Locating Introductory Mechanics Problems Along the Well-structured-Ill-structured Continuum

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Most textbooks code problem difficulty with a single number (or color), which fails to describe the different ways a problem can be challenging for a student. We have developed an objective coding scheme for introductory mechanics questions that provides instructors and students with scores that are based on the process by which problems are solved.

ACE Problem Solving Process

We encourage students to follow a three-step process that is similar to Polya's:

- *Analyze the task*: interpret and understand what is provided in the task.
- *Create a plan*: connect the given information and goal with models/ concepts/ relationships
- *Execute the plan*: follow the plan until the goal is attained.

Features of a problem may make one of the three steps more difficult than the others. For example, some problems provide physical information directly while others conceal it within intricate contexts, which alters the *Analyze the task* difficulty.

Of course, problem-solving is not a linear process as experienced solvers move back and forth between the steps often repeating each one several times. (To learn more about our work on how students decide to move between steps based upon a self-monitoring of their work, please visit our PERC poster or contact us.)

Well-structured and Ill-structured Problems

Well-structured problems include all of the necessary information, whereas ill-structured problems are missing required information, and/ or contain ambiguous information that could result in multiple acceptable solutions. Often problems are portrayed as existing at one of two extrema when in reality there are many degrees of "structuredness" a problem can have along this continuum.

Introduction

Inspired by information overload and cognitive load theories, we created a coding scheme that is based upon the number of features a solver must consider within each of the three problem-solving steps.

The explicitness of each feature is also used to determine the score for each step.

- *Explicit (E)*: These are features that are presented in straightforward physics language (eg "moves at a constant velocity", "begins at x=0", "Compute the object's final velocity.", etc.)
- *Implicit of the First Order (I_1)*: Features that requires a single step of logic to connect to a physical variable or model, are considered of type I_1. These are typically synonyms for physical information stated in everyday language (eg "walks at a steady pace", etc.)
- *Implicit of the Second Order (I_2)*: These features require more than one step to decode. Examples include a question that asks "Will you catch the train?", assumptions that were not specified by the question or information that is inferred from multiple features distributed throughout the problem.

Analyze the Task

These features are inherent within the problem itself. In a mechanics problem, the relevant features include:

- Values of physical quantities
- Motions of objects
- Interactions between objects
- Goal of the problem

Features of type *E* are assigned a zero and type I_1 a one. The *Analyze* score is the sum of these.

Create a Plan

The features that contribute to the *Create* score are ones that are developed by the solver. Each assumption made ("ignore air drag") contributes one point. Our scores assume that the solver make the fewest and simplest assumptions necessary that do not contradict the given information.

Any I_2 values, motions, interactions and goals that are inferred from the assumptions, or multiple components of the problem statement, contribute one point each. Similarly, physical information presented in the problem that is now determined to be extraneous, also contributes one point to the *Create* score.

The number of physical models (conservation of energy, etc.) that one uses to connect the information also is added to the *Create* score.

Execute the Plan

This score captures how difficult the calculations are. The score is number of variables and physical constant in the final algebraic solution. (Variables or constants, such as mass, that cancel when simplifying the final solution are not counted.)

As part of the simplification process, one may require geometric of trigonometric relationships. Each of that is used also contributes one point to the *Execute* score.

The *Execute* score for textbook problems that guide students through a solution with multiple prompts/ parts is simply the sum of the *Execute* scores for each prompt.

Examples

(A 0, C 8, E 5) A 12g bullet collides with a 100g wooden block initially at rest on a horizontal surface. After impact, the block slides 7.50m before coming to rest. If the coefficient of friction between the block and the surface is 0.65, what was the speed of the bullet immediately before impact?

Create score= 3 Assumptions (point particles, closed system, insignificant air drag) + 1 I_2 motions (constant acceleration) + 1 I_2 interaction (weight near the surface of the earth) + 3 Models (linear kinematics, Newton's second law, conservation of momentum)
Execute score= 5 variables & physical constants

(A 3, C 12, E 5) You are once again in court as a technical advisor. This time you are working with the defense in a murder case. The victim was killed with a single bullet. A second bullet, which missed the victim, was found embedded in the victim's chair. The lawyer for whom you're working is currently questioning one of the police officers who investigated the crime scene.

Lawyer: In what type of chair did you find the bullet?
Detective: A leather reading chair with wooden legs.
L: How heavy was the chair?
D: Forty pounds.
L: How did the chair respond to being struck with the bullet?
D: It slid across the floor.
L: How do you know this?
D: The floor had a small amount of dust, except near the chair legs where they had cleared the floor as they slid.
L: How long were these scuffs?
D: Two inches.
L: What kind of floor was in the room?
D: It's a hardwood floor made from oak boards.
L: What was the mass of the bullet retrieved from the chair?
D: Three-tenths of an ounce.
L: Have you tested the gun you found in my client's possession the night of the murder?
D: Yes
L: What is the muzzle velocity of the bullets fired from that gun?
D: The muzzle velocity is one thousand miles per hour.
L: Thank you. I have no more questions.

I_2 interaction
I_1 value
I_2 interaction

As the lawyer sits down, what do you tell her?

Create score= 5 Assumptions (point particles, closed system, velocity independent friction, horizontal surface, insignificant air drag) + 2 I_2 motions (constant acceleration, constant velocity) + 1 I_2 interaction (weight near the surface of the earth) + 1 I_2 goal + 3 Models (linear kinematics, Newton's second law, conservation of momentum)
Execute score= 5 variables & physical constants

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