

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

Robert G.M. Hausmann

Timothy J. Nokes

Learning Research and Development Center
University of Pittsburgh



National Science Foundation
WHERE DISCOVERIES BEGIN

Translational Kinematics

Eqn. 1	$\bar{v} = \frac{\Delta s}{\Delta t} = \frac{(s_f - s_i)}{(t_f - t_i)}$	
Eqn. 2	$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{(v_f - v_i)}{(t_f - t_i)}$	
Eqn. 3	$v_f = v_i + \bar{a}t_f$	when $t_i = 0$
Eqn. 4	$s_f = v_i t + 1/2 \bar{a} t_f^2$	when $s_i = 0$
Eqn. 5	$v_f^2 = v_i^2 + 2\bar{a}s_f$	

Translational Kinematics Problem

- ◆ A Boeing 737 ($m = 70,535$ 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

Eqn. 6	$\bar{\omega} = \frac{\Delta\theta}{\Delta t} = \frac{(\theta_f - \theta_i)}{(t_f - t_i)}$	
Eqn. 7	$\bar{\alpha} = \frac{\Delta\omega}{\Delta t} = \frac{(\omega_f - \omega_i)}{(t_f - t_i)}$	
Eqn. 8	$\omega_f = \omega_i + \bar{\alpha}t_f$	when $t_i = 0$
Eqn. 9	$\theta_f = \omega_i t + 1/2\bar{\alpha}t_f^2$	when $\theta_i = 0$
Eqn. 10	$\omega_f^2 = \omega_i^2 + 2\bar{\alpha}\theta_f$	

Rotational Kinematics Problem

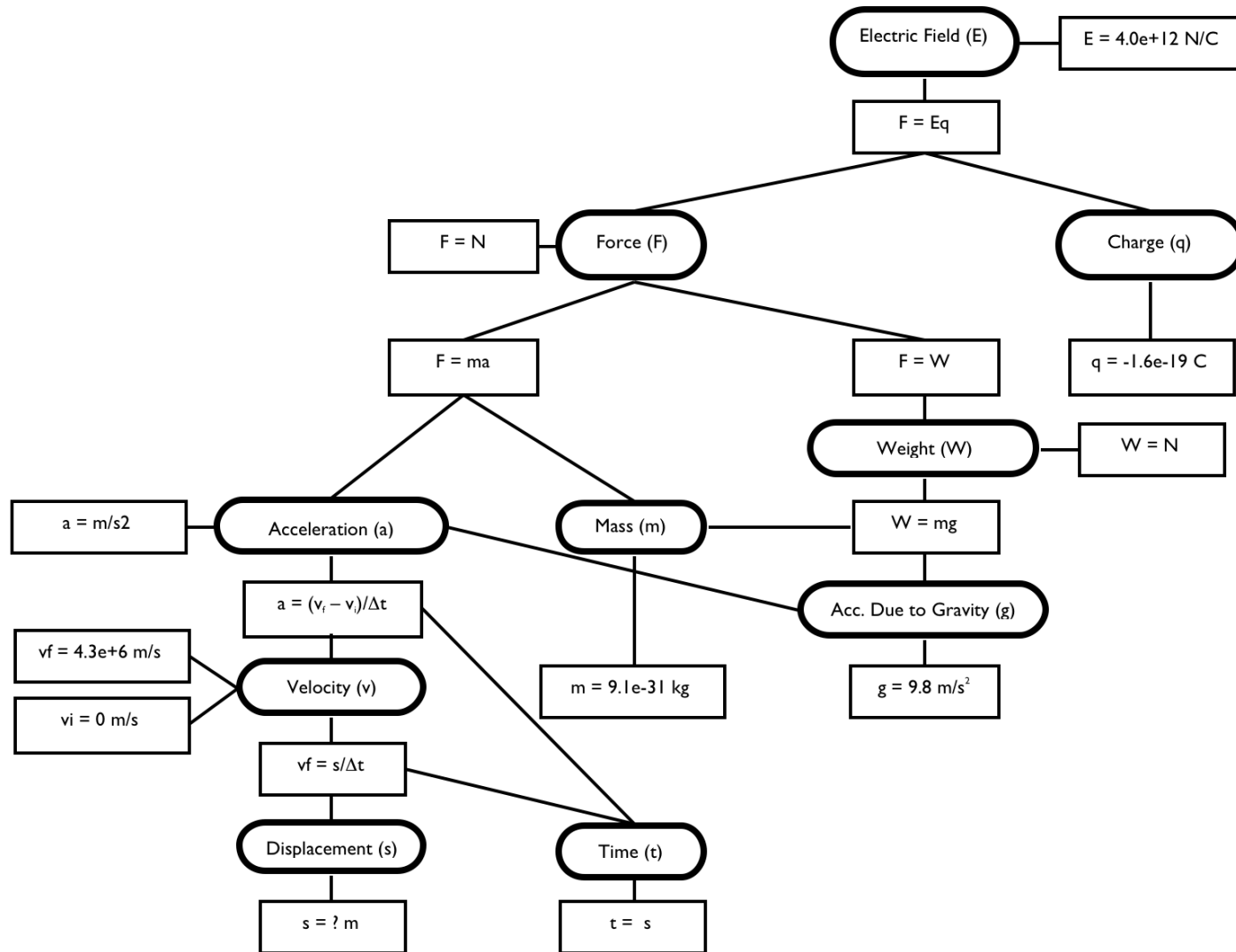
- ◆ Inside a Rolex watch, there is a rotating wheel ($m = .004$ kg) with a radius of 9.14 mm. Its constant rotation is in the counterclockwise direction, which is taken as the positive direction. What is the angular velocity of the wheel, if it requires 3.00 seconds to rotate through 90 radians?

Outline

- ◆ Motivation for our experiment
 - Pedagogical assumptions
 - Empirical findings
 - Domain
- ◆ Specific aims
 - Research questions
- ◆ Stages
 1. Educational datamining
 2. Design intervention

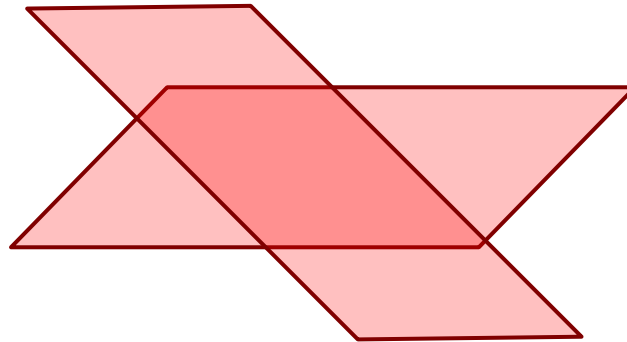
Next

Pedagogical Assumption



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.

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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

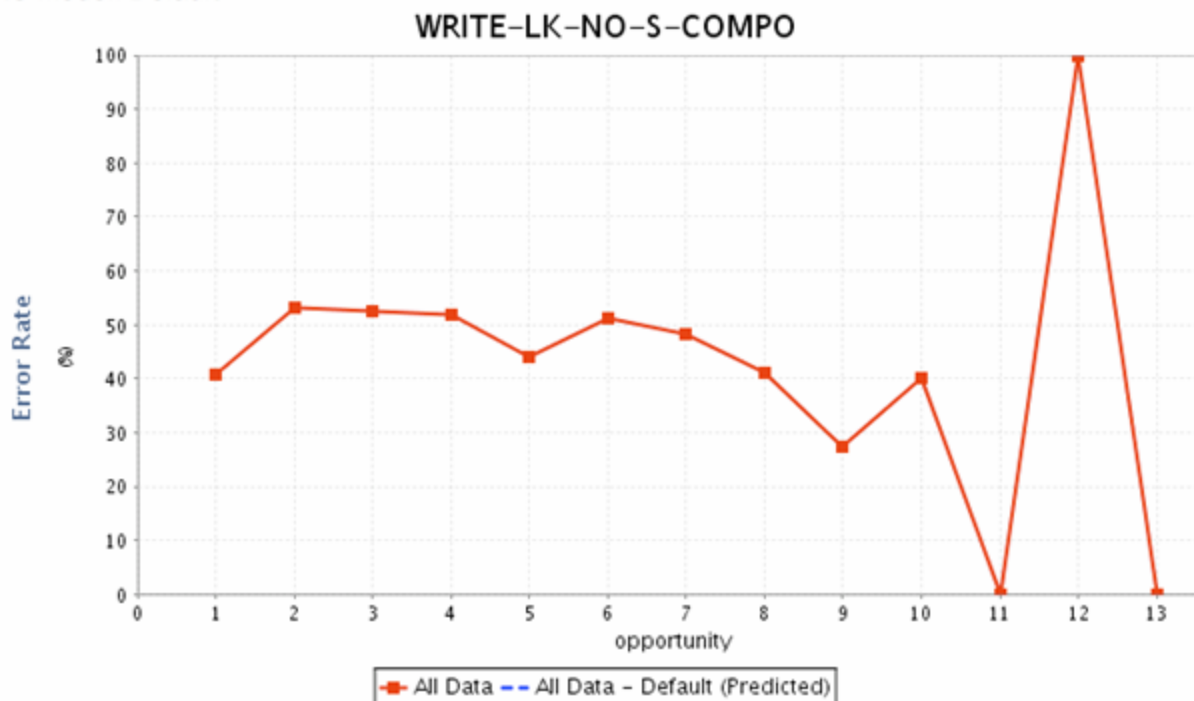
1. Can we use the student performance on the translational kinematics knowledge components to predict the error rates for rotational kinematics?
2. Based on the answer to the first research question: Use analogical comparison to support knowledge components that fail to transfer.

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: $\omega1_x = \omega0_x + \alpha_x * t$ 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: $v1_x = v0_x + a_x * t$

Dataset: USNA Physics Fall 2006
Sample(s): All Data
KC Model: Default

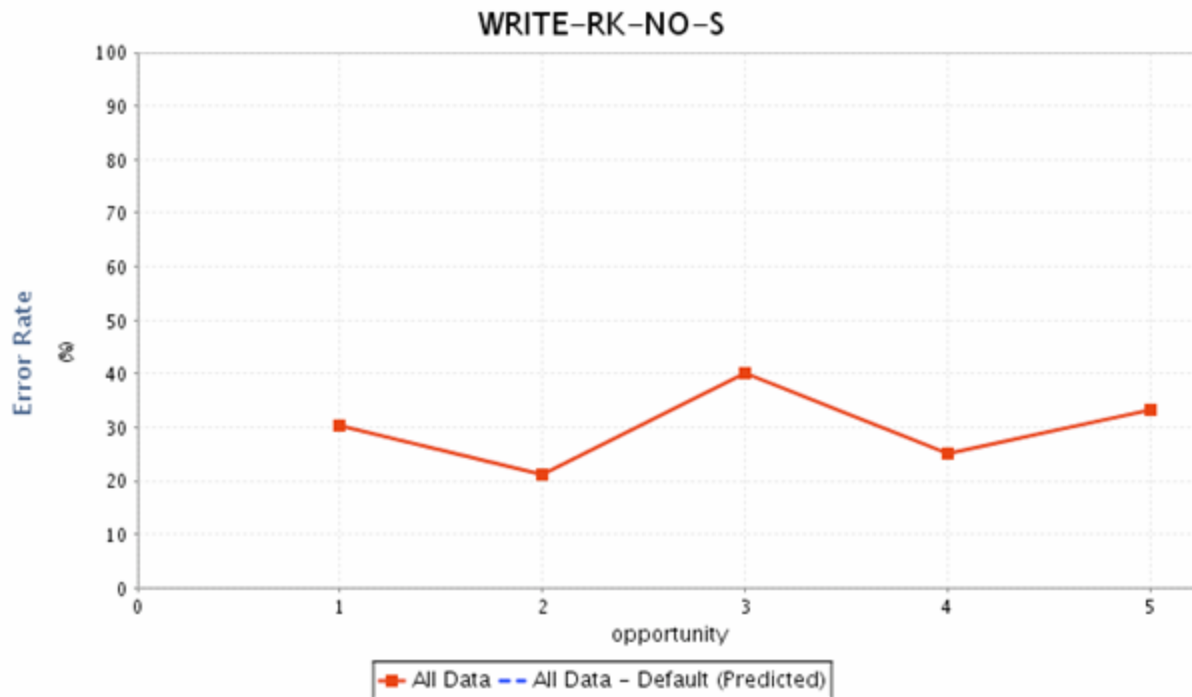


Min and Max Opportunity Cutoffs have not been set.
Number of included observations (Number dropped)
All Data: 409 (0)

All Data	
Opportunity Number	1 2 3 4 5 6 7 8 9 10 11 12 13
Number of Observations	66 64 61 56 50 45 31 17 11 5 1 1 1

Example: $\omega1_x = \omega0_x + \alpha_x * t$

Dataset: USNA Physics Fall 2006
Sample(s): All Data
KC Model: Default



Min and Max Opportunity Cutoffs have not been set.
Number of included observations (Number dropped)
All Data: 127 (0)

All Data					
Opportunity Number	1	2	3	4	5
Number of Observations	53	47	20	4	3

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 1
Derivation That the Acceleration of an Object in Free Fall Is Constant

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

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.

Contact Information

Robert G.M. Hausmann

University of Pittsburgh
706 Learning Research and
Development Center
3939 O' Hara Street
Pittsburgh, PA, 15260-5179

Phone: 412.624.7536

Fax: 412.624.9149

Email: bobhaus@pitt.edu

Web: <http://www.pitt.edu/~bobhaus>

Timothy J. Nokes

University of Pittsburgh
508 Learning Research and
Development Center
3939 O' Hara Street
Pittsburgh, PA, 15260-5159

Phone: 412.624.7789

Fax: 412.624.9149

Email: nokes@pitt.edu

Web: [Laboratory](#)