Harnessing what you know:
The role of analogy in robust learning

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# Translational Kinematics

<table>
<thead>
<tr>
<th>Eqn. 1</th>
<th>[ \bar{v} = \frac{\Delta s}{\Delta t} = \frac{(s_f - s_i)}{(t_f - t_i)} ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eqn. 2</td>
<td>[ \bar{a} = \frac{\Delta v}{\Delta t} = \frac{(v_f - v_i)}{(t_f - t_i)} ]</td>
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<tr>
<td>Eqn. 3</td>
<td>[ v_f = v_i + \bar{a} t_f \quad \text{when } t_i = 0 ]</td>
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<tr>
<td>Eqn. 4</td>
<td>[ s_f = v_i t + \frac{1}{2} \bar{a} t_f^2 \quad \text{when } s_i = 0 ]</td>
</tr>
<tr>
<td>Eqn. 5</td>
<td>[ v_f^2 = v_i^2 + 2 \bar{a} s_f ]</td>
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</tbody>
</table>
Translational Kinematics

Problem

- A Boeing 737 \((m = 70,535 \text{ kg})\) is cruising at an altitude of 9,140 m. Its constant motion is east, which is taken as the positive direction. What is the velocity of the airplane, if it requires 4.00 seconds to travel 800 m?
## Rotational Kinematics

<table>
<thead>
<tr>
<th>Eqn. 6</th>
<th>$\bar{\omega} = \frac{\Delta \theta}{\Delta t} = \frac{\theta_f - \theta_i}{(t_f - t_i)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eqn. 7</td>
<td>$\bar{\alpha} = \frac{\Delta \omega}{\Delta t} = \frac{\omega_f - \omega_i}{(t_f - t_i)}$</td>
</tr>
<tr>
<td>Eqn. 8</td>
<td>$\omega_f = \omega_i + \bar{\alpha} t_f$ when $t_i = 0$</td>
</tr>
<tr>
<td>Eqn. 9</td>
<td>$\theta_f = \omega_i t + \frac{1}{2} \bar{\alpha} t_f^2$ when $\theta_i = 0$</td>
</tr>
<tr>
<td>Eqn. 10</td>
<td>$\omega_f^2 = \omega_i^2 + 2 \bar{\alpha} \theta_f$</td>
</tr>
</tbody>
</table>
Rotational Kinematics

Problem

Inside a Rolex watch, there is a rotating wheel \((m = 0.004 \text{ kg})\) with a radius of 9.14 mm. Its constant rotation is in the counterclockwise direction, which is taken as the positive direction. What is the angular velocity of the wheel, if it requires 3.00 seconds to rotate through 90 radians?
Outline

- Motivation for our experiment
  - Pedagogical assumptions
  - Empirical findings
  - Domain

- Specific aims
  - Research questions

- Stages
  1. Educational datamining
  2. Design intervention
Pedagogical Assumption

- Electric Field (E)
  - \( E = 4.0 \times 10^{12} \text{ N/C} \)
  - \( F = Eq \)

- Charge (q)
  - \( q = -1.6 \times 10^{-19} \text{ C} \)

- Force (F)
  - \( F = ma \)

- Mass (m)
  - \( m = 9.1 \times 10^{-31} \text{ kg} \)
  - \( W = mg \)

- Velocity (v)
  - \( v_f = s/\Delta t \)
  - \( v_f = 4.3 \times 10^6 \text{ m/s} \)
  - \( v_i = 0 \text{ m/s} \)

- Displacement (s)
  - \( s = ? \text{ m} \)

- Time (t)
  - \( t = s \)

- Acceleration (a)
  - \( a = m/s^2 \)
  - \( a = (v_f - v_i)/\Delta t \)

- Weight (W)
  - \( W = N \)

- Acc. Due to Gravity (g)
  - \( g = 9.8 \text{ m/s}^2 \)
Empirical Evidence

- Knowledge transfer is difficult to obtain (Barnett & Ceci, 2002; Mestre, 2005).
  - Example: Find the area of a parallelogram (Wertheimer, 1959).
Background Literature

- Abundance of research on transfer of prior knowledge:
  - Projectile motion (Champagne, Klopfer, & Anderson, 1980)
  - Circular motion (McCloskey, Caramazza, & Green, 1980)
  - Misconceptions represent positive transfer of scientifically inaccurate knowledge.

- Lack of research focused on the failure of transfer within a course.
Domain Selected: Rotational Kinematics

- Shares same deep structure to translational kinematics,
- but very different surface features:
  - Point particle (translational) vs. extended body (rotational)
    - \(a \rightarrow \alpha; \ v \rightarrow \omega; \ s \rightarrow \theta\)
- Additional concepts: radial & tangential acceleration
- Perfect domain for analogy and transfer.
Outline

- Motivation for our experiment
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- Specific aims
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- Stages
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Specific Aims

1. Determine which concepts *transfer* and which concepts *fail* to transfer.

2. Design an intervention based on cognitive science principles of analogy to facilitate the transfer of difficult concepts.
Research Questions

1. Can we use the student performance on the translational kinematics knowledge components to predict the error rates for rotational kinematics?

2. Based on the answer to the first research question: Use analogical comparison to support knowledge components that fail to transfer.
Educational Datamining: Knowledge Components in Andes

- Stage 1: Conduct a rigorous task analysis of both domains (i.e., translational & rotational)
  
  A. Start with current Andes KC model and revise:
    - Example: \( v1_x = v0_x + a_x t \) WRITE-LK-NO-S
    - Example: \( \omega 1_x = \omega 0_x + \alpha_x t \) WRITE-RK-NO-S
  
  B. Develop a knowledge-component analysis for both domains (see Greg Cox’s PSLC internship poster).
    - Test different models within translational by applying them to different problems in translational.
    - Once the model has been validated, we will see if it predicts transfer on rotational problems.
Example: \( v_{1 \_ x} = v_{0 \_ x} + a_{x \_} t \)
Example: $\omega_{1\_x} = \omega_{0\_x} + \alpha_{\_x\_t}$
Educational Datamining: Knowledge Components in Andes

- Stage 1: Conduct a rigorous task analysis of both domains (i.e., translational & rotational)

C. Conceptual knowledge component analysis (Ploetzner & VanLehn, 1997)

<table>
<thead>
<tr>
<th>No.</th>
<th>Proposition</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The object is a body</td>
<td>Given</td>
</tr>
<tr>
<td>2</td>
<td>The object is not the earth</td>
<td>Given</td>
</tr>
<tr>
<td>3</td>
<td>The object is not massless</td>
<td>Assumed</td>
</tr>
<tr>
<td>4</td>
<td>Gravity should not be ignored on this problem</td>
<td>Assumed</td>
</tr>
<tr>
<td>5</td>
<td>There exists a gravitational force on the object due to the earth</td>
<td>Rule 1 applied to 1, 2, 3, and 4</td>
</tr>
<tr>
<td>6</td>
<td>The object is falling</td>
<td>Given</td>
</tr>
<tr>
<td>7</td>
<td>The gravitational force on the object causes the object’s acceleration</td>
<td>Rule 89 applied to 5 and 6</td>
</tr>
<tr>
<td>8</td>
<td>The magnitude of the object’s acceleration is proportionally related to the magnitude of the gravitational force on the object</td>
<td>Rule 100 applied to 7</td>
</tr>
<tr>
<td>9</td>
<td>The magnitude of the gravitational force on the object is constant</td>
<td>Rule 2 applied to 5</td>
</tr>
<tr>
<td>10</td>
<td>The magnitude of the object’s acceleration is constant</td>
<td>Qualitative reasoning on 8 and 9</td>
</tr>
</tbody>
</table>
Output from Stage 1

- Revised knowledge-component model for kinematics:
  - Use learning curves from translational kinematics to predict the errors on the complimentary KCs found in rotational kinematics.
  - Use learning curves to predict transfer to new concepts (i.e., radial & tangential acceleration)
  - Develop a taxonomy of problem-solving strategies.
Output from Stage 1

- Student profiles: analysis of individual differences
  - Examples of profiles:
    - Help abusers vs. Help avoiders
    - Forward-chaining vs. Backward-chaining strategies
    - Plus new profiles
  - Dependent Variables: error rates, hint usage, as well as chronometric variables
  - Goal: differentiate between the transfer of knowledge components from the transfer of problem-solving approaches and strategies.
Student Profiles and Adaptive Analogical Comparisons

- Stage 2: Design an intervention around knowledge component model and student profile.
- Given a certain student profile, design an intervention. For example:
  - If students do not understand a general principle
    - Comparisons across domains may help
    - Nokes and VanLehn (2008) found comparisons of worked examples improved understanding of physics concepts.
  - Difficulty with problem-solving skills
    - Different types of analogical comparisons facilitate learning different parts of the skill (Nokes & Ross, 2007)
      - Surface-different comparisons help principles access
      - Near-miss comparisons (1 salient change) help principle use
Student Profiles and Adaptive Analogical Comparisons

Stage 2: Design intervention around knowledge component model and student profile.
  – Why do students fail to understand rotational kinematics?
  – Hypotheses:
    ◆ Expert blindspot (Nathan & Koedinger, 2000): If a topic is trivial and uninteresting, then it must be easy to learn.
    ◆ Z-axis: little practice on solving problems in z-direction
    ◆ Greek symbols: students have a difficult time mapping symbols to the noun phrases (VanLehn & van de Sande, in press)
      – Lack of semantic association between the concepts and symbols
Previous Interventions

- Nokes and VanLehn (2008) used an *in vivo* experiment that linked the problem features to the abstract concepts and principles of the domain.
  - Analogical comparison => schema abstraction

- Representation has a powerful effect on problem solving
  - Design a new representation that highlights the connection between translational and rotational kinematics.
Relations to PSLC

- Educational data-mining
  - How to take advantage of the vast store of data in the DataShop to test hypotheses of knowledge representation, learning, and transfer;
  - Then link educational modeling back to *in vivo* experimentation to further test hypotheses explored in the data analysis and modeling.

- Coordinative learning
  - Understanding the coordination of multiple representations between examples and principles as well as between domains (translational and rotational).
  - Also extends analysis and transfer of KC’s to problem-solving strategies and meta-cognitive behaviors and transfer of those skills.
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