following instructions. The question clearly includes "*Using your graphical description*." If the students try to calculate displacement by using one of the kinematics equations, he is not approaching it correctly. Students must calculate the area under the velocity vs. time curve in order to properly arrive to their answer. "Students do not recognize the meaning of areas under kinematics graph curves," (Beichner, 755).

Question 3: DMVG

The dot diagram represents a jogger running at a constant velocity. Students are to use their general constant velocity equation (d=vt) in order to solve the problem. Any inclusion of acceleration in a student's answer for this problem is a clear indication of his lack of conceptual understanding of acceleration.

For the verbal representation, students must mention either constant velocity or constant acceleration. The grader should not accept constant speed unless it is accompanied by constant direction. The dot diagram clearly shows that the object is traveling in a straight line and the velocity vectors are not changing directions.

Students must now make graphs out of their verbal representation. "Students should be asked to translate from motion events to kinematics graphs and back again," (Beichner, 755). They should be able to figure out that the acceleration has a value of zero m/s/s and the velocity has a value of 4 m/s for the entire time of motion. The position will increase with a constant slope until it reaches a value of 20 m on the 5th second.

Question 4: MGDV

The final question of the RRK starts with a train that is slowing down in the *negative* direction. Students must understand that an object that slows down is accelerating in the opposite direction. For example, if a car is slowing down while traveling east, the acceleration vector is pointing west. Students are asked to calculate the time but they must first calculate the acceleration which should yield a positive number. This reinforces the idea that a positive acceleration does not always mean speeding up. Once they determine the acceleration, they can easily figure out the time of motion.

Once the time of motion is determine, students have enough quantities to sketch all three graphs. The position vs. time graph for this problem will be the hardest to sketch. Students must first realize that the object is moving in the negative direction; therefore the graph should be below the horizontal axis. Next, they must draw a curve with a steep negative slope initially and a flatter, non-zero negative slope at the end. They usually have a very difficult time figuring out this solution.

Students will now draw dot diagrams based on their graph. "Unless they are explicitly led to do so, students do not consciously connect the graphs with actual or visualized motions; they treat them as uninterpreted abstractions," (Arons, 28). Again, for ease of grading, I included the direction for what would be considered the positive direction for this problem. Obviously there is no definitive positive or negative direction, but by including the sign of the direction for this problem, there will only be one correct direction. Students must now draw dots from right to left, decrease the spaces between the dots, and have acceleration vectors pointing to the right while the velocity vectors, which should decrease in size sequentially, will point to the left.

Finally, students should be able to extrapolate information from the dot diagram to make a verbal description of the motion. This seems like a very easy task, but it's as difficult as the one before. Just as stated, students must use their information from the dot diagram in order to answer the verbal part. If they have an incorrect dot diagram, their verbal description should be a continuance of their diagram and not the graph, which most students will be inclined to do. Therefore, students may not get full credit even if they correctly describe the motion verbally if they incorrectly described it diagrammatically.

Grading:

Although the test is constructed in a way that is relatively easy to grade, there are still some unavoidable issues that may or may not be solved depending on the grader. For starters, the RRK follows the rule that the approach for a problem within a question must sequentially follow the problem before it. For the VDGM question, students must use the graph in order to solve the problem mathematically.

The problem this causes is similar to problems we face when grading the NYS Physics Regents exam. If a student gets the initial problem incorrect, she can still receive full credit for the next problem if she carries along the previously incorrect answer. In this case, a student may not have any idea how to draw the dot diagram for Question 4 and will draw 5 evenly spaced dots with no acceleration and equally sized vectors for all 5 dots.

They will clearly be marked incorrect for the incorrect dot diagram. But for the verbal description, a student could write "the object is traveling at a constant velocity of 50 m/s for 5 seconds." Technically, she will be marked correct because her verbal description correctly relates to her diagrammatical representation. I have yet to figure out a way to eliminate this shortcoming. The student was able to translate a dot diagram into words, but she clearly took the easy way out. On the other hand, I would not give her credit if she states that the object is slowing down in the negative direction if her dot diagram does not display this. The purpose of this exercise/assessment is to ensure that there is at least one question where the students must translate a dot diagram into words.

Delivery of RRK:

For most formative assessments, I feel that it is best to administer the assessment three times—once before the introduction to the unit, once directly after, and once at the end of the year. The first time should be used to help teachers and students analyze where their strengths and weaknesses are regarding the concepts of the topic. The second exam should show where/if improvements were made. Unlike most articles, a third exam is equally important. Students could sometimes memorize a few ideas without actually internalizing the concept in order to pass an exam. Those memorized ideas will leave their system in a matter of time and will be harder to recall for a later exam unless they completely understood the material.

For that reason, I administer the RRK right before the subtopic of graphical motion, directly after that topic, and once again in June when they are reviewing for the NYS Regents exam. Students need to know important words like position, initial velocity, final velocity, etc. in order to answer any of the questions, so I wait until we at least introduce the general concepts and mathematical equations of kinematics.

An important aspect of any assessment tool is the method of delivery. Assessment data is most accurate when it is properly administered. For example, when I first handed out the Force Concept Inventory to my students, I made the terrible mistake of saying, "this will not be graded." After all, they cannot be graded on something they've not seen before in my class. The problem is high school students will not take exams seriously when they hear those words. The data was terrible, and some students either chose choice "c" for all questions or they left most of them blank. The next year, I used a rather productive method, and I've used it flawlessly year after year. I call it "the Physics IQ Test" and mention that it's hands down, documented and solid proof that this test will determine the smartest student in the class. It's amazing how well students work under these conditions. During the post test, I tell them that it is now being graded (since they've seen the material in class), and the students work equally as hard. Obviously every student and every school is different, but this works impeccably with the students in my class.

Conclusion:

Relating Representation in Kinematics is a wonderful tool that could be used as a formative assessment or a classroom activity to help strengthen the concepts of motion and shorten the gaps of misconceptions. The RRK has been shortened to fit into one or two periods depending on the class time and students' skill levels. It is also only 4 pages long, which will conveniently not take much paper or time while copying. Hopefully, we can all use the RRK to ultimately lead the students to a better overall understanding of kinematics. Clear comprehension of kinematics at the beginning of the year will lead to a strong understanding of the topics that follow. "We have shown that improving student understanding of kinematics also improves student learning of dynamics, *even if dynamics is taught in a traditional manner*," (Sokoloff & Thornton, 343).

References

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3. Hestenes, D., Wells, M. & Swackhamer, G. (1992, March). Force concept inventory. *The Physics Teacher*, 30(3) 141-153.

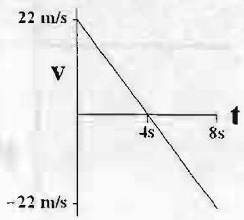
4. Sokoloff, D.R. & Thornton, R.K. (1998, April). Assessing student learning of Newton's laws: The Force and Motion Conceptual Evaluation and the Evaluation of Active Learning Laboratory and Lecture Curricula. *The Physics Teacher*, 66(4) 338-352.

Name____Per________Date______________

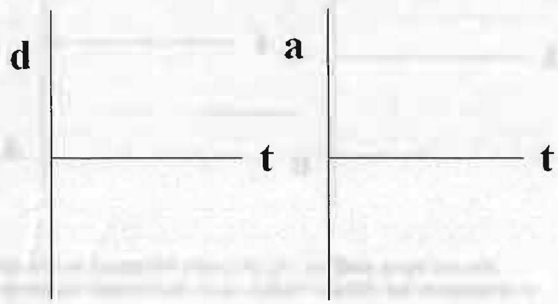
Relating Representations in Kinematics (RRK)

Question 1: #3? or #4

Below is a velocity vs. time graph for a ball in motion:



a) Sketch (qualitatively) the position vs. time (start at the origin) and acceleration vs. time graphs for this motion:



b) Write a brief story about the motion of the ball (what is the ball doing?). Make sure to include any quantities that are given in the previous representation:

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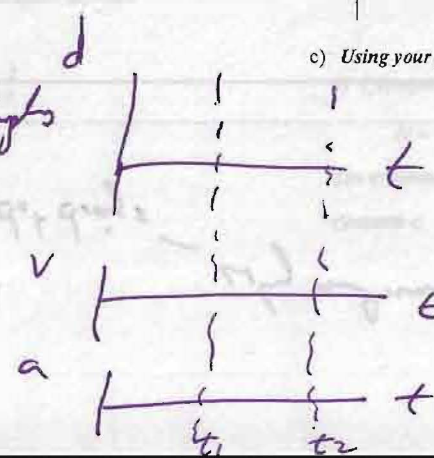
c) *Using your verbal description*, calculate the acceleration of the ball throughout the 8 seconds of motion (Show all work):

coin toss prob

why not align graphs vertically to compare same t_n?



d) Draw a dot diagram to represent this motion. Assume the dots are taken after each second. Make sure to include velocity & acceleration vectors and any quantities that are given in the previous representation:

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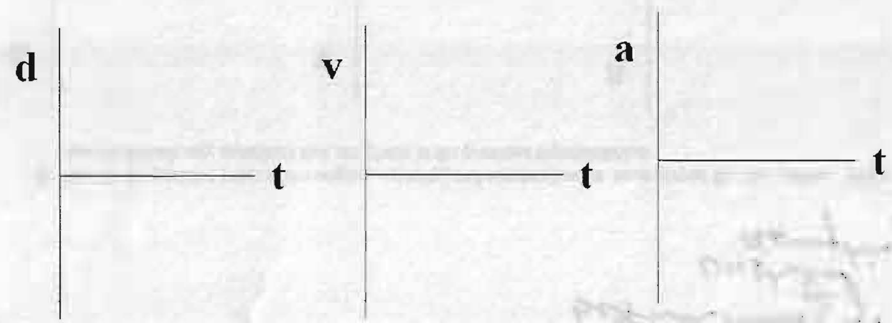
Question 2: OK Constant $\vec{a}$

A car starts from rest and accelerates at a constant rate of 6 m/s/s until it reaches a speed of 30 m/s.

a) Draw a dot diagram to represent this motion. Assume the dots are taken after each second. Make sure to include velocity & acceleration vectors:

b) *Using your dot diagram,* sketch the position (start at the origin), velocity, and acceleration vs. time graphs for this motion. Make sure to include any quantities that are given in the previous representation:



c) *Using your graphical description,* calculate the displacement of the car (Show all work):

easyist. This problem seems easyist + defines dot diags — why make it #1?

Question 3:

The following is a dot diagram of a person jogging:

Constant $\vec{v}$

t=0					
4 m/s	4 m/s	4 m/s	4 m/s	4 m/s	4 m/s
v ⟶	v ⟶	v ⟶	v ⟶	v ⟶	v ⟶
•	•	•	•	•	•

a) Assuming the dots are taken after each second, what is the jogger's displacement? (Show all work)

b) Write a brief story about the motion of the jogger (what is she doing?). Make sure to include any quantities that are given in the previous representation:

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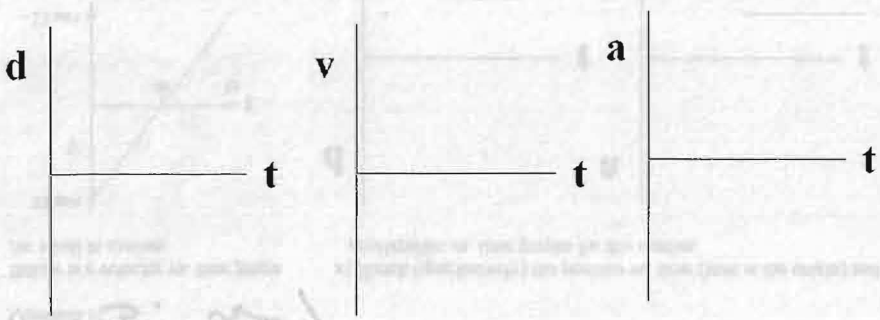
c) ***Using your verbal description,*** sketch the position (start at the origin), velocity, and acceleration vs. time graphs for this motion. Make sure to include any quantities that are given in the previous representation:



Question 4:

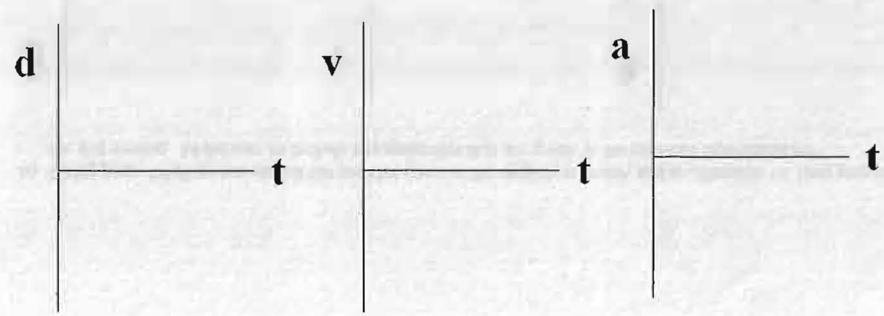
n alternative X'scriptions is a constant between these (an unstated assumption)

The following numerically represents the motion of a train:

Vi = -50 m/s   Vf = -25 m/s   d = -150 m

a) Calculate the time of motion (Show all work):

b) Sketch the position (start at the origin), velocity, and acceleration vs. time graphs for this motion. Make sure to include any quantities that are given in the previous representation:



c) ***Using your graphical description,*** draw a dot diagram to represent this motion. Assume the dots are taken after each second. Make sure to include velocity & acceleration vectors and any quantities that are given in the previous representation (**right of the page is the positive direction**):

d) ***Using your dot diagram,*** write a brief story about the motion of the train (what is it doing?). Make sure to include any quantities that are given in the previous representation:

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