In-vivo Experimentation

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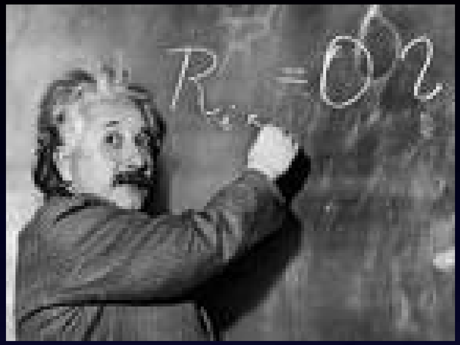
What do we want our theories to be like?



- General, capture diverse array of data
- Falsifiable
- Risky Predictions
- Parsimonious
- Generalizable

Philosophy of Science criteria for makes a good theory

Laboratory Experiments

Satisfies some criteria: falsifiable, risky predictions, parsimonious

- Lab: Golden aspects
- Easy random assignment and control
- Single, simple manipulations that isolate independent effects
- Strong internal validity
- Very fine-grained measures: RT's, trace-methods, imaging techniques

But Generalization?

A core criteria of a useful theory

Classroom Experiments

- Class
- Random; Quasi
- Complex, multiple component interventions
- Ecological validity
- Coarse-grained measures: large scale assessments

Continuum of Possibilities

- Lab
- Random assignment and control
- Single, simple manipulations
- Internal validity
- Fine-grained measures: RT's, trace-methods, imaging techniques

- Class
- Random; Quasi
- Complex, multiple component interventions
- Ecological validity
- Coarse-grained measures: large scale assessments

Bridging the Gap

In Vivo
Experiment

- Lab
- Random assignmen
- Single, simple manipulations
- Internal validity
- Fine-grained measures: RT's, trace-methods, imaging techniques

- Class
- Random; Quasi
- Complex, multiple component interventions
- Ecological validity
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LearnLab
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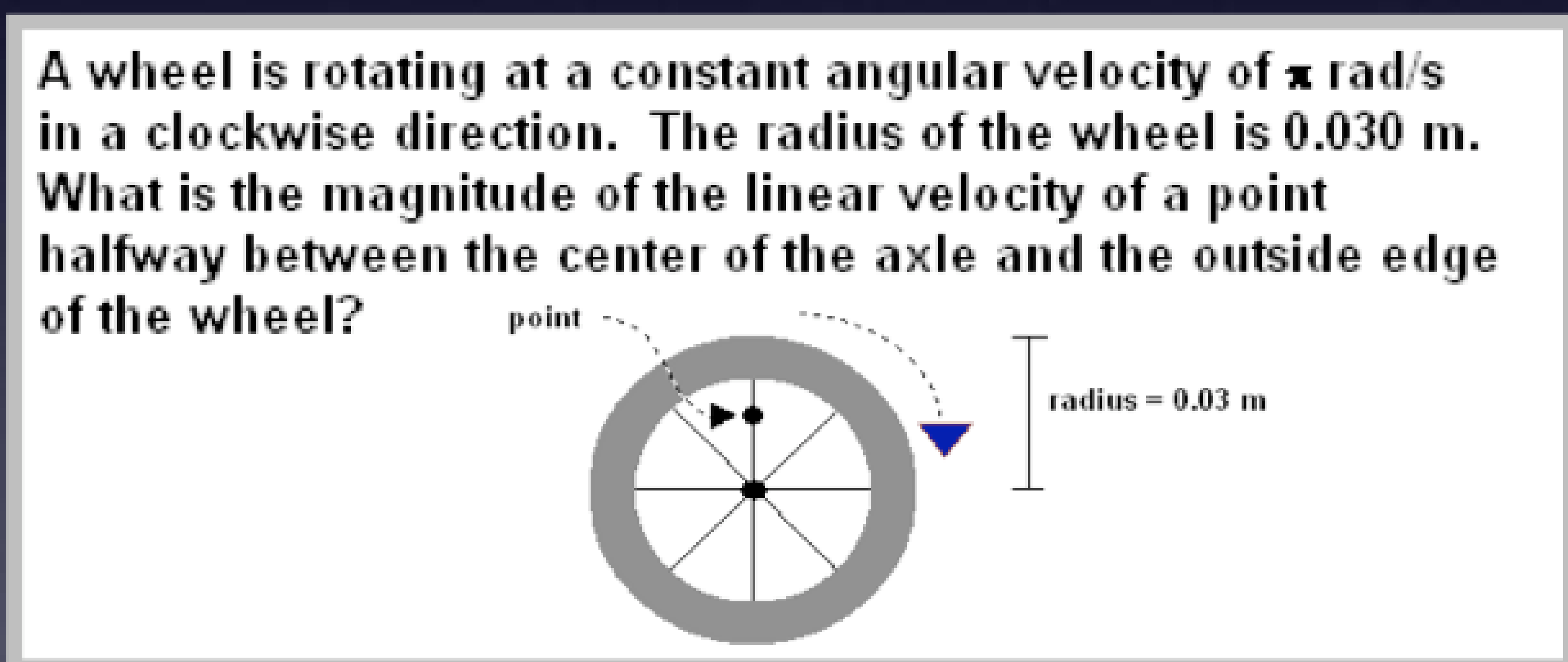
In Vivo Experiment

- Lab
- Random assignment ✓
- Single, simple manipulations
- Internal validity
- Fine-grained measures: RT's, trace-methods, imaging techniques ✓

- Class
- Random; Quasi
- Complex, multiple component interventions
- Ecological validity ✓
- Coarser-grained measures: large scale assessments

Problem

- How can we facilitate students' deep learning and understanding of new concepts in physics?
  - Clues from expertise research (Ericsson and Smith, 1991)


A wheel is rotating at a constant angular velocity of π rad/s in a clockwise direction. The radius of the wheel is 0.030 m. What is the magnitude of the linear velocity of a point halfway between the center of the axle and the outside edge of the wheel?

Perceive deep structure

Forward-working strategies

Transfer to new contexts

<u>Key component</u>: understanding the relations between principles and problem features

Problem Analysis

- Students use prior examples to solve new problems
  - Statistics (e.g., Ross, 1989); Physics (e.g., VanLehn, 1998)
- Helps with near transfer problems but not far
- They lack a deep conceptual understanding for the relations between principles and examples

How can we facilitate the learning of these conceptual relations?

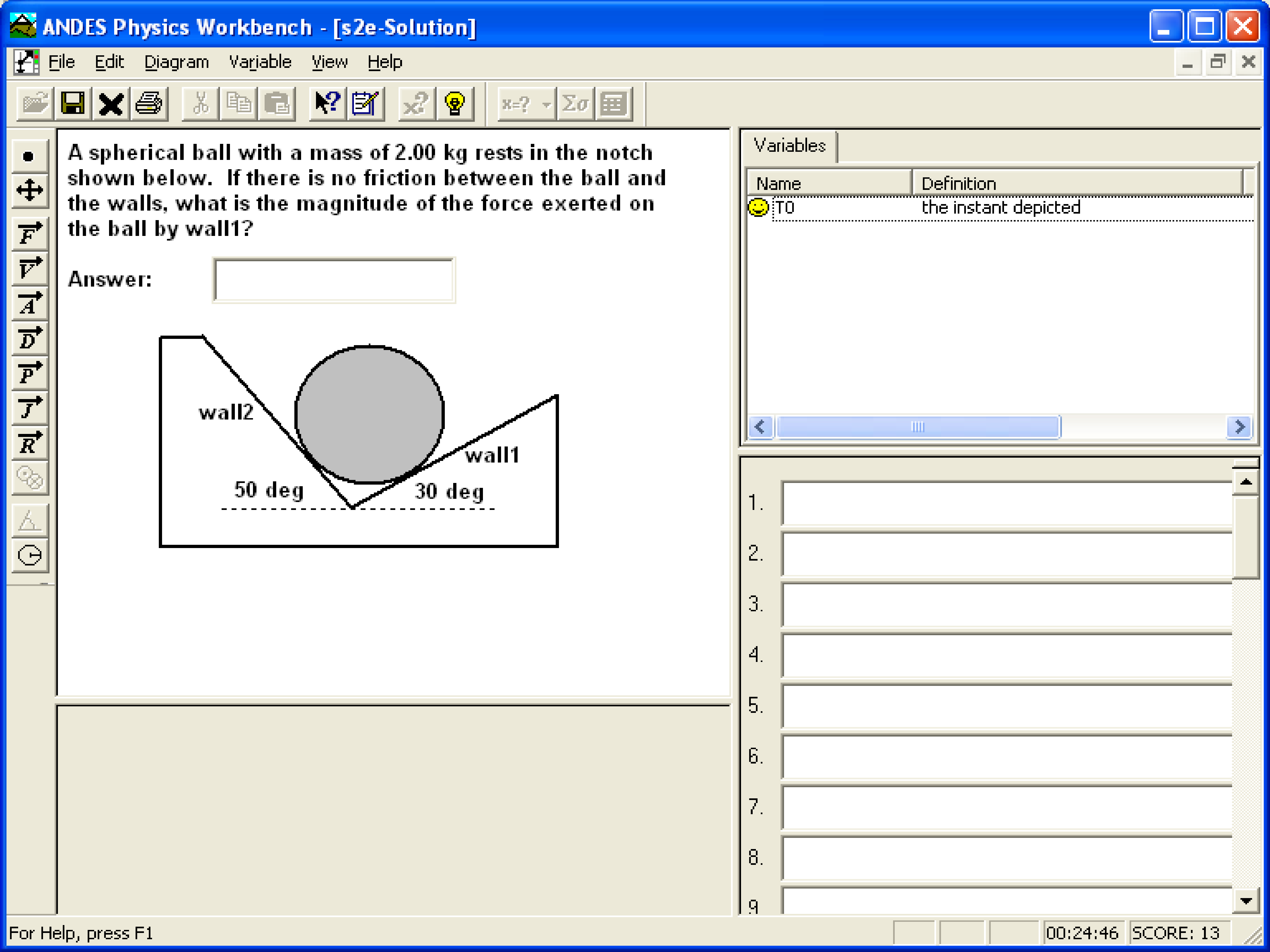
<u>Learning principles</u>: *self-explanation* and *analogy*

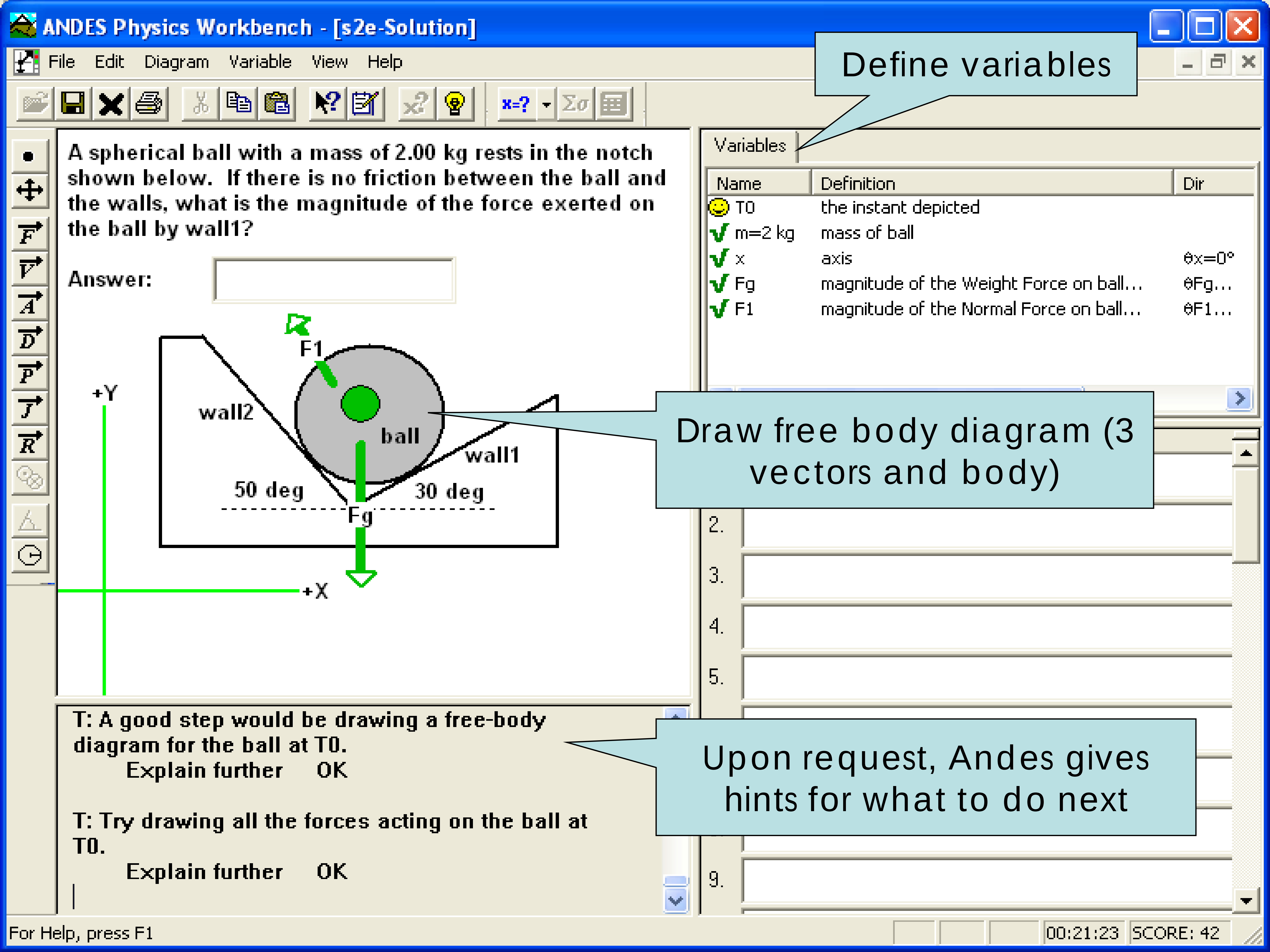
Hypotheses

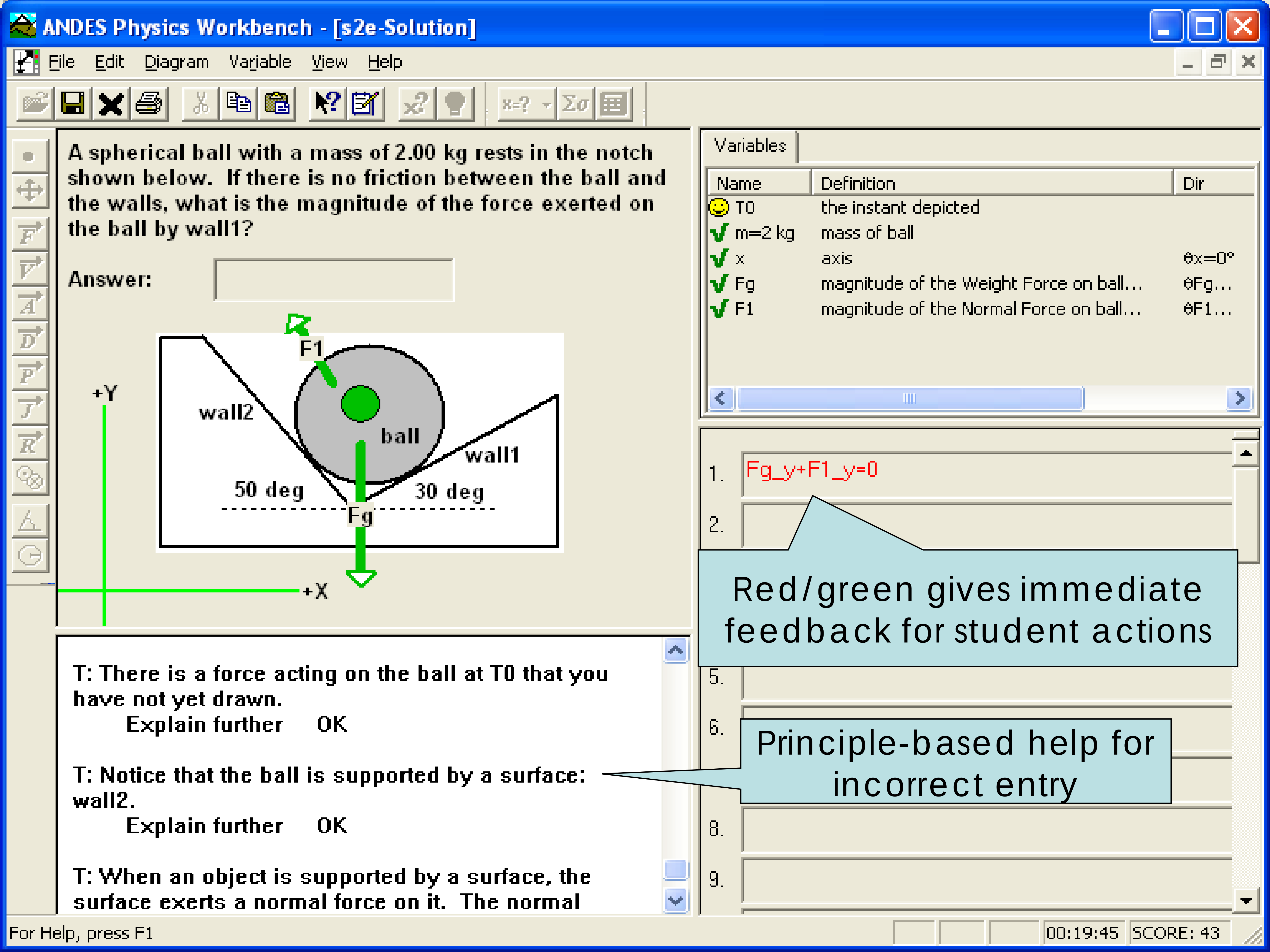
- Self-explanation and analogy can serve as two pathways to learning the ***conceptual relations*** between principles and examples in physics
- Self-explanation (Chi, 2000)
  - Generating inferences (Chi & Bassok, 1989)
  - Helps repair mental models (Chi et al., 1994)
  : Relates concepts to problem features
- Analogy (Gentner, Holyoak, & Kokinov, 2001)
  - Comparison highlights common causal structure (Gentner, Lowenstein, & Thompson, 2003)
  - Schema acquisition (Gick & Holyoak, 1983)
  : Abstracts critical conceptual features

Design Details

- Participants
  - In Vivo: 78 students at the USNA
- Learning phase
  - Booklets with principles and examples
    - Control: read examples
    - Self-explain: explain examples
    - Analogy: compare examples
  - Everyone talked aloud
- Test phase
  - Normal
  - Transfer


ANDES Physics Workbench - [s2e-Solution]
File Edit Diagram Variable View Help
A spherical ball with a mass of 2.00 kg rests in the notch shown below. If there is no friction between the ball and the walls, what is the magnitude of the force exerted on the ball by wall1?
Answer:
wall2
wall1
50 deg
30 deg
Variables
Name
Definition
T0
the instant depicted
1.
2.
3.
4.
5.
6.
7.
8.
9
For Help, press F1
00:24:46
SCORE: 13


ANDES Physics Workbench - [s2e-Solution]
File Edit Diagram Variable View Help
Define variables
A spherical ball with a mass of 2.00 kg rests in the notch shown below. If there is no friction between the ball and the walls, what is the magnitude of the force exerted on the ball by wall1?
Answer:
F1
+Y
wall2
ball
wall1
50 deg
30 deg
Fg
+X
Variables
Name
Definition
Dir
T0
the instant depicted
m=2 kg
mass of ball
x
axis
θx=0°
Fg
magnitude of the Weight Force on ball...
θFg...
F1
magnitude of the Normal Force on ball...
θF1...
Draw free body diagram (3 vectors and body)
2.
3.
4.
5.
9.
T: A good step would be drawing a free-body diagram for the ball at T0.
Explain further OK
T: Try drawing all the forces acting on the ball at T0.
Explain further OK
Upon request, Andes gives hints for what to do next
For Help, press F1
00:21:23
SCORE: 42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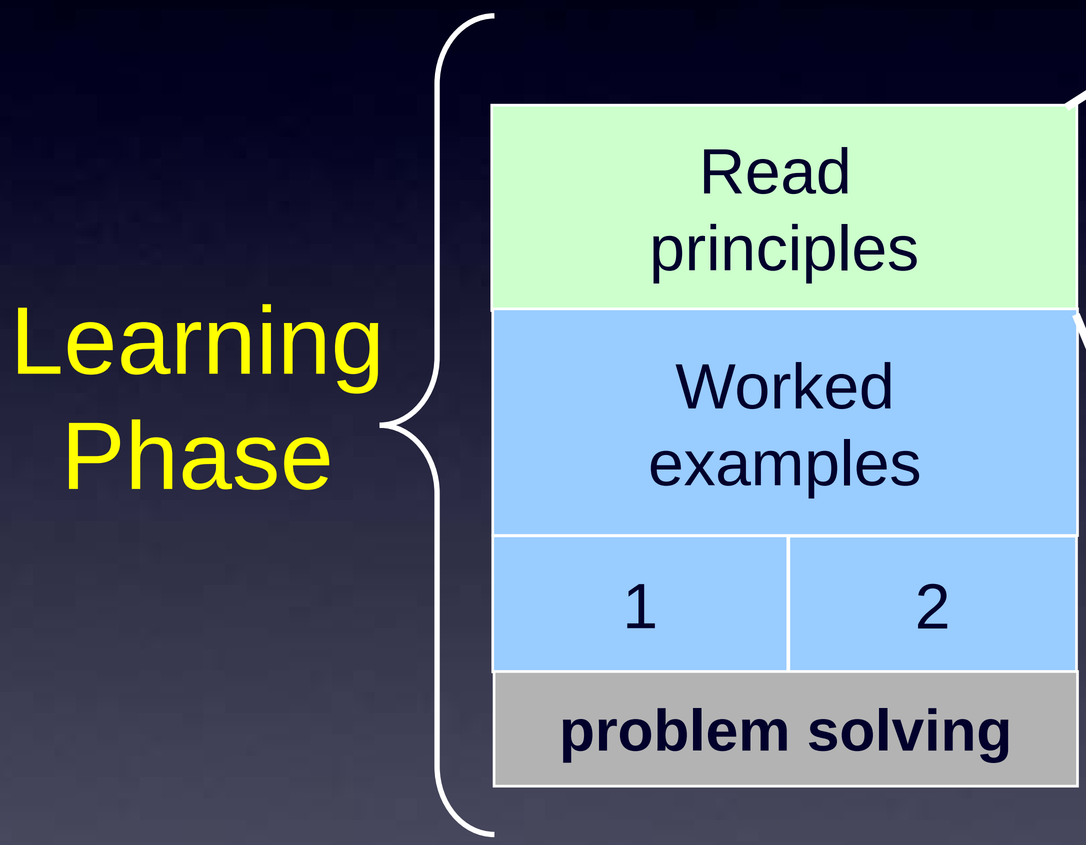
Answer:
F1
+Y
wall2
ball
wall1
50 deg
30 deg
Fg
+X
Variables
Name
Definition
Dir
T0
the instant depicted
m=2 kg
mass of ball
x
axis
θx=0°
Fg
magnitude of the Weight Force on ball...
θFg...
F1
magnitude of the Normal Force on ball...
θF1...
1.
Fg_y+F1_y=0
2.
5.
6.
8.
9.
Red/green gives immediate feedback for student actions
Principle-based help for incorrect entry
T: There is a force acting on the ball at T0 that you have not yet drawn.
Explain further OK
T: Notice that the ball is supported by a surface: wall2.
Explain further OK
T: When an object is supported by a surface, the surface exerts a normal force on it. The normal
For Help, press F1
00:19:45
SCORE: 43

Procedure and Design



<u>Angular Velocity</u>:

The angular velocity represents the rate at which the angular position of a particle is changing as it moves in a circular path; it is the number of radians the particle covers within an interval of time (usually a second). In terms of the calculus, angular velocity represents the instantaneous rate of change (i.e., the first derivative) of angular displacement.

Procedure and Design: Control

Learning Phase

- Read principles
- Worked examples
  - 1
  - 2
- **problem solving**

1) A spaceship is negotiating a circular turn of radius 2000 mi at a constant speed of 18,000 mi/h. Assume the motion is counterclockwise, and that this is the positive direction.

(a) What is the angular velocity?

Givens: $r = 2000mi,\ v = 18000\,{}^{mi}\!/\!_{h}$

Sought: ω_z

$$\omega_z = \frac{v}{r}$$

$$\omega_z = \frac{}{2000mi}$$

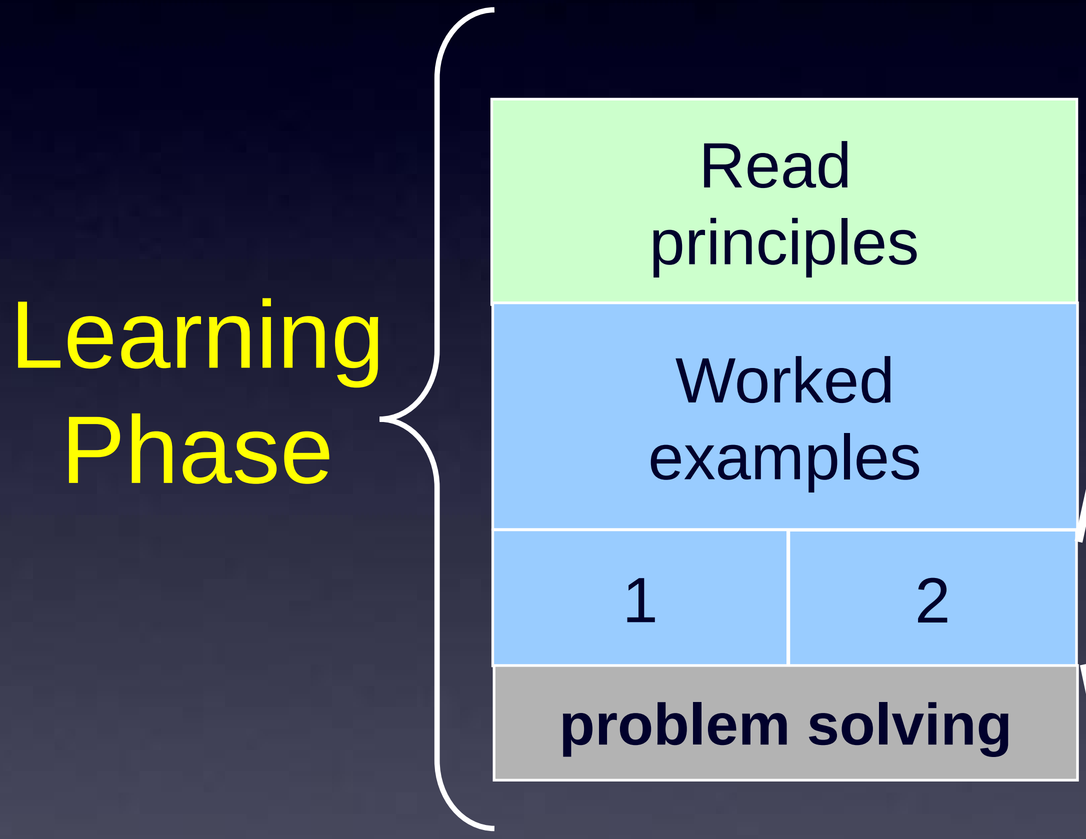
$$\omega_z = 9\,{}^{rad}\!/\!_{h}$$

Read Explanation

The angular velocity (ω_z) is the rate at which the angular position of the spaceship is changing as it moves in a circular orbit.

We choose the formula that relates angular velocity with translational speed (v), since we are given speed of the spaceship and radius of the orbit (r) in the statement of the problem.

Procedure and Design: Self-explain



1) A spaceship is negotiating a circular turn of radius 2000 mi at a constant speed of 18,000 mi/h. Assume the motion is counterclockwise, and that this is the positive direction.

(a) What is the angular velocity?

Givens: $r = 2000mi$, $v = 18000\ {}^{mi}/_{h}$

Sought: ω_z

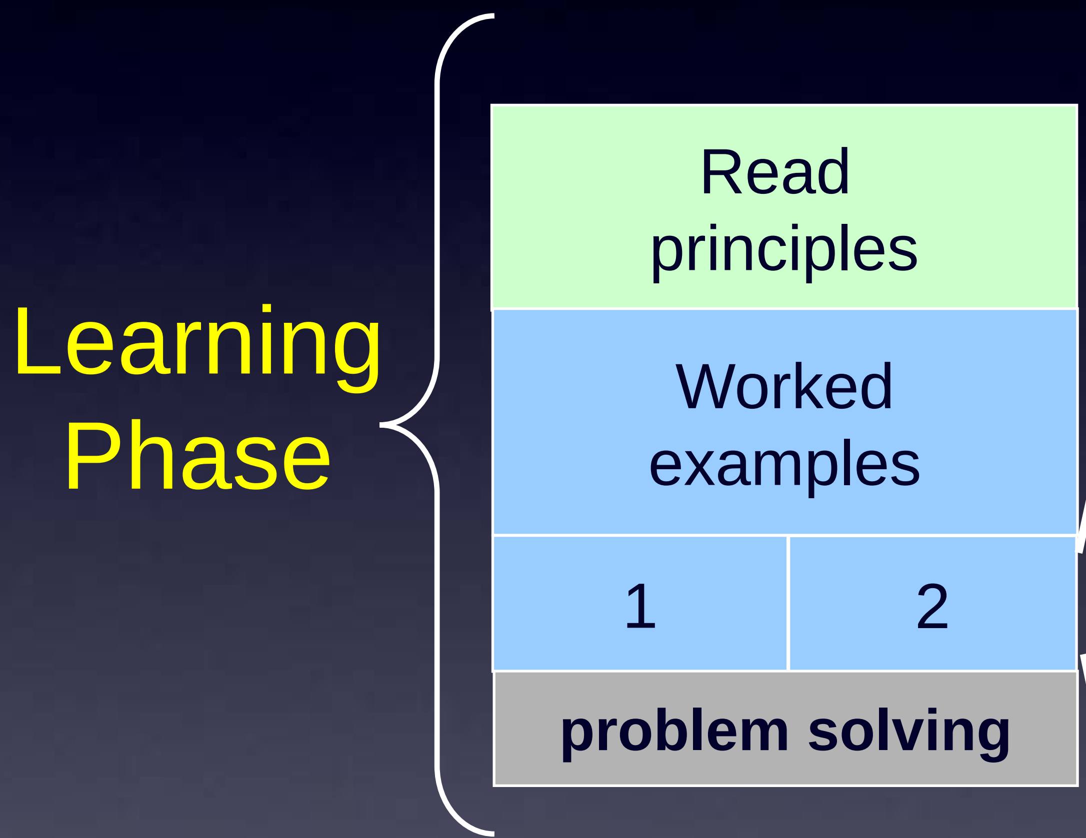
Generate Explanation

$$\omega_z = \frac{v}{r}$$

$$\omega_z = \frac{}{2000mi}$$

$$\omega_z = 9\ {}^{rad}/_{h}$$

Procedure and Design: Analogy



1) A spaceship is negotiating a circular turn of radius 2000 mi at a constant speed of 18,000 mi/h. Assume the motion is counterclockwise, and that this is the positive direction.

(a) What is the angular velocity?

Givens: $r = 2000mi$, $v = 18000\, {}^{mi}\!/\!_{h}$

Compare

Sought: ω_z

$$\omega_z = \frac{v}{r}$$

$$\omega_z = \frac{}{2000mi}$$

$$\omega_z = 9\, {}^{rad}\!/\!_{h}$$

The angular velocity (ω_z) is the rate at which the angular position of the spaceship is changing as it moves in a circular orbit.

We choose the formula that relates angular velocity with translational speed (v), since we are given speed of the spaceship and radius of the orbit (r) in the statement of the problem.

Procedure and Design

Learning Phase

- Read principles
- Worked examples
  - 1
  - 2
- problem solving

Control

Self-explain

Analogy

Test Phase

Immediate test

Normal: problem solving (isomorphic)

Transfer: problem solving (irrelevant values); multiple choice

-- *Class instruction* --

Delayed test

Andes

Procedure and Design

Learning Phase

Read principles	
Worked examples	
1	2
problem solving	

Control

Self-explain

Analogy

Test Phase

<u>Immediate test</u>

Normal: problem solving (isomorphic)

Transfer: problem solving (irrelevant values); multiple choice

-- *Class instruction* --

<u>Delayed test</u>

Andes

Procedure and Design

Learning Phase

Read principles	
Worked examples	
1	2
problem solving	

Control

Self-explain

Analogy

Test Phase

Immediate test

Normal: problem solving (isomorphic)

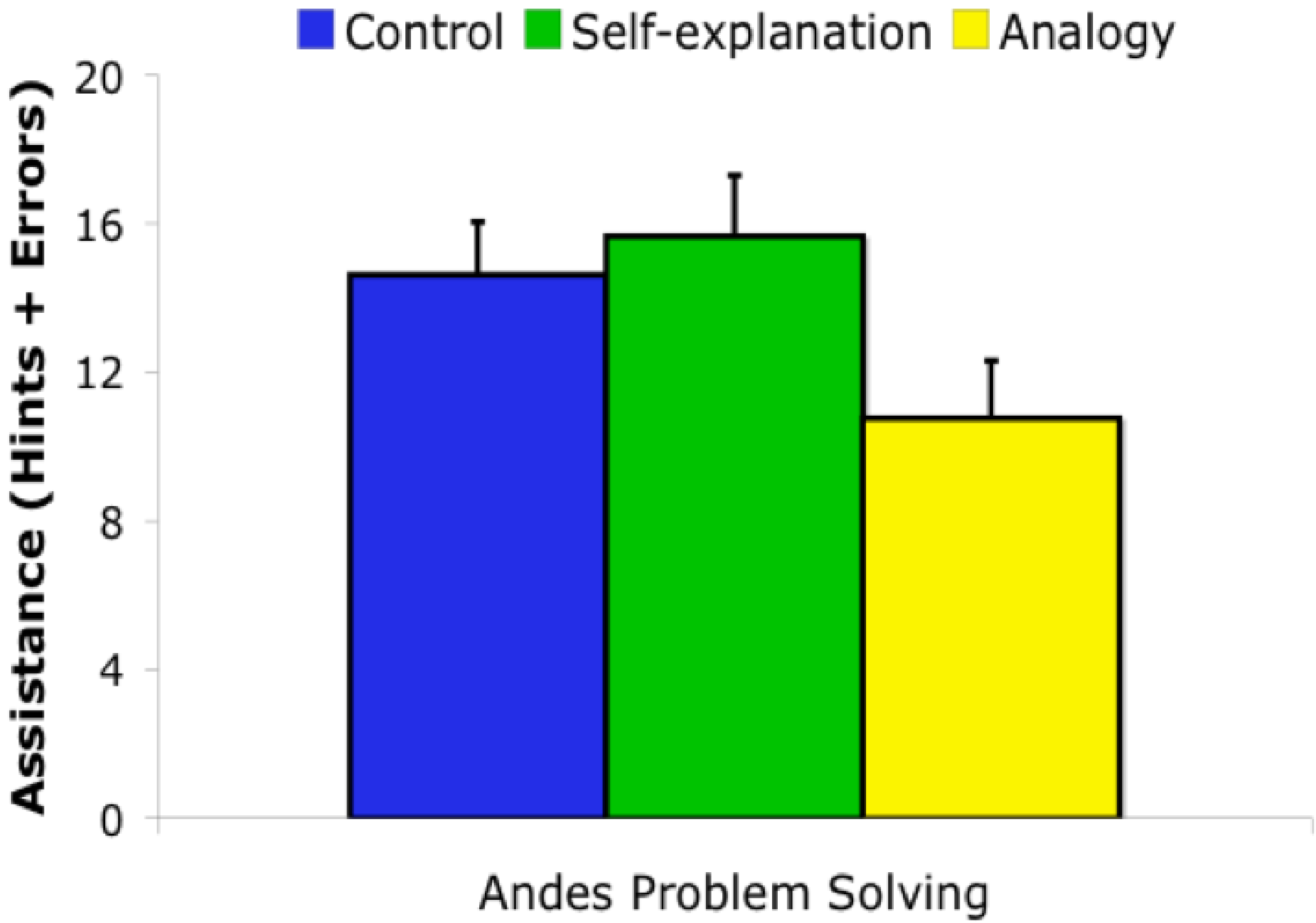
Transfer: problem solving (irrelevant values); multiple choice

-- *Class instruction* --

Delayed test

Andes

Andes performance



Summary - Macro-level

- Normal Test
  - *Isomorphic - different sought value*

    Control = Self-explain > Analogy

- Transfer Tests
  - Near Transfer - *irrelevant info*
  - Far Transfer - *qualitative reasoning*

    Self-explain = Analogy > Control
  - Andes Homework

    Analogy > Self-explain = Control

Explanation - Micro-level

Control and Self-explain better on Normal test

- Practice
  - Construct problem solving steps
  - Construct knowledge linking equations to problem types

Analogy and Self-explain better on Transfer tests

- Worked examples
  - Construct principle justification
  - Analogy and Self-explain engaged in processes to create knowledge to link problem features to abstract principles
  - Refine knowledge

Analogy better on Andes Homework

- Preparation for future learning (lecture)
  - Conceptual knowledge more abstract

Conclusion

- Core laboratory features can successfully be implemented in classroom experiments (fine-grained measures; variety of assessments)
- Tests generalization of *learning principles* (a few of many see www.learnlab.org)
  - Initial positive evidence for self-explanation and analogy
  - Affords theoretical explanations at Macro (intervention) and Micro levels (mechanisms)
- Not merely a test bed, but also raises new questions:
  - Individual differences; Preparation for future learning
  - Do our theories scale?
  - Theoretical integration? How do the principles work together?

In Vivo Steps

- Steps
  0. Become an expert (content domain)
  1. Generate a hypothesis (in vitro => in vivo)
  2. Select a domain site and instructors
  3. Develop materials
  4. Design study
  5. Formulate a procedure
  6. Run experiment & log to Datashop
  7. Report your results

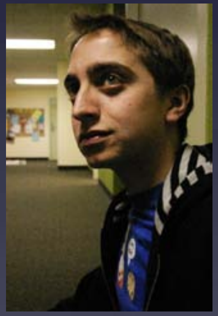
Acknowledgements

CogSci Learning Lab


Alicia Chang

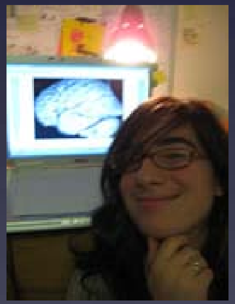

Dan Belenky


Soniya Gadgil


Max Lichtenstein


Greg Cox


Alyssa Thatcher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Kurt VanLehn


Bob Hausmann

Ted McClanahan, Bob Shelby,
Brett Van De Sande, Anders Weinstein,
Mary Wintersgill

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