Robust Assessment Instrument for Student Problem Solving

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Project Description

Goal:
○ Design a robust instrument to evaluate written solutions to physics problems, for use in physics education research and instruction.

○ The instrument should be general (not specific to instructor practices or technique)

○ The instrument must satisfy criteria for:
  ● **validity** – the instrument measures what it claims to measure (face, content, construct, criterion-related)
  ● **reliability** – stability of scores over time and across different raters (intrarater and interrater)
Solution characteristics

**Inexperienced problem solvers:**
- Little representation (jump quickly to equations)
- Haphazard formula-seeking and solution pattern matching

**Experienced problem solvers:**
- Low-detail overview of the problem before equations
  - *qualitative analysis* aids in selecting relevant physics principles
- Correctly apply physics to specific conditions in problem
- Some processes are automatic / implicit

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### Rubric Scores (in general)

<table>
<thead>
<tr>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete &amp; appropriate</td>
<td>Minor errors (one part missing or inappropriate)</td>
<td>More than one error</td>
<td>Fundamental misunderstanding</td>
<td>Is not expressed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NA(Problem)</th>
<th>NA(Solver)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not necessary for this problem</td>
<td>Explicit statement not necessary for this solver</td>
</tr>
</tbody>
</table>
## One Category: Logical Progression

<table>
<thead>
<tr>
<th></th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The entire problem solution is focused and organized logically.</td>
<td>The solution is focused and organized with minor inconsistencies and/or extraneous steps that don’t guide the solution.</td>
<td>The solution is focused and organized with multiple inconsistencies and/or extraneous steps that don’t guide the solution.</td>
<td>Parts of the solution are focused and organized. There are multiple inconsistencies and/or extraneous steps that don’t guide the solution.</td>
<td>Nothing written can be interpreted as logical progression. The entire solution is unorganized and contains obvious logical breaks.</td>
</tr>
</tbody>
</table>

- 4: The entire problem solution is focused and organized logically. The steps taken might not be linear, but guide the solver toward an answer.
- 3: The solution is focused and organized with minor inconsistencies and/or extraneous steps that don’t guide the solution.
- 2: The solution is focused and organized with multiple inconsistencies and/or extraneous steps that don’t guide the solution.
- 1: Parts of the solution are focused and organized. There are multiple inconsistencies and/or extraneous steps that don’t guide the solution.
- 0: Nothing written can be interpreted as logical progression. The entire solution is unorganized and contains obvious logical breaks.
A batter in a baseball game hits the ball over the center field fence for a home run. The ball is struck 120 cm above the ground with an initial velocity of 40 m/s at an angle of 26° above the horizontal. A player on the other team makes a great effort to catch the ball, but it flies well above him. At a point just in front of the center field fence, 110 m from where the ball was hit, he leaps straight upward so that his glove reaches a point 3.0 m above the ground. How far above his glove does the ball pass?

**Example**

**Instructor Solution**

**Physics Approach:** NA(S)

**Useful Description:** 4

**Specific Application:** 4

**Math Procedures:** 4

**Logical Progression:** 4

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Ball is hit at 
\[ t_0 = 0 \text{ s} \quad x_0 = 0 \text{ m} \quad y_0 = 0 \text{ m} \]

with initial velocity
\[ \vec{V}_0: V_x = 40 \cos 26^\circ \quad V_y = V_s \sin 26^\circ = 17.53 \text{ m/s} \]

**It passes over the fielder at**

\[ t = ? \quad x = 110 \text{ m} \quad y = ? \]

The target is \( y = -1.8 \text{ m} \)

\[ x = V_x t \quad y = V_y t - \frac{1}{2} g t^2 \]

\[ t = \frac{x}{V_x} \quad y = V_y \frac{x}{V_x} - \frac{1}{2} g \left( \frac{x}{V_x} \right)^2 \]

\[ t = \frac{110 \text{ m}}{35.95 \text{ m/s}} \quad y = 17.53 \frac{110 \text{ m}}{35.95 \text{ m/s}} - \frac{1}{2} (9.8 \text{ m/s}^2) \left( \frac{110 \text{ m}}{35.95 \text{ m/s}} \right)^2 \]

\[ t = 3.060 \text{ s} \]

Height above glove is 7.76 m - 1.8 m = 6.0 m
A batter in a baseball game hits the ball over the center field fence for a home run. The ball is struck 120 cm above the ground with an initial velocity of 40 m/s at an angle of 26° above the horizontal. A player on the other team makes a great effort to catch the ball, but it flies well above him. At a point just in front of the center field fence, 110 m from where the ball was hit, he leaps straight upward so that his glove reaches a point 3.0 m above the ground. How far above his glove does the ball pass?

**Example Student Solution**

**Physics Approach:** 1

**Useful Description:** 3

**Specific Application:** 1

**Math Procedures:** 3

**Logical Progression:** 3

\( V^2 - V_0^2 = 2a (x - x_0) \)

\( V^2 - (40 \text{ m/s})^2 = 2 (9.8 \text{ m/s}^2) (110 \text{ m} - 0 \text{ m}) \)

\( V^2 = -2156 + (40 \text{ m/s})^2 \)

\( V = V_0 + at \)

\( 23.58 \text{ m/s} = 40 \text{ m/s} + (9.8 \text{ m/s}^2) t \)

\( t = 1.67 \text{ sec} \)

\( h_3 = h_f - h_2 \)

\( h_3 = 54.47 \text{ m} - 3 \text{ m} \)

\( h_3 = 51.47 \text{ m} \)

This is not an accurate logical answer. It is too large.
Halliday, Resnick, & Walker
Instructor Solution CD-ROM
*Solutions sparse

Calc-Based Mechanics Professor
Solutions to Textbook Problems
Homework, Spring 2007
*Solutions more detailed
Data from Fall 2004

- One class of 241 students
- (788 total calc-based students)
- 60% freshmen, 25% sophomore, 7% junior, 4% senior
- 70% science, math, engineering

Data from Fall 2004

- One class of 167 students
- (258 total alg-based students)
- 15% freshmen, 50% soph, 15% junior, 10% senior
- 62% pre-architecture, kinesiology, ag/animal science
Instructors

Halliday, Resnick, Walker Instructor Solns
(38 Chapters x 2 problems each)

Students

Calculus-Based Mechanics Final Exam
5 Problems x 20 Student Solutions

Professor Solutions to Textbook Problems
Calculus-Based Mechanics Homework

Algebra-Based Mechanics Final Exam
3 Problems x 20 Student Solutions
**Inter-rater Reliability**

Independent scoring of student solutions by a PER graduate student and a high school physics teacher (N=160)

<table>
<thead>
<tr>
<th>Category</th>
<th>% agree (exact)</th>
<th>% agree (within 1)</th>
<th>Cohen’s kappa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physics Approach</td>
<td>71.3</td>
<td>97.1</td>
<td>0.62</td>
</tr>
<tr>
<td>Useful Description</td>
<td>75.0</td>
<td>99.2</td>
<td>0.63</td>
</tr>
<tr>
<td>Specific Application</td>
<td>61.3</td>
<td>96.9</td>
<td>0.48</td>
</tr>
<tr>
<td>Math Procedures</td>
<td>65.6</td>
<td>99.4</td>
<td>0.51</td>
</tr>
<tr>
<td>Logical Progression</td>
<td>63.1</td>
<td>96.9</td>
<td>0.49</td>
</tr>
<tr>
<td><strong>OVERALL</strong></td>
<td><strong>67.3</strong></td>
<td><strong>98.5</strong></td>
<td><strong>0.55</strong></td>
</tr>
</tbody>
</table>

**Kappa:**
- <0 No agreement
- 0-0.19 Poor
- 0.20-0.39 Fair
- 0.40-0.59 Moderate
- 0.60-0.79 Substantial
- 0.80-1 Almost perfect
A First Look

- The rubric discriminates between instructor and student solutions. *(criterion-related validity)*
- The rubric does not depend on the amount of writing.
- Independent *interrater reliability* is good, and would improve with training.

**More work to be done!**

- Continue testing the rubric on student solutions: different topics, courses, exams (quizzes).
- Review of the rubric categories and content by faculty and problem solving researchers. *(face & content validity)*
- Interrater reliability testing with and without training.
- Revisions to the rubric.
References


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