A Conceptual Approach to Physics Problem Solving

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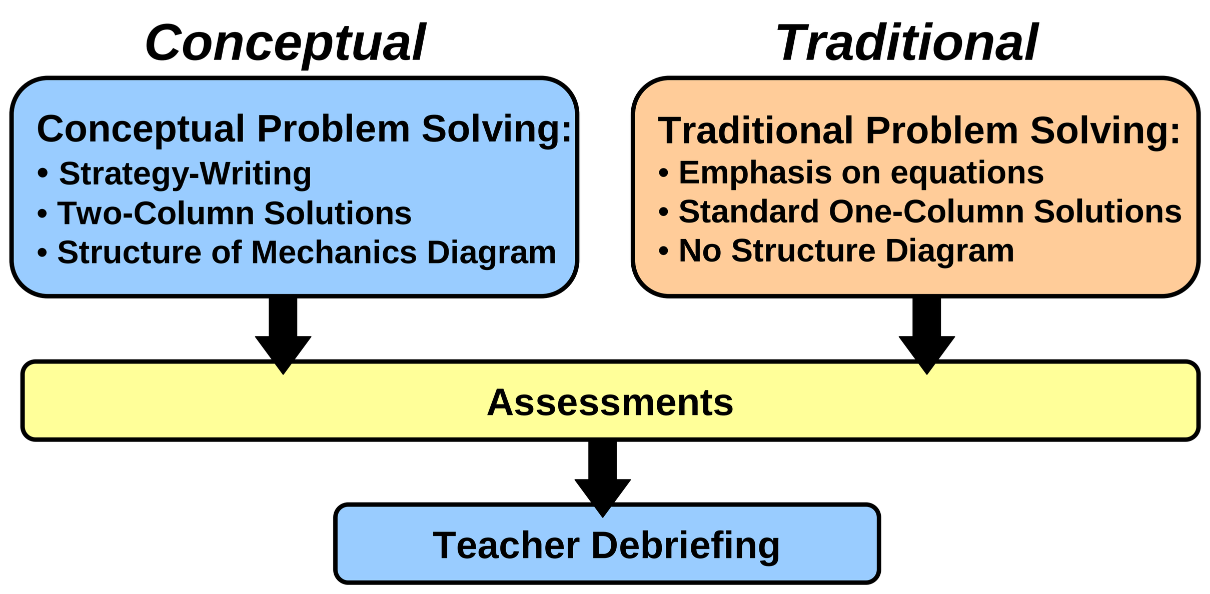
Introduction

Goal: Refine and evaluate an instructional intervention called *Conceptual Problem Solving* (CPS).

Approach: Students write a strategic analysis [1] of a problem based on principles and procedures, followed by a two-column solution.

Study Design

4 high schools participated with one conceptual and one traditional class in each school



Conceptual Analysis

CPS seeks to help students integrate knowledge of basic physics principles with problem solving [1,2] through the use of strategy-writing, two-column solutions, and a structure of mechanics diagram.

A *strategy* is a written conceptual analysis of a problem including the major *Principle*, a *Justification* for why that principle is appropriate, and a *Plan* for applying the principle [1].
A *two-column solution* illustrates side-by-side how written plan steps match to equations.

Assessments

Five assessments were administered at the end of the fall term. Not every school took every test.

1. **Categorization:** shown a model problem and two alternatives; select the alternative that would be solved most like the model problem
2. **Conceptual Questions:** multiple-choice format
3. **Equation Instantiation:** shown a problem and worked solution in symbolic form; asked to assign /match the appropriate values for each quantity in the final expression
4. **Finding Errors:** shown a worked-out solution that includes a physics error and asked to identify and describe the error in writing
5. **Problem Solving:** 3-5 standard physics problems

Example Materials

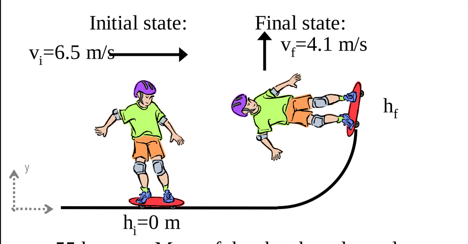
Strategy & Two-Column Solution

Problem: A skateboarder enters a curved ramp moving horizontally with a speed of 6.5 m/s, and leaves the ramp moving vertically with a speed of 4.1 m/s. The skateboarder and the skateboard have a combined mass of 55 kg. Find the height of the ramp, assuming no energy loss to frictional forces.

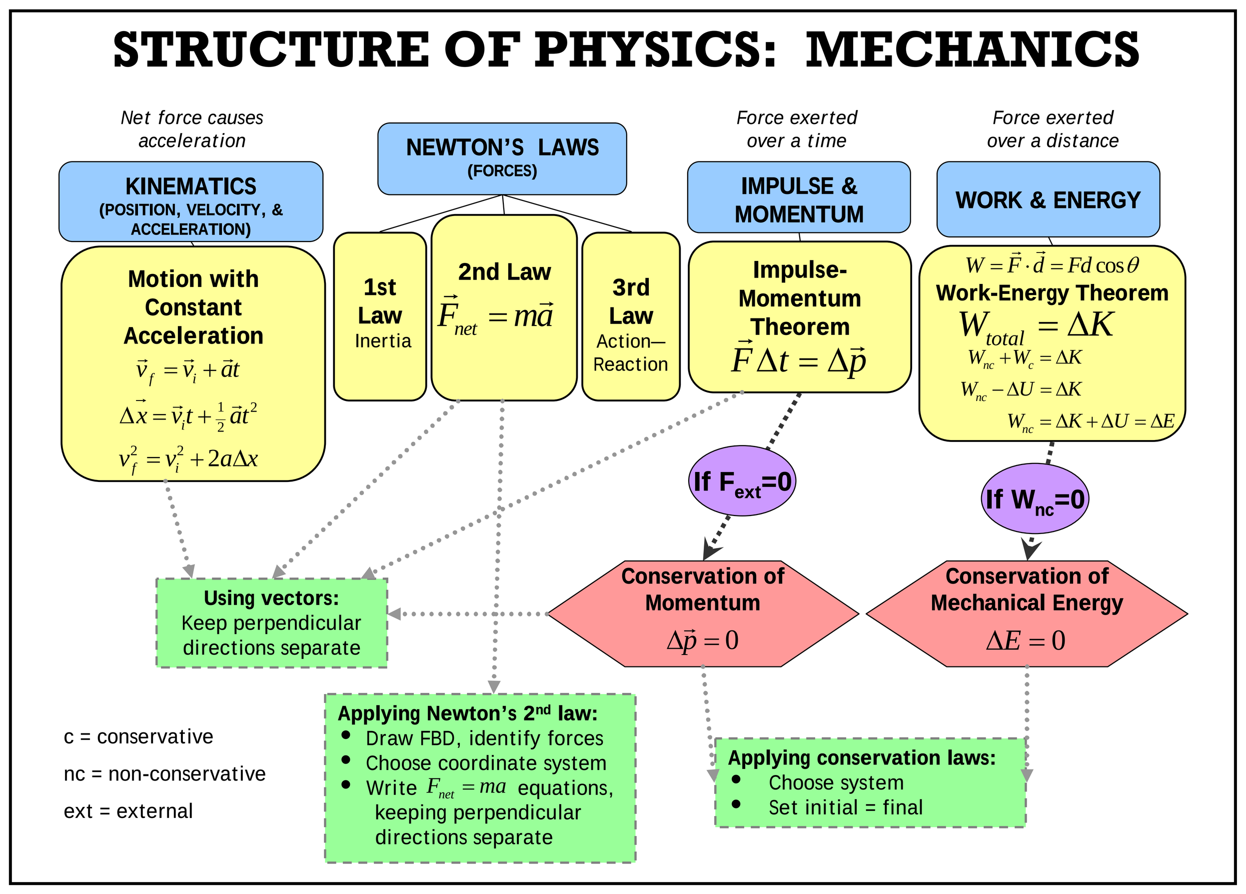
Principle: Conservation of energy: the total mechanical energy (sum of kinetic and potential energies) of an isolated system is the same in the initial and final states.

Justification: Mechanical energy is conserved if there are no non-conservative forces that do net work on the system. The normal force exerted on the skateboarder is a non-conservative force, but the work that the normal force does is 0 because its direction is always perpendicular to the displacement. The gravitational force is conservative and we are ignoring non-conservative frictional forces. Therefore, mechanical energy is conserved.

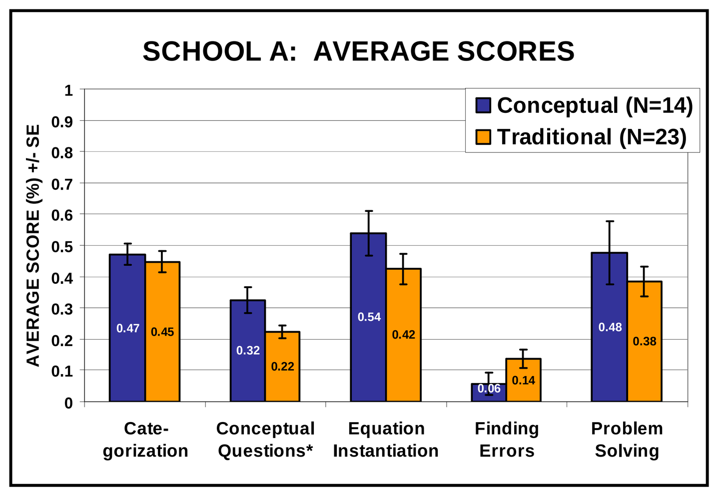
Plan: 1) Draw a picture and assign symbols for quantities in the problem. Choose a coordinate system. 2) Write an equation for conservation of mechanical energy. Expand the equation to include the initial and final kinetic and potential energy terms. 3) Solve for the height of the ramp. Substitute values to get an answer.

Plan step	*Equations used in step*
1.Draw a picture and assign symbols for quantities in the problem. Choose a coordinate system.	 m=55 kg — Mass of the skateboarder and skateboard combined v_i=6.5m/s — Initial speed of skateboarder v_f=4.1m/s — Final speed of skateboarder h_i=0m — Initial height of skateboarder h_f — Height of the ramp (final height of the skateboarder)
2. Write an equation for conservation of mechanical energy. Expand this equation to include the initial and final kinetic and potential energy terms.	$\Delta E = 0 \Rightarrow E_i = E_f$ $K_i + U_i = K_f + U_f$ $\frac{1}{2}mv_i^2 + mgh_i = \frac{1}{2}mv_f^2 + mgh_f$ $\frac{1}{2}mv_i^2 + 0 = \frac{1}{2}mv_f^2 + mgh_f$
3. Solve for the height of the ramp. Substitute values to get an answer.	$mgh_f = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$ $h_f = \frac{\frac{1}{2}\cancel{m}v_f^2 - \frac{1}{2}\cancel{m}v_i^2}{\cancel{m}g}$ $h_f = \frac{\frac{1}{2}v_f^2 - \frac{1}{2}v_i^2}{g}$ $= \frac{\frac{1}{2}(4.1m/s)^2 - \frac{1}{2}(6.5m/s)^2}{(9.8m/s^2)} = 1.3m$

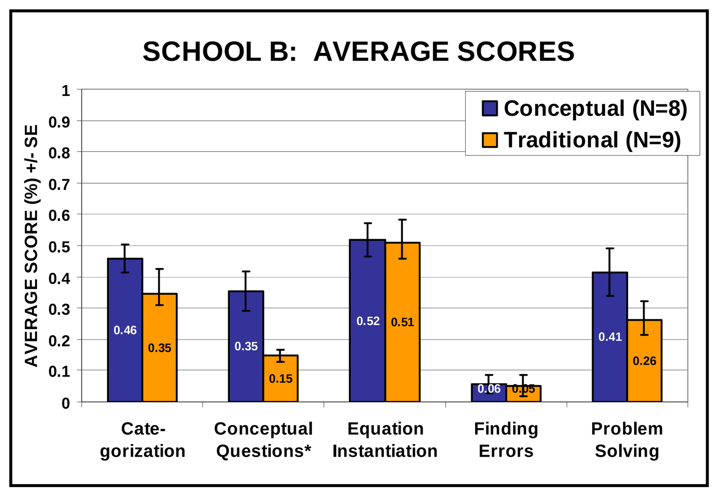
Structure of Mechanics Poster



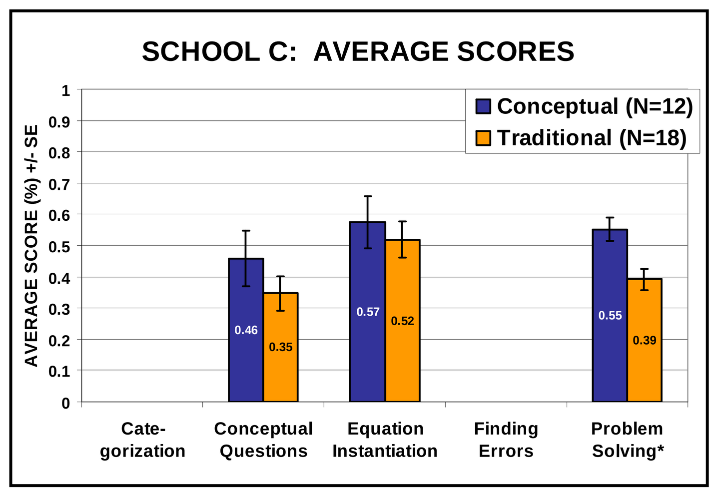
Results



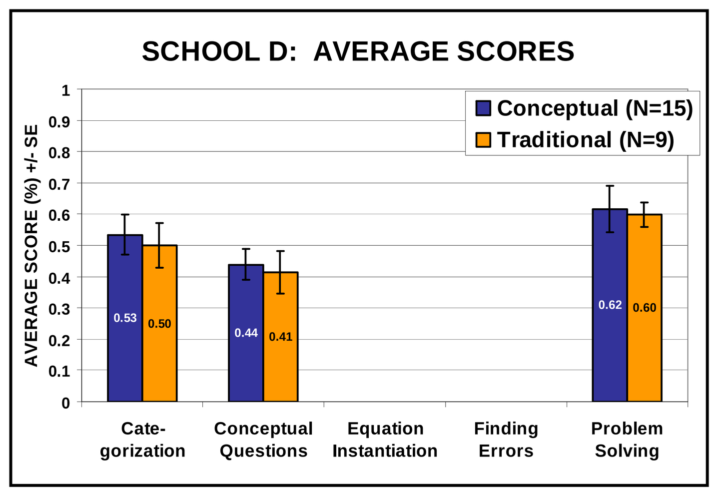
SCHOOL A: There were advantages for the conceptual class over the traditional on Equation Instantiation and Problem Solving. The Conceptual Questions showed a strong advantage for the CPS (p<0.02).



SCHOOL B: There were advantages for the conceptual class over the traditional on Categorization and Problem Solving tests. The Conceptual Questions showed a large 20% difference (p<0.005).



SCHOOL C: There were advantages for the conceptual class over the traditional on all tests taken. The Problem Solving showed an impressive 16% difference (p<0.01).



SCHOOL D: There were no differences between the conceptual problem solving and traditional classes (1-3% for each of the tests).

Discussion

- **Despite sparse use there was generally a small but consistent advantage to the conceptual problem solving classes at every school**
- **Approach flexible enough to allow different styles of implementation across teachers**
- **Required very little training of teachers**
- **A future study will investigate in greater detail how teachers use the synthesizing structure of mechanics diagram**

Acknowledgements

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