Developing a Useful Instrument to Assess Student Problem Solving

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Problem Solving Measure

- Problem solving is one of the primary teaching goals, teaching tools, and evaluation techniques of physics courses.

- Issues:
  - There is no standard way to evaluate problem solving that is valid, reliable, and easy to use.
  - A single numerical score gives an inadequate description of a student’s skill at solving problems.

- A more detailed and meaningful measure of problem solving would be useful for both research and instruction.

- How do we measure a complex skill such as problem solving?
What is *problem solving*?

- **“Problem solving** is the process of moving toward a goal when the path to that goal is uncertain” (Martinez, 1998, p. 605)

- What is a *problem* for one person might not be a problem for another person.

- Problem solving involves decision-making.
  - If the steps to reach a solution are immediately known, this is an *exercise* for the solver.

Problem Solving Process

- Understand / Describe the Problem
  - Redescribe information from problem
  - Introduce symbolic notation
  - Identify key concepts

- Devise a Plan
  - Use concepts to relate target to known information
  - Appropriate math procedures

- Carry Out the Plan

- Look Back
  - Check answer


Inexperienced solvers:
- Knowledge disconnected
- Little representation (jump to equations)
- Inefficient approaches (formula-seeking & solution pattern matching)
- Early number crunching
- Do not evaluate solution

Experienced solvers:
- Hierarchical knowledge organization or **chunks**
- Low-detail overview of the problem before equations
  - **qualitative analysis**
- Principle-based approaches
- Solve in symbols first
- Evaluate their solution


Project Description

Goal:
- Use this research literature and data (problem solutions) to design a robust instrument to evaluate written solutions to physics problems
  - Establish criteria for appropriate use & training

- The instrument should be *general*
  - not specific to instructor practices or technique
  - applicable to a variety of problem types and topics

- Must consider issues of *reliability* & *validity*:
  - **reliability** – stability of scores across different raters
  - **validity** – the instrument measures what it claims to measure (score interpretation is supported by empirical evidence and theoretical backing)
**Instrument at a glance (Rubric)**

<table>
<thead>
<tr>
<th>CATEGORY:</th>
<th>SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Useful Description</td>
<td></td>
</tr>
<tr>
<td>Physics Approach</td>
<td></td>
</tr>
<tr>
<td>Specific Application</td>
<td></td>
</tr>
<tr>
<td>Math Procedures</td>
<td></td>
</tr>
<tr>
<td>Logical Progression</td>
<td></td>
</tr>
</tbody>
</table>

- **Minimum number of categories that include relevant aspects of problem solving**
- **Minimum number of scores that give enough information to improve instruction**
- **Minimum training to use**
### Rubric Scores (in general)

<table>
<thead>
<tr>
<th></th>
<th>5</th>
<th>4</th>
<th>3</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Complete &amp; appropriate</td>
<td>Minor omissions or errors</td>
<td>Parts missing and/or contain errors</td>
<td>Most missing and/or contain errors</td>
</tr>
<tr>
<td>1</td>
<td>All inappropriate</td>
<td>No evidence / missing</td>
<td>Not necessary for this problem</td>
<td>Not necessary for this solver</td>
</tr>
<tr>
<td>0</td>
<td>NA Problem</td>
<td>NA Solver</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
To raise money for a University scholarship fund, the new IT dean has volunteered to bungee jump from a crane if contributions can be found for 10 scholarships. To add some interest, the jump will be made from 42 m above a pool of water. A 30m bungee cord would be attached to the dean. First you must convince the dean that your plan is safe for a person of his mass, 70kg. Your plan has the dean stepping off a platform and being in free fall for 30 m before the cord begins to stretch.

a) Determine the spring constant of the bungee cord so that it stretches only 12m, which will just keep the dean out of the water. (Assume that the dean is a point-like object).

b) Find the dean’s speed 7m above the water.
\[ \begin{align*} \text{At 7 m above water,} \\
E &= mgh + \frac{1}{2}kx_z^2 + \frac{1}{2}mv^2 \quad \text{this is equal to } mgh, \text{ where } x_z = 12 - 7 \text{ m} = 5 \text{ m} \\
\frac{1}{2}mv^2 &= mgh - mgh - \frac{1}{2}kx_z^2 \\
v &= \sqrt{2mg(H-h) - \frac{1}{2}kx_z^2} \\
v &= 16.57 \text{ m/s} \\
m &= 70 \text{ kg} \\
E_i &= mgh \\
E_f &= \frac{1}{2}kx^2 \quad \text{The velocity } v = 0 \text{ when the diver is on the platform and when he is at the bottom of the jump, so } kx^2 = 0 \\
mgh &= \frac{1}{2}kx^2 \\
k &= \frac{2mgh}{x^2} = \frac{2(70 \text{ kg})(9.8 \text{ m/s}^2)(42 \text{ m})}{(12 \text{ m})^2} \\
&= 406.2 \text{ N/m} \\
\end{align*} \]
a. $x = 12 \text{ m}, F = ma, a = -9.8 \text{ m/s}^2$

\[ F = -kx \]

\[ ma = -kx \]

\[ (70 \text{ kg})(-9.8 \text{ m/s}^2) = -k(12 \text{ m}) \]

\[ k = 57,167 \text{ N/m} \]

b. Use conservation of energy

\[ PE_{\text{top}} = KE_{\text{bottom}} + PE_{\text{bottom}} \]

\[ mgh = \frac{1}{2}mv^2 + \frac{1}{2}kx^2 \]

$x$ equals $12 \text{ m} - 7 \text{ m} = 5 \text{ m}$ because that is the distance the spring will be stretched.

\[ (70 \text{ kg})(57,167)(12 \text{ m}) = \frac{1}{2}(70 \text{ kg})(v^2) + \frac{1}{2}(57,167)(5 \text{ m})^2 \]

\[ v^2 = \frac{(70 \text{ kg})(57,167)(12) - \frac{1}{2}(57,167)(5)^2}{\frac{1}{2}(70 \text{ kg})} \]

\[ v = 69.15 \text{ m/s} \]
\[ F = -kx \]

\[ ma = -kx \]

\[ (70 \text{ kg})(9.8 \text{ m/s}^2) = k \cdot 12 \text{ m} \]

\[ k = \frac{ma}{x} = 57.2 \text{ N/m} \]

\[ \text{b) } V^2 = V_0^2 + 2a(\Delta x) \]

\[ V_0 = \sqrt{mgh} \quad \text{(where } h = 30 \text{ m}) \]

\[ \Delta x = 5 \text{ m} \]

\[ a = -\frac{\sqrt{mgh}}{12 \text{ m}} \]

\[ V = \sqrt{mgh + 2\left(-\frac{\sqrt{mgh}}{12 \text{ m}}\right)(5)} \]

\[ V = \sqrt{143 + 2(-12)(5)} = 16 \text{ m/s} \]
Developing the Rubric

1. Draft instrument based on literature & archived exam data
2. Preliminary tests with two raters (consistency of scores)
3. Pilot instrument with graduate students (brief training)
4. Analyze pilot data (written feedback & scores)
5. Revise rubric and training materials
6. Re-pilot with graduate students &/or faculty; collect & score exams
7. Final data analysis & reporting
What have we learned?

- **Preliminary testing (two raters)**
  - Distinguishes instructor & student solutions
  - Score agreement between two raters – good

- **Pilot testing (8 Graduate Students)**
  - confusion about NA scores (want more examples)
  - influenced by traditional grading experience
    - *Unwilling to score math & logic if physics incorrect*
  - difficulty distinguishing approach & application
  - multi-part problems more difficult to score
  - score agreement improved slightly with training
Work in Progress!

Materials on the Web:

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(Click on Jennifer Docktor)

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ADDITIONAL SLIDES
A block of mass $m = 2$ kg slides down a frictionless ramp of height $h = 2$ m. Use conservation of energy to determine the speed of the block at the bottom of the ramp.

**Physics Approach:**
physics concept or principle stated in problem
Range of detail in solutions

Useful Description: unnecessary for this solver NA(S)
Rubric Categories (based on research literature)

- **Useful Description**
  - organize information from the problem statement symbolically, visually, and/or in writing.

- **Physics Approach**
  - select appropriate physics concepts and principles to use

- **Specific Application of Physics**
  - apply physics approach to the specific conditions in problem

- **Mathematical Procedures**
  - follow appropriate & correct math rules/procedures

- **Logical Progression**
  - (overall) solution progresses logically; it is coherent, focused toward a goal, and consistent

Note: 4 of the 5 categories are qualitative
Problem Solving Process

1. Identify & define the problem
2. Analyze the situation
3. Generate possible solutions/approaches
4. Select approach & devise a plan
5. Carry out the plan
6. Evaluate the solution

References


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