Investigating Trajectories of Learning & Transfer of Problem Solving Expertise from Mathematics to Physics to Engineering

PI: Dean Zollman
Kansas State University

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Project Activities

This project is a step in creating a knowledge base on the evolution of students' problem solving skills over the span of three years of STEM courses. Over the course of the project we will investigate the development and transfer of problem solving skills in undergraduate mathematics, physics and engineering courses. During this first year we used individual semi-structured interviews to capture fine grained data about individual student's problem solving. Based on these insights we began the enhancement of an adaptive online system which will collect data from large numbers of students.and map the students' trajectories as the build toward problem solving expertise. The longitudinal study is just beginning so during the first year phase, we focused primarily on cross-sectional studies in courses in mathematics, physics and engineering.

Research Questions: During the first year of this grant we addressed the following research questions

1. What kinds of difficulties do students have when transferring their problem solving skills across problems in different representations?
2. How can we facilitate students' transfer of problem solving skills across problems in different representations?
3. How can we improve on online homework systems to obtain the data needed in the longitudinal study?
4. What views of mathematics held by electrical engineering students are important for oru study?

Methodology for Research Questions 1 & 2:: The first two questions were addressed during four sessions of individual think aloud interviews. Each interview was conducted after an exam in the class. In each interview, students were asked three problems, except in Interview 1 when only two problems were asked.

- Original problem: a problem from the recent exam
- Graphical problem: modified version of original problem in which part of info is given as graph.
- Functional problem: modified version of original problem in which part of info is given as a function

Participants: The participants were students who were currently enrolled in first semester calculus-based physics. They included the following

- 5 students in electrical engineering
- 6 students in mechanical engineering
- 3 students in chemical engineering
- 2 students in civil engineering
- 1 student in architectural engineering
- 1 student in environmental engineering
- 1 student in chemistry
- 1 student in open option

Interview Topics and Problems: The interview questions were based on the following topics

- *Interview 1: 1D Kinematics*
  - Original Exam Problem

    The position of an object moving along an x axis is given by $x = 3t^3 - 2t + 4$, where x is in meters and t in seconds.

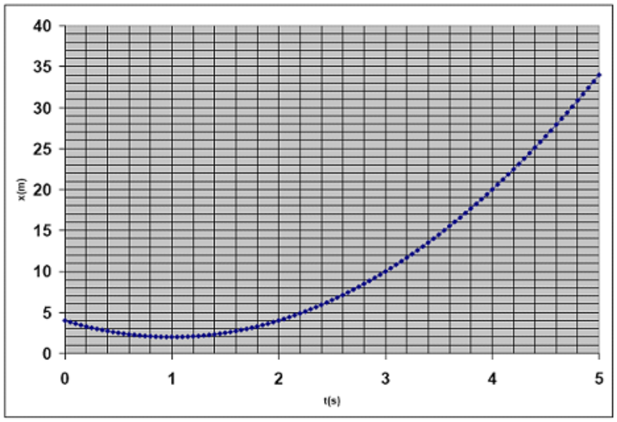
    a) Find at least one time when the velocity is zero.

    b) What is the average acceleration between 0 and 3 seconds?

    c) What is the acceleration at $t = 3$ seconds?

  - Graph Problem

    The position of an object moving along an x axis versus time is given by the graph below, where x is in meters and t in seconds.



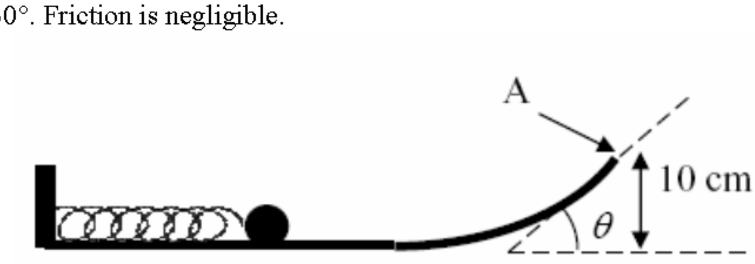
a) Find at least one time when the velocity is zero.

b) What is the average acceleration between 0 and 5 seconds?

c) What is the acceleration at $t = 3$ seconds?

- *Interview 2: Work & Energy – no Friction*
  - Original Exam Problem

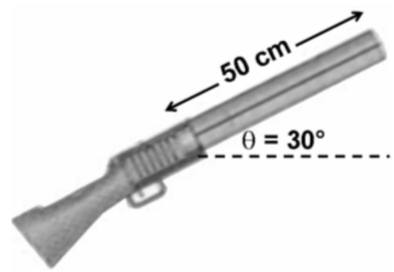
A spring of spring constant 3.0 kN/m is compressed a distance of 1.5 cm and a small ball is placed in front of it. The spring is then released and the small ball, mass 0.1 kg, is fired along the slope and launched into the air at point A which is 10 cm above the spring. The angle θ of velocity at launch is 30°. Friction is negligible.



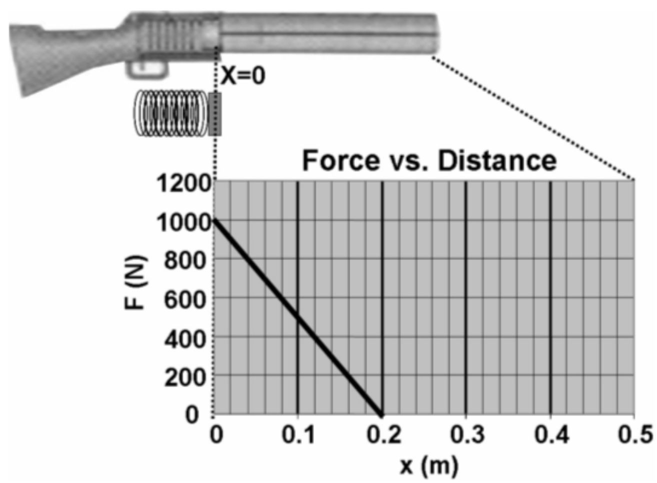
What is the speed of the ball at the launch point (point A)?

  - Graph Problem

A 0.1 kg bullet is loaded into a gun (muzzle length 0.5 m) compressing a spring as shown. The gun is then tilted at an angle of 30° and fired.



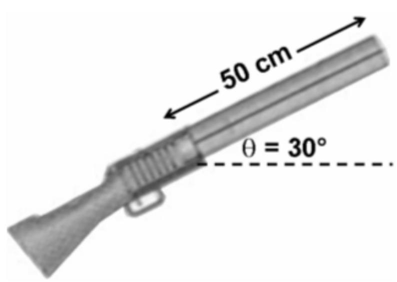
The only information you are given about the gun is that the barrel of the gun is frictionless and when the gun is held horizontal, the net force F (N) exerted on a bullet by the spring as it leaves the fully compressed position varies as a function of its position x (m) in the barrel as shown in the graph below.



What is the muzzle velocity of the bullet as it leaves the gun, when the gun is fired at the 30° angle as shown above?

- Function Problem

A 0.1 kg bullet is loaded into a gun (muzzle length 0.5 m) compressing a spring to a maximum of 0.2 m as shown. The gun is then tilted at an angle of 30° and fired.

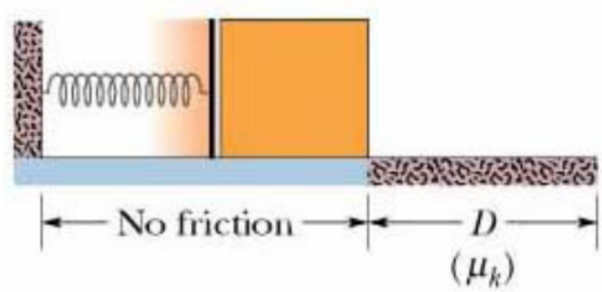


The only information you are given about the gun is that the barrel of the gun is frictionless and that the gun contains a non-linear spring such that when the held horizontal, the net force, F (N) exerted on a bullet by the spring as it leaves the fully compressed position varies as a function of the spring compression, x (m) as given by: $F = 1000x + 3000x^2$

What is the muzzle velocity of the bullet as it leaves the gun, when the gun is fired at the 30° angle as shown above?

- *Interview 3: Work & Energy – with Friction*
  - Original Exam Problem

A 3.5 kg block is accelerated from rest by a spring, spring constant 632 N/m that was compressed by an amount x. After the block leaves the spring it travels over a horizontal floor with a coefficient of kinetic friction $\mu_k = 0.25$. The frictional force stops the block in distance D = 7.8 m.

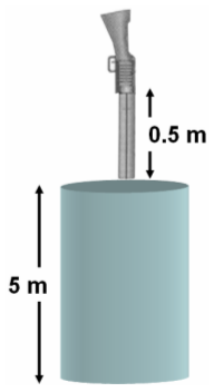


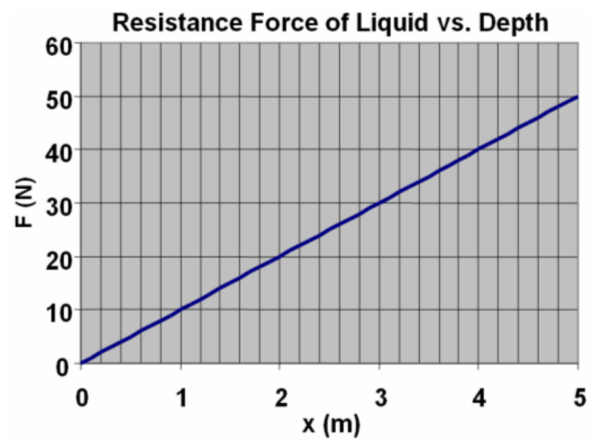
What was the spring compression *x*?

  - Graph Problem

A 0.1 kg bullet is loaded into a gun compressing a spring. The gun is tilted vertically downward and the bullet is fired into a drum 5.0 m deep, filled with a liquid.

The barrel of the gun is frictionless. The resistance force provided by the liquid changes with depth as shown in the graph below. The bullet comes to rest at the bottom of the drum





What is the spring compression x?

- Function Problem

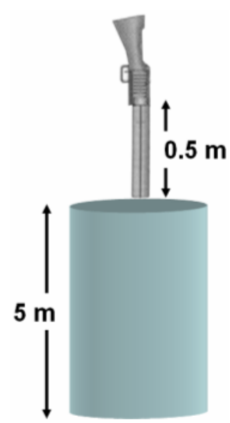
A 0.1 kg bullet is loaded into a gun compressing a spring. The gun is tilted vertically downward and the bullet is fired into a drum 5.0 m deep, filled with a liquid.

The barrel of the gun is frictionless. The frictional force F(N) provided by the liquid changes with depth x(m) as per the following function.

$$F = 10x + 0.6x^2$$

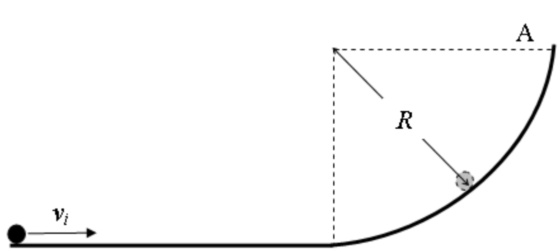
The bullet comes to rest at the bottom of the drum

What is the spring compression x?



- *Interview 4: Rotational Energy*
  - Original Exam Problem

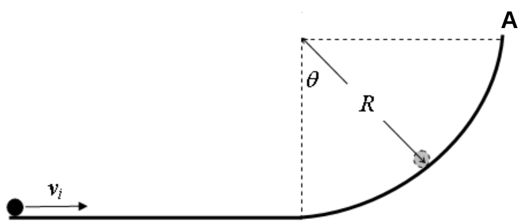
A hoop radius r = 1 cm, and mass m = 2 kg is rolling at an initial speed v_i of 10 m/s along a track as shown. It hits a curved section (radius R = 2.0 m) and is launched vertically at point A. .



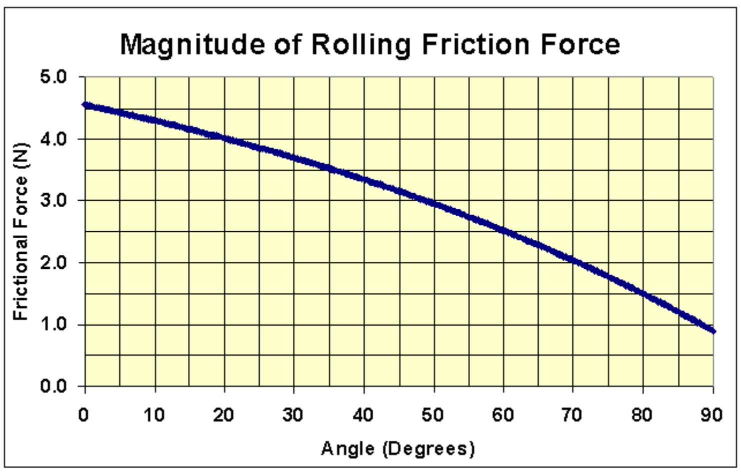
What is the launch speed of the hoop as it leaves the slope at point A?

- Graph Problem

A sphere radius $r = 1$ cm, and mass $m = 2$ kg is rolling at an initial speed v_i of 5 m/s along a track as shown. It hits a curved section (radius $R = 1.0$ m) and is launched vertically at point A.



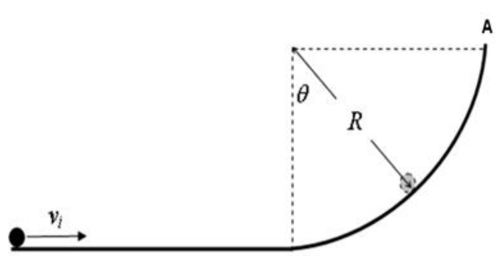
The magnitude of the rolling friction force acting on the sphere varies as angle θ as per the graph shown below



What is the launch speed of the hoop as it leaves the slope at point A?

- Function Problem

A sphere radius $r = 1$ cm, and mass $m = 2$ kg is rolling at an initial speed v_i of 5 m/s along a track as shown. It hits a curved section (radius $R = 1.0$ m) and is launched vertically at point A.



The magnitude of the rolling friction force F_{roll} (N) acting on the sphere varies as angle θ (radians) as per the following function

$$F_{roll}(\theta) = -0.7\theta^2 - 1.2\theta + 4.5$$

Data Collection and Organization: All interviews were video and audio taped. Student work on problem sheets was also collected. For each problem, from listening/viewing audio/video, and from students' sheets, we wrote down in our own words a description of what happened, in a table as shown below. We refer to this as the 'pseudo-transcript'

Questions asked	*Student's responses to questions*	*Difficulties*	*Hints given*	*Student's responses to hints*	*Student's writing*

Data Analysis: We used a phenomenographic approach to analyze the pseudo transcript. The pseudo-transcript was coded for the difficulties that students expressed while solving the problem. The pseudo-transcript was also coded for the hints provided by the researcher.

Methodology for Research Question 3: We have created over a dozen new online problems for calculus. These problems allow for open-ended responses, including graphs, and are graded automatically by the computer. They are being used this summer in the math placement for new students so we will have improved information about student ability and knowledge at entrance, in preparation for our longitudinal study of how they grow during their undergraduate education.

As in previous semesters, automatic homework generation modules were offered to Electrical Engineering students in the Fall 2009 and Spring 2009 Linear Systems courses. Chen Jia, Masters student in Electrical Engineering, upgraded the zero-input response and unit-impulse response modules to incorporate detailed plots of system responses that illustrate higher-level mathematical concepts associated with these types of homework problems. For example, the plots illustrate the relationships between the graphical depiction of a response signal and its constituent parts: the separate modes that contribute to these responses and their relationships to the initial conditions for these second-order systems (for three types of damping and bounded versus unbounded responses). Mr. Jia has also addressed a number of minor bugs in these software modules, which address complex numbers, signals, driven/undriven response, Fourier series, and discrete Fourier transforms. He is currently working on upgrades to the Fourier series modules that make these learning experiences more effective and help students to visualize how signals can be constructed from sinusoidal building blocks. Mr. Jia devoted much of the early Spring 2009 semester to learning the nuances of Java, PHP, and SQL as they relate to these software-driven learning experiences. Module surveys archived student reactions to the use of these modules as learning experiences.

Methodology for Research Question 4: We have completed six interviews with electrical engineering students in differential equations to get a sense of how they think about mathematical topics. The results of these interviews, which have not been analyzed yet, will inform the development of instruments for the future.