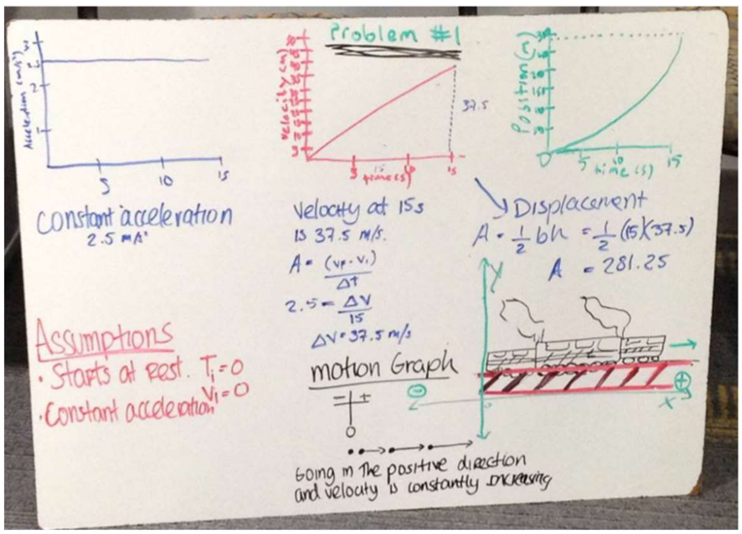
Worksheet – Model Building (For the Instructor)

Introduction

The goal is to have students build a conceptual model for a situation involving (primarily) electric potential energy. A "model" here refers to a coordinated set of multiple representations (diagrams, graphs, equations, words) that cover the physics involved. Such a model can be used to explain, predict, and/or describe a physical situation.

Is that a little vague? Here is an example (by students!) of a conceptual model in mechanics for an accelerating train[1].



There is no question to be solved here, but if the students can build a model, they understand the relevant physics, are able to communicate that understanding, and are well prepared to tackle any problem.

McPadden & Brewe (2017) review the research on the use of multiple representations by students. A couple of key takeaways:

1. Research indicates that "**using multiple representations improves students conceptual understanding and ability to solve problems**."
2. "Studies indicate that students do not naturally use the representations as their instructors intend. Therefore, **it is important that we teach students how and when to use representations** in order for them to use multiple representations effectively."

As a physicist, when I'm solving a question, I might only actually use a subset of these representation (especially when I know the problem type). However, when I'm faced with a real problem (one where it's not clear what the path to the solution is), I naturally turn to this model building to gain some insight (although I never really called this "model building" before, just problem solving…). I don't know when I learned to do this, but the goal is to explicitly <u>teach</u> this practice to the students with this activity.

---

[1] McPadden & Brewe 2017, PHYS. REV. PHYS. EDUC. RES. 13, 020129

The situation for the model building worksheet was chosen because it offers a rich collection of representations. It was inspired by a suggested problem (part a) from Knight's[2] Instructor Manual, Chapter 25.

1. A 2 mm diameter plastic bead is charged to -1 nC.
    a. An alpha particle is fired at the bead from far away with a speed of 10^6 m/s and collides head-on. What is the impact speed?
    b. An electron is fired at the bead from far away. It "reflects", with a turning point 0.1 mm from the surface of the bead. What was the electron's initial speed?

[2] Knight, Randall D. *Physics for Scientists and Engineers: A Strategic Approach, 4th Ed*. Pearson., 2017

<u>The Activity (In Class)</u>

1. **(~5 minutes… not too long.)**
   Start out by introducing the concept of a model to the students.
   a. Show the students an example of a conceptual model (like the one above for an accelerating train). Give them a few minutes so that they have a chance to make sense of what they are seeing.
   b. Ask the students, based on the example, to explain what a model is.
   c. Motivate that our goal is not to solve a problem, but to come up with as many representations of the physical situation as possible.

2. Get the students into groups at the whiteboards. I suggest groups of about four.

3. Give each group a copy of the worksheet and have them assign one note-taker to copy what they have on the board onto the paper.
   a. Emphasize that it's important for the note-taker to be taking things down as the group is working on the board, since you are going to collect these worksheets and choose one to distribute as the class solution.

4. **(~25-30 minutes… enough time to construct a model, but not necessarily finish)**
   Have the groups build their model for case 1.
   a. Re-emphasize that the goal here is to get as many different representations as possible.
   b. From my experience, students jump into the model building fairly well after seeing the example, but you'll likely have to lead them along at points during this process.

      i. If need be, you can start by being somewhat vague to the class as a whole ("What kind of diagrams can you make?", "What can you graph?", "What kind of assumptions can you make?", "Describe what is happening with words").

      ii. After **~10 minutes**, you can start giving more specific suggestions to individual groups. Take a look around the class to see what kind of representations are missing (my groups often overlooked energy & potential, and almost all missed equipotentials and field lines). We'd like at least one example of each representation in the class, so if you see something missing for the class a whole, you can give an individual group a push in that direction.

5. **(~15 minutes)**
   Have each group pair with another and have them present their models to one another.
   a. Emphasize that the note-takers should add to their worksheet based on this discussion.

6. **(~10 minutes)**
   Wrap-up with a class discussion. The students have been at this for a while, so I'd keep this short.

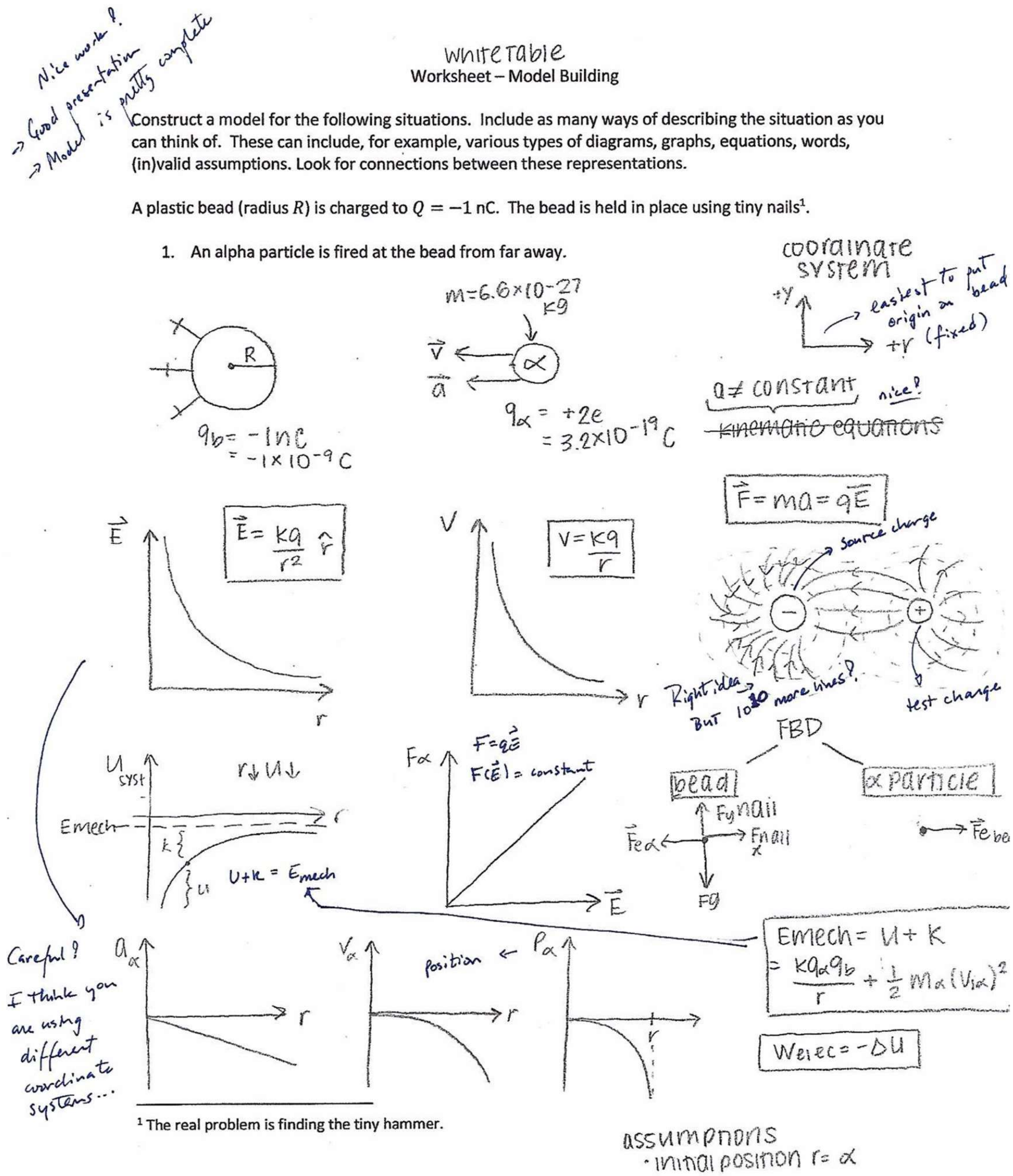
   You could ask the students to share some of the points below:
   a. What they discussed during the group presentations.
   b. What types of representations they forgot.

c. What (is)are the possible physical outcome(s) for the situation?
d. What are the connections between different representations? (e.g. force and energy)

This is a good time to quickly summarize the motivation for the activity. I tell my students that they should feel like physicists at this point.

7. Don't forget to collect the worksheets.

An Example From my Class (annotated by me)



The Activity (Follow Up)

I followed up the activity by taking the most complete model from my class, annotating it and posting it as a solution. I spent about ~5 minutes going over it at the beginning of next class. I wanted to show the students that I valued the work that they did.

In the future, I'd like to further emphasize model building in my course. Doing something once isn't enough to build a skill. This requires repetition, reinforcement, and evaluation (this last point will motivate the students and also communicate that I value this skill).

I'd like to

1. Do this at least one more time in class.
2. Have an evaluation specifically for model building. This could either be a homework to be passed in, or a quiz. A couple of possible scenarios to be modelled come to mind:
    a. Similar to the worksheet: an electron is fired at a negatively charged bead from far away.
    b. The motion of a charged particle in a parallel-plate capacitor.

Worksheet – Model Building (For the Student)

Construct a model for the following situation. Include as many ways of describing the situation as you can think of. These can include, for example, various types of diagrams, graphs, equations, words, (in)valid assumptions. Look for connections between these representations.

A plastic bead (radius R) is charged to $Q = -1$ nC (The bead is held in place using tiny nails[3]).

A proton is fired at the bead from far away.

[3] The real problem is finding the tiny hammer.