



Misconceptions in Science and Math: Two Views of What They Really Are, and Implications for Teaching

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Outline of this Talk

- Background
- Just what are misconceptions?
- Examples from the sciences and math
- Two contemporary views
 - Misconceptions as personal theories
 - Misconceptions as activation of knowledge pieces in response to context
- Two more examples
- Take-home messages from this talk

Background

- Misconceptions in science have been widely studied for many years
- Misconceptions have been cataloged in physics, astronomy, biology, math and other disciplines (e.g., history)
- In some areas such as physics, very large bibliographies exist (Pfundt & Duit, <http://www.ipn.uni-kiel.de/aktuell/stcse/stcse.html>)
- Conferences have been held on misconceptions, the most notable was held at Cornell in '87 with two thick proceedings
- Professional videos exist on students' misconceptions in biology and earth science, and how difficult it is for students (and teaching) to overcome them:
A Private Universe, Lessons from Thin Air (Annenberg)

Just what are misconceptions?

- Misconceptions are beliefs, ideas, concepts that are in conflict with currently held scientific thought.
- Why should we care about them? (they interfere with what we are trying to teach)
- How do they form? (constructivism; current knowledge filters what we learn)
- How is a misconception different from an error or mistake? (conflict)
- Why can't solid science teaching by a good teacher result in misconception-free students? (think of politics)
- Bottom line: Developing a self-consistent conceptual system by which we reason in our disciplines is a time-consuming effortful process. Often we get over misconceptions by the normal process of developing expertise without any "aha" experience.

Examples from the sciences and math

Math:

Write an algebraic equation to represent the following relationship: There are six times as many students as professors at this university. Use S to represent the number of students and P to represent the number of professors.

- Very common answer: $6S=P$
- Causes: left-to-right translation of the problem statement and confusion between variables and labels.
- Once they write $6S=P$, it is hard to dissuade them that this is not the correct expression.

Examples from the sciences and math

Physics:

- Force of the hand acting on a ball tossed in the air
- Bigger objects exert larger forces on lighter objects when they interact
- Heavier objects fall faster than lighter objects
- Blocking the top half of a lens while an image is formed results in only half the image
- Other topics: Relativity, thermodynamics, etc.

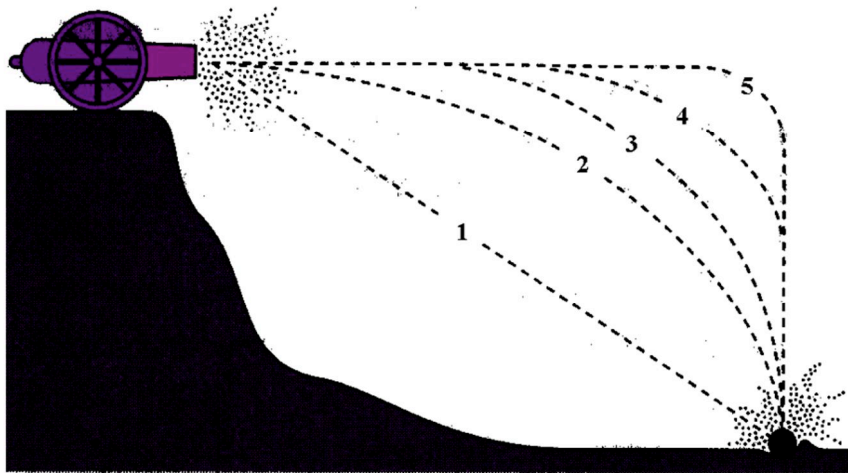
More about the situation in physics

- Misconceptions tests exist in physics:
Mechanics (Force Concept Inventory—FCI, Mechanics Baseline Test; Force and Motion Conceptual Inventory—FMCI); E & M (Conceptual Survey of Electricity & Magnetism--CSEM)
- Sample questions from the FCI

FCI consists of qualitative questions that probe basic conceptual understanding

FCI Question #12 (Cannon)

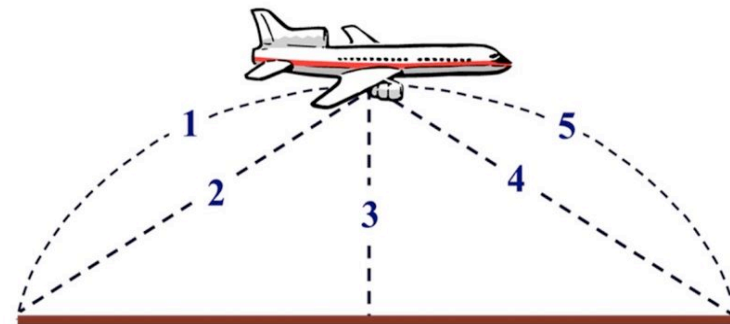
A ball is fired by a cannon from the top of a cliff as shown below. Which of the paths 1-5 would the cannon ball most closely follow?



FCI Question #23 (Airplane)

A bowling ball accidentally falls out of the cargo bay of an airliner as it flies in a horizontal direction.

As observed by a person standing on the ground and viewing the plane as in the figure below, which path would the bowling ball most closely follow after leaving the airplane?



What has the FCI accomplished?

- Brought home the fact that students emerge from physics classes with poor conceptual understanding
- Forced physics faculty to think of ways of teaching that help students acquire conceptual understanding
- Made the value of physics education research more apparent
- Vignette from Eric Mazur's pre-med physics class at Harvard

Examples from the sciences and math

Biology:

- On how plants make food:
 - ❖ The soil loses weight as plants grow in it; the soil is the plant's food, roots absorb soil, plants convert energy from the sun directly into matter, plants give off mainly carbon dioxide, the leaf's main function is to capture rain and water vapor in the air, plants get their food from the roots and store it in the leaves, chlorophyll is the plant's blood, chlorophyll is not available in the air in autumn and winter so the leaf cannot get food
- The solid, heavy stuff that trees are made of (wood) comes from minerals in the soil
- Evolution: Animals consciously change to survive environmental challenges

Examples from the sciences and math

Astronomy/earth science:

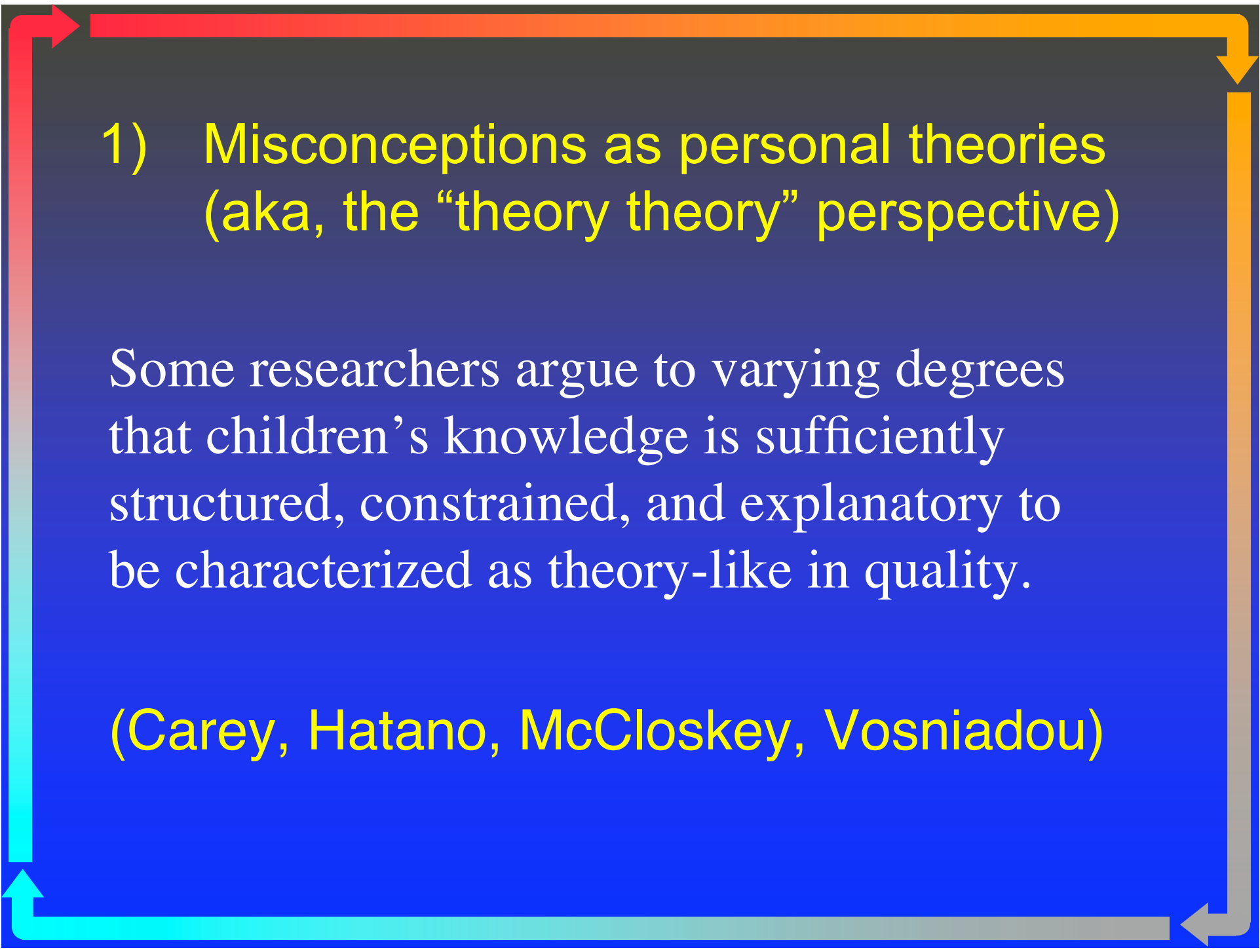
- Young children's belief that the Earth is flat.
- Seasons are caused by proximity of Earth to sun.
- Stars vanish in the daytime and "come out" at night
- The moon has a hemisphere in perpetual darkness called the "dark side."

A decorative border surrounds the slide content. It consists of four thick arrows forming a square frame. The top arrow is red and orange, pointing right. The right arrow is orange and yellow, pointing down. The bottom arrow is yellow and green, pointing left. The left arrow is green and cyan, pointing up.

Two contemporary views:

- 1) Misconceptions as personal theories
- 2) Misconceptions as activation of knowledge pieces in response to context

Caveat: The two “theories” I’m about to discuss have strong followings. Feelings about which is better for explaining empirical findings run deep.



1) Misconceptions as personal theories (aka, the “theory theory” perspective)

Some researchers argue to varying degrees that children’s knowledge is sufficiently structured, constrained, and explanatory to be characterized as theory-like in quality.

(Carey, Hatano, McCloskey, Vosniadou)



1) Misconceptions as personal theories (aka, the “theory theory” perspective)

- Students possess coherent theories about science from having constructed them.
- These are cognitive entities that are activated and applied as bundled units to situations.
- They are remarkably consistent.



1) Misconceptions as personal theories

What to do about this in the class?

- Help students deconstruct their “naïve theories” and reconstruct appropriate scientific theories.
- How? Look for misconceptions and help students overcome them.

1) Misconceptions as personal theories

What conditions are thought to help students reconstruct their understanding?

Posner, Strike, Hewson and Gerzog (1982) argue that four conditions need to be present in order for students to undergo a conceptual change:

- 1) Students must become dissatisfied with their existing conception
- 2) Students must possess some minimum understanding of the scientific concept
- 3) Students must view the scientific concept as plausible
- 4) Students must view the scientific concept as useful for interpreting or predicting various phenomena.

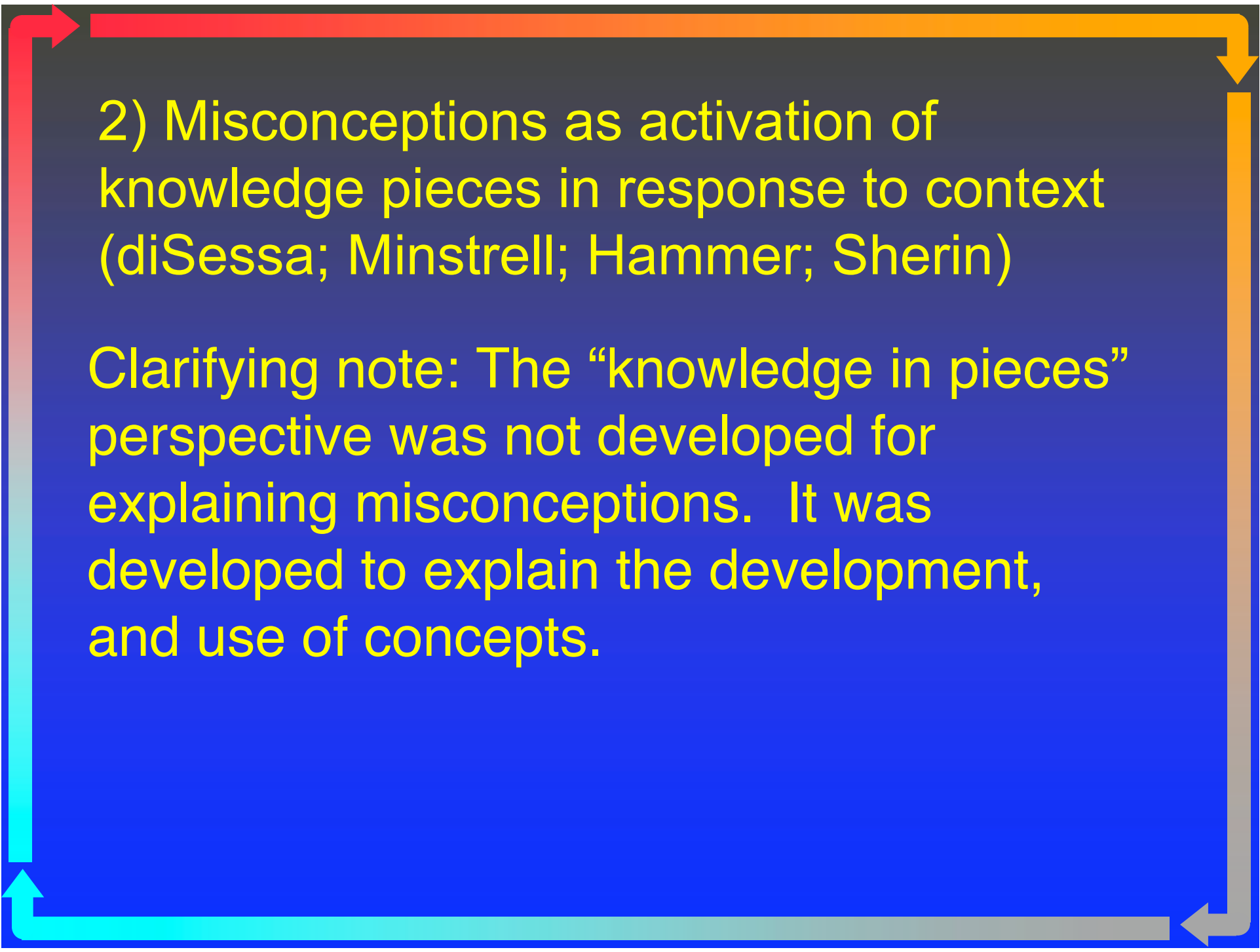


Summary of the personal theory model of misconceptions

Misconceptions are complex cognitive entities that are applied wholesale

They are sufficiently structured to be considered naïve theories; they are consistently applied by students and are resistant to change

Teacher's job is to help students deconstruct incorrect theories and build correct ones.



2) Misconceptions as activation of knowledge pieces in response to context (diSessa; Minstrell; Hammer; Sherin)

Clarifying note: The “knowledge in pieces” perspective was not developed for explaining misconceptions. It was developed to explain the development, and use of concepts.

2) Misconceptions as activation of knowledge pieces in response to context

- 👉 People possess pieces of knowledge that are acquired through experience or formal schooling and that need no justification (e.g., more effort yields larger result; effort must be continued to maintain an effect; things balance when there is equal influence from opposing directions).
- 👉 Knowledge pieces are activated in response to context to reason about the context.
- ✓👉 Which knowledge pieces get activated are highly dependent on context. Which pieces of knowledge are activated depend on some cuing priority.
- ✓👉 Pieces of knowledge activated are “compiled” in real time to make sense of context.
- ✗👉 Change the context slightly and a new set of knowledge pieces get activated and compiled—result: new misconceptions.
- ✗👉 How does one reconcile experts’ knowledge within this framework?

2) Misconceptions as activation of knowledge pieces in response to context

What to do about this in the class?

- Help students activate the appropriate knowledge pieces
- Help students build lots and lots of knowledge pieces (i.e., build a rich knowledge base in memory)
- Help students make appropriate associations between knowledge pieces and context (i.e., help them compile appropriate knowledge pieces on the fly)
- Don't worry if students still make conceptual errors after your best efforts. The knowledge in pieces perspective predicts conceptual errors—to not find them would refute the model



Summary of the knowledge in pieces model of misconceptions

Misconceptions result from the compilation of knowledge pieces activated in real time in response to context.

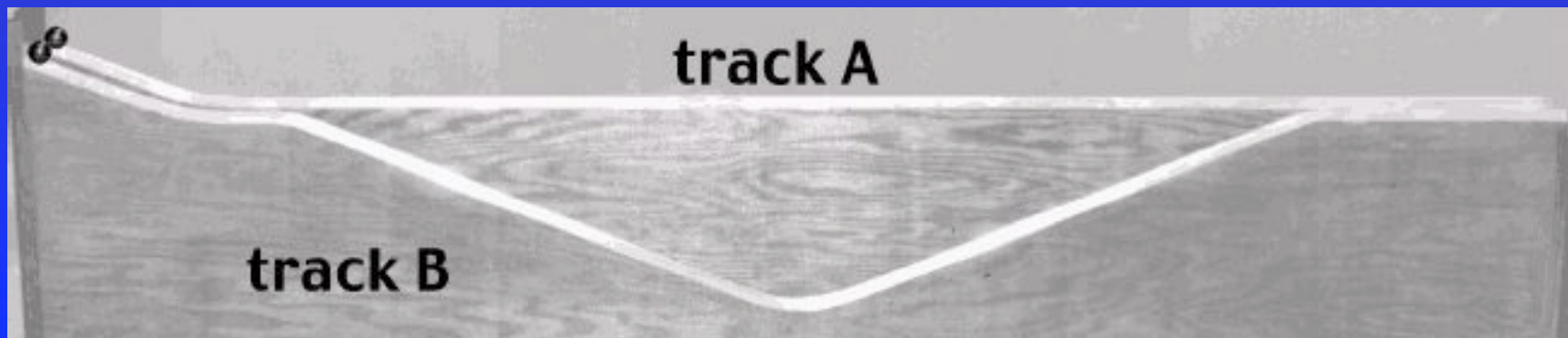
Concepts are complex compilations of various knowledge pieces. You should observe lots of inconsistent application of concepts because the compilation is very sensitive to the pieces activated that comprise the compilation.

A teacher's job is to help students construct lots of knowledge pieces, to organize those pieces hierarchically, and to link them to procedures for applying them and to contexts for applying them.

Two more examples:

#1 Judging the Realism of Motion

1) We constructed 5 animations of the motion of two balls moving along the tracks shown and asked students to pick which depicted realistic motion.



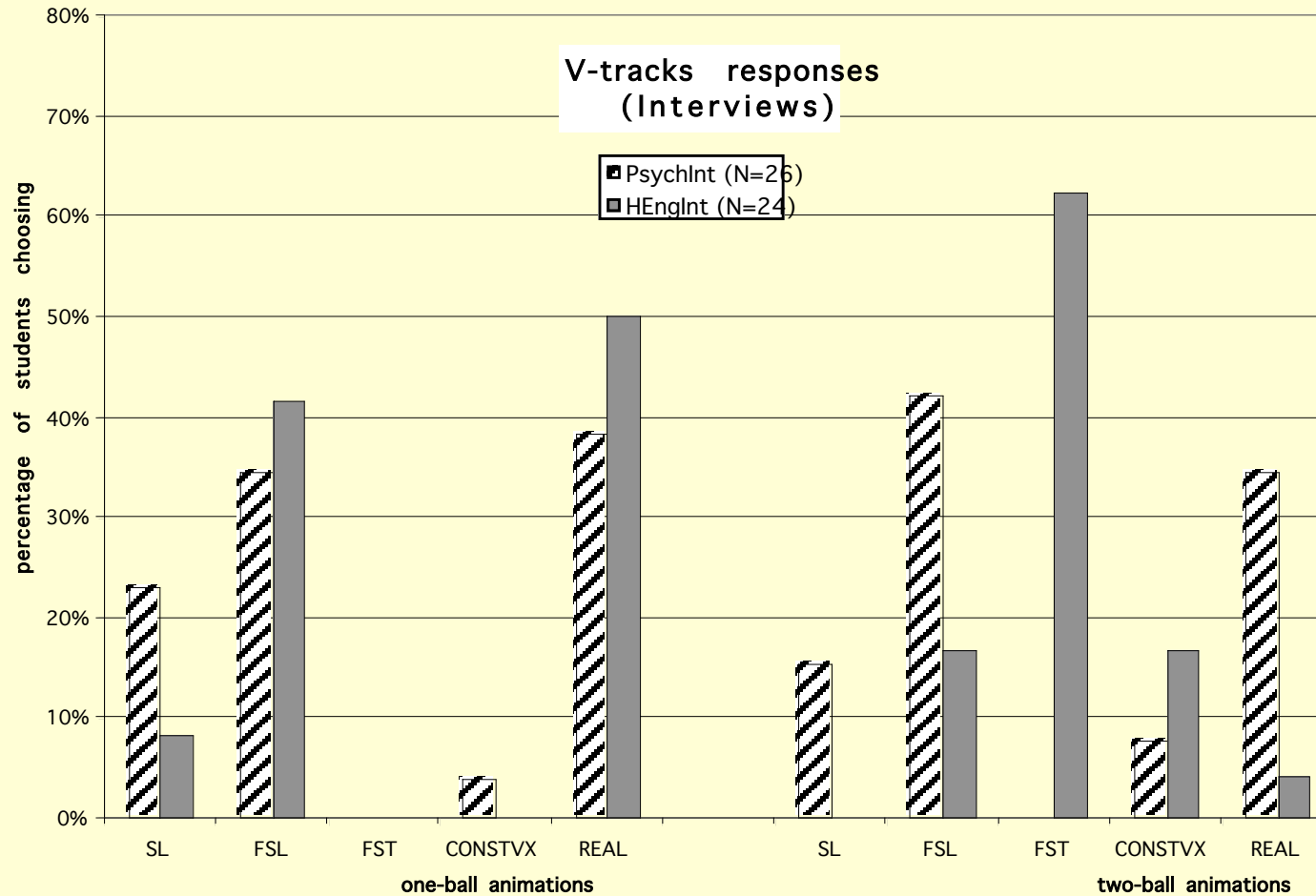
Judging the Realism of Motion

Experiment:

- 1) Two groups of students: honors engineering students, students enrolled in ed. psych.
- 2) Students shown one-ball animations first, then two-ball animation.
- 3) Students interviewed individually and asked to “think aloud” as they reasoned about the realism of the motion.

Let's take a look at the animations

What leads to the following very interesting performance pattern?





Students' Reasoning

Students had expectations about what should happen on different portions of the track, and they made observations to judge if their expectations were met.

Sample expectations: Ball should speed up going downhill; ball should slow down going uphill; ball should not undergo sudden speed changes without an apparent cause.



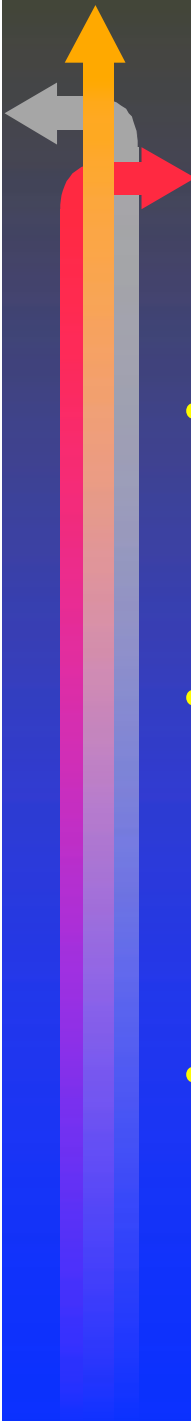
Observation Strategies

- Students' methods for making observations differed between the one-ball and two-ball cases:
 - In one-ball animations, students use the fixed reference frame of the track to make judgments about speed and speed changes.
 - In two-ball animations, students used relative position of the two balls (e.g., “faster” meant gap between the balls was increasing).



More findings from interviews:

- Observations in one-ball case were sensitive enough to detect the ball speeding up while going uphill.
- Observations in two-ball case often were not.
- Tie expectation very strong among physics students--justified in terms of conservation of energy arguments.
- Data strongly suggests that most physics students did not detect the anomalous motion with two balls, whereas most of the psychology students did.
- Even when physics students detected anomaly in two-ball case, tie expectation often over-rode it.

A decorative graphic on the left side of the slide. It features a vertical bar with a color gradient from blue at the bottom to orange at the top. Three arrows are positioned at the top of the bar: a grey arrow pointing left, a red arrow pointing right, and an orange arrow pointing up.

What do students do if inconsistency in choices is pointed out?

- 16 of the physics students who answered inconsistently across 1-ball and 2-ball were asked to make their choices consistent.
- 13 of the 16 students picked FST in the two-ball case, and among those, 8 (62%!) stuck to this choice, despite being shown the unrealistic motion of ball B in the one ball case.
- Among the 13 who picked FST in the two-ball case, 6 had selected REAL in the one-ball case, and 4 of those stuck with FST in this task.



What do our findings suggest?

- People possess pre-existing knowledge that filters how they observe and reason about situations.
- What knowledge in memory is triggered into action for reasoning depends on context.
- “A little science knowledge can be a dangerous thing.” Even when students try to apply knowledge they are learning, they lack the requisite expertise to determine when that knowledge is transferable to novel contexts.

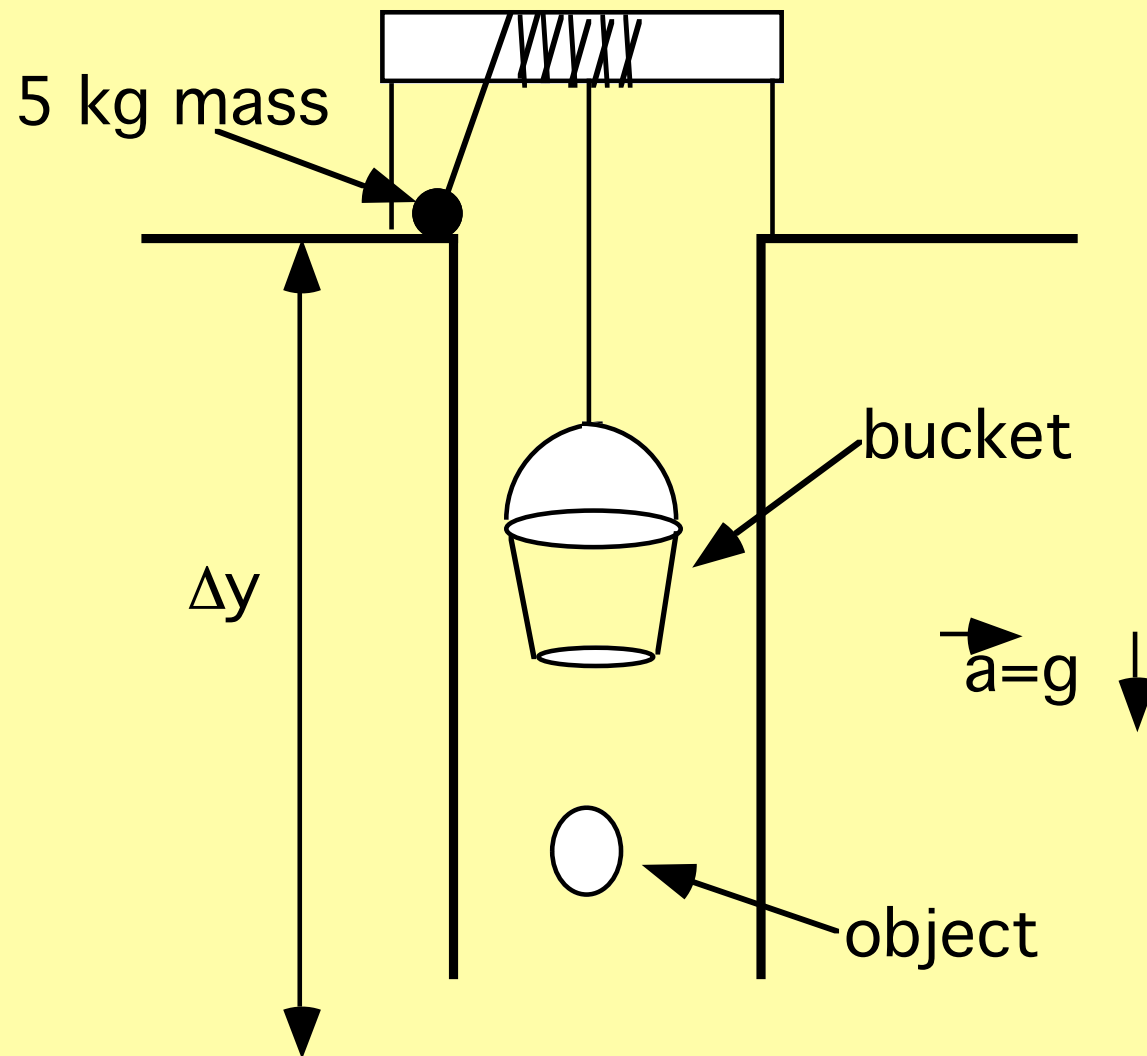
#2: Problem Posing

Experiment:

- 1) Students given “concept scenario” and asked to pose problems that matched the scenario.
- 2) Students asked to explain how the problems posed matched the scenario.

Scenario: Mechanical energy is conserved, followed by conservation of momentum, followed by conservation of mechanical energy with potential energy increasing and kinetic energy decreasing.

Example of piecemeal matching of scenario



Example of piecemeal matching of scenario

A bucket is being dropped by a massless rope with an acceleration of $g = 9.8 \text{ m/s}^2$ in the y-direction.

Connected to the rope is a mass of 5 kg. After the bucket is dropped into the well which has a depth of $\Delta y = 100 \text{ m}$; the bucket collides (& sticks) with an object with a mass of 10 Kg and an initial velocity of 0 m/s after 70 m. Given the bucket has a mass of 25 Kg. find the velocity at the collision of the bucket and object and find the final velocity of the bucket and object at the bottom of the well Also, the rope is 101 m long. In addition find the final energy of the mass connected to the rope which had an initial height of 0 m.

What are some take-home messages from this talk?

- Students possess/exhibit misconceptions.
- Are they cognitive entities that are recalled as units and applied consistently, or compilation of fine-grained knowledge pieces that are extremely sensitive to context?
- Depending on which you believe, the implications for classroom intervention strategies are somewhat different.
- Good news: Eventually, many students overcome misconceptions as they learn more science.

The image features a central 3D-style text graphic that reads "The End!!!". The text is rendered in a bold, sans-serif font with a color gradient from yellow to orange and a 3D effect. It is positioned in the center of a rectangular frame. The background of the frame is a blue gradient, transitioning from a darker blue at the top to a lighter blue at the bottom. The frame is bordered by a thick, multi-colored line that follows the perimeter of the rectangle. The colors of the border transition from red at the top-left corner, through orange and yellow, to cyan and blue at the bottom-left corner, and finally to grey at the bottom-right corner. Small arrowheads are visible at the corners of the border, indicating a clockwise direction.