Physics Education Laboratory
Lecture 10
PCK for Dynamics / Energy

Francesco Longo - 28/10/24

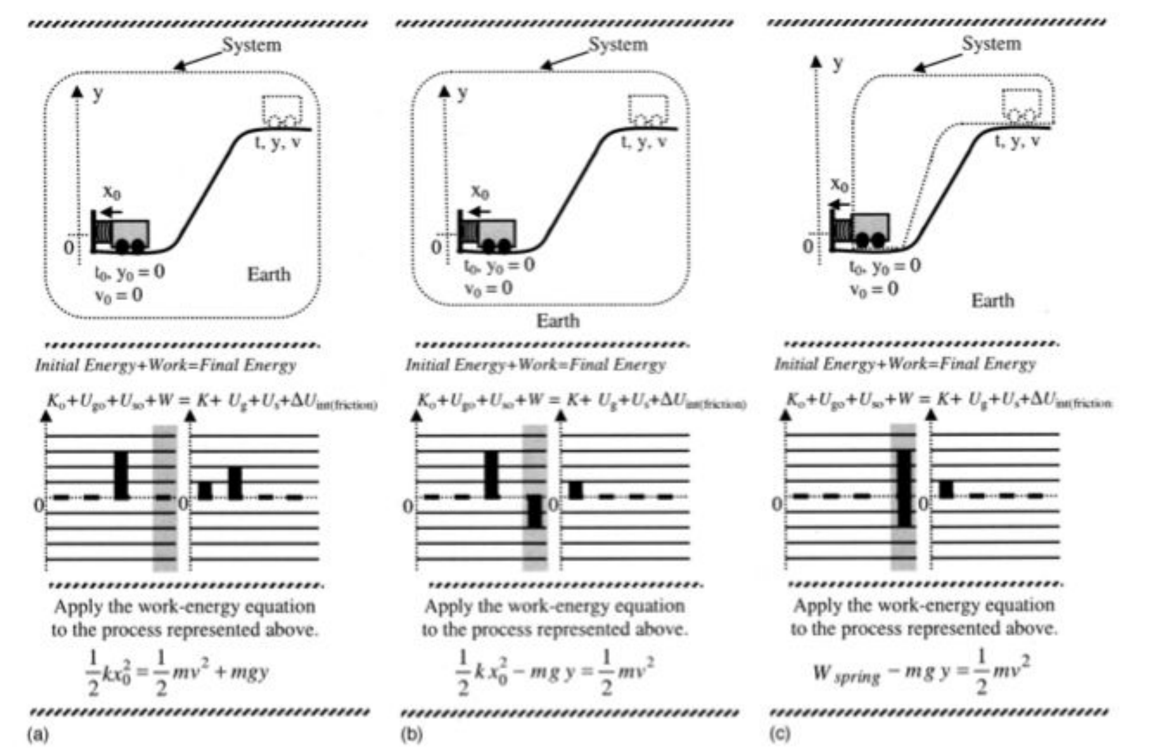
Genuine understanding is most likely to emerge...if people possess a number of ways of representing knowledge of a concept or skill and can move readily back and forth among these forms of knowing.

(Gardner, 1991)

The different systems are chosen for the same physical process.

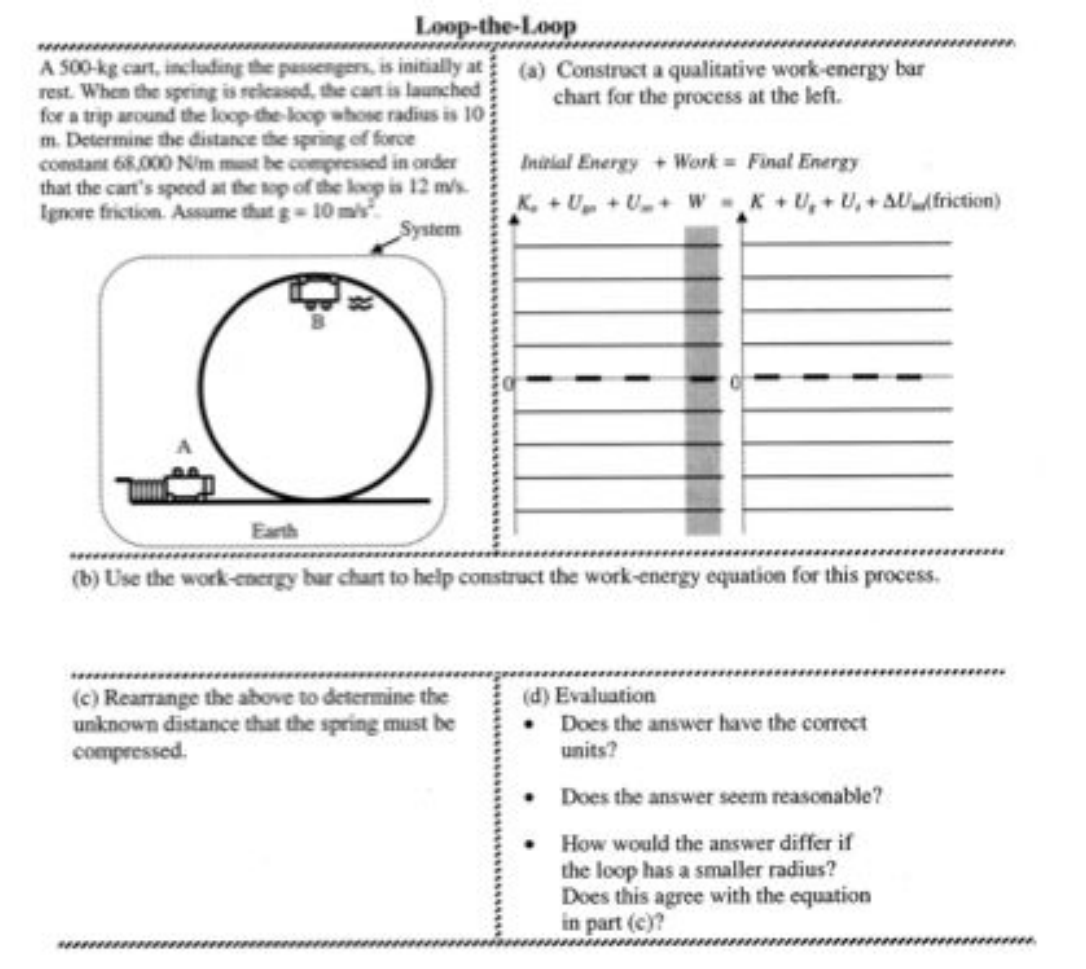
(a) The cart, the spring, and Earth are in the system.
(b) The cart and the spring are in the system, but not Earth.
(c) The system includes only the cart.
For each chosen system there is one work–energy bar chart and the corresponding generalized work–energy equation.

In practice, it would be easy for students to use a system that includes Earth and the spring, although the choice of the system does not affect the physical results.



One of the quantitative problems included in the Active Learning Problem Sheets. Students solve these problems using the multiple-representation strategy after having developed skills to construct qualitative representations.

These multiple-representation problems help students develop qualitative understanding about the physical processes and develop problem- solving expertise, instead of using only an equation- centered method.



Loop-the-Loop

A 500-kg cart, including the passengers, is initially at rest. When the spring is released, the cart is launched for a trip around the loop-the-loop whose radius is 10 m. Determine the distance the spring of force constant 68,000 N/m must be compressed in order that the cart's speed at the top of the loop is 12 m/s. Ignore friction. Assume that $g = 10\ m/s^2$.

(a) Construct a qualitative work-energy bar chart for the process at the left.

Initial Energy + Work = Final Energy

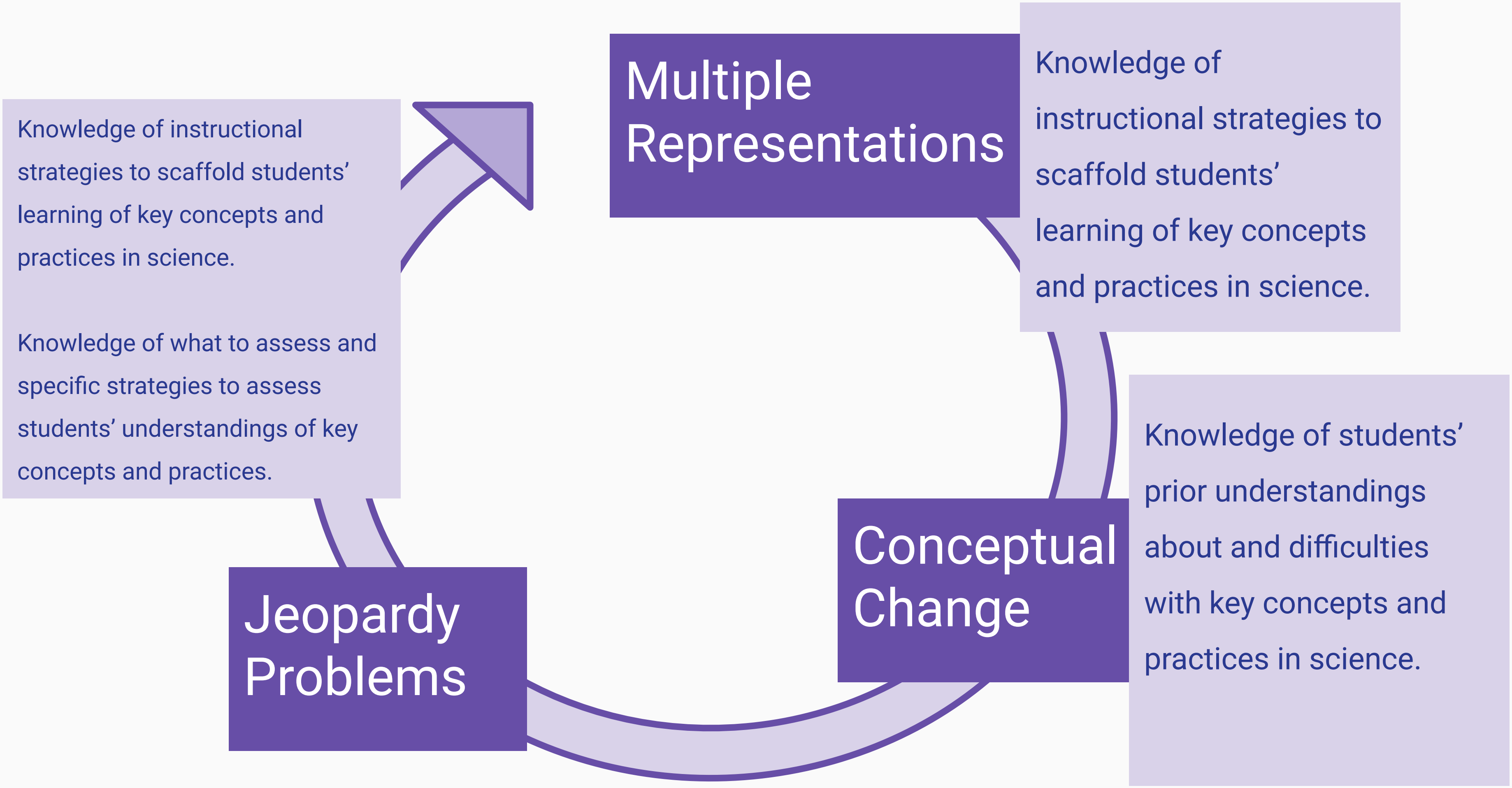
$K_o + U_{go} + U_{so} + W = K + U_g + U_s + \Delta U_{int}$(friction)

(b) Use the work-energy bar chart to help construct the work-energy equation for this process.

(c) Rearrange the above to determine the unknown distance that the spring must be compressed.

(d) Evaluation

- Does the answer have the correct units?
- Does the answer seem reasonable?
- How would the answer differ if the loop has a smaller radius? Does this agree with the equation in part (c)?



HOW TO DEVELOP DIFFERENT PCK'S ASPECTS and CONTENT KNOWLEDGE FOR TEACHING

Jeopardy problems

Physics Jeopardy problems require students to work backwards. Instead of constructing and solving equations pertaining to a given physical situation, students are asked to construct a proper physical situation from a given equation or graph.

(Cui et al., 2006)

EXAMPLES:

Jeopardy problems ensure that "students cannot use formula-centered, plug-and-chug problem solving methods, rather they must give meaning to symbols in the equation" and "help students to learn to translate between representations in a more robust manner."

(Van Heuvelen et al., 1999)

Jeopardy Equations:

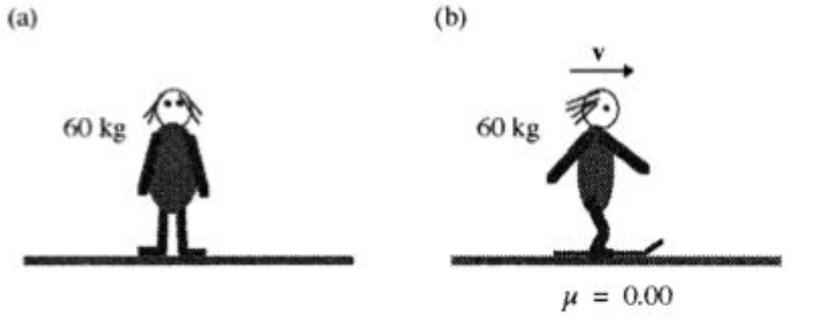


Fig. 1. The equation $N-(60\text{ kg})(9.8\text{ m/s}^2)=0$ describes the situations shown in (a) and (b).

In Equation Jeopardy, you reverse the normal process by providing a mathematical equation as the given information and asking the student to construct an appropriate physical situation that is consistent with the equation.

Consider a Jeopardy Problem involving the component form of Newton's second law applied to an object on an incline,

$$150\ \text{N} - (14.5\ \text{kg})(9.8\ \text{m/s}^2)\sin 34° - (0.32)(14.5\ \text{kg}) \times (9.8\ \text{m/s}^2)\cos 34° = (14.5\ \text{kg})a_x .$$

With a little work, a physicist will recognize that something exerts a 150-N force parallel to a 34° incline while pulling (or pushing) a 14.5-kg object up the incline. There is friction with a 0.32 kinetic friction coefficient between the object and the inclined surface. This Jeopardy Problem is somewhat more challenging.

We can ask the students to translate from the mathematical representation to a physics sketch, a free-body diagram in this case, and then from the diagram to a picture-like sketch of an appropriate physical situation.

Finally, students could be asked to invent a word problem that is consistent with the equation.

Diagram and Graph Jeopardy problems:

In Diagrammatic and Graphical Jeopardy Problems, students are first given a diagram or graph.

They then invent a word or picture description and a math description for a process that is consistent with the diagram or graph. Consider the force diagram in Fig. 2(a). Tell as much about the situation as you can.

The force diagram could describe a box or block moving downward at constant velocity along a vertical wall (Fig. 2(b)).

The normal force indicates that the object is pressed against a vertical wall. The kinetic friction force indicates that the object is moving down.

Notice that the y components of the forces parallel to the wall's surface add to zero.

This provides a nice opportunity to confront the common belief “misconception” that there must be a net force in the direction of motion in order for that motion to continue.

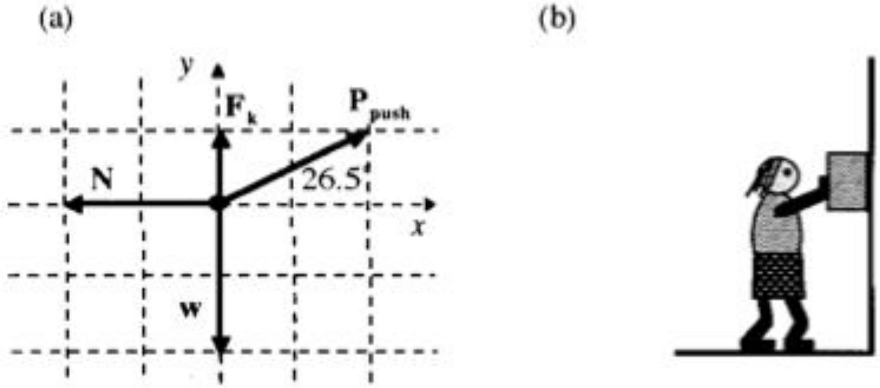


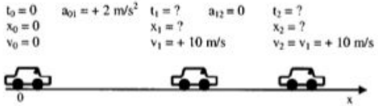
Fig. 2. The free-body diagram shown in (a) represents the process shown in (b).

Multiple Representations in Kinematics

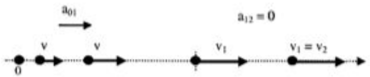
Verbal Representation

A car at a stop sign initially at rest starts to move forward with an acceleration of 2 m/s^2. After the car reaches a speed of 10 m/s, it continues to move with constant velocity.

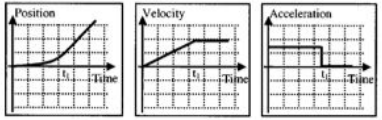
Pictorial Representation



Physical Representation (Motion Diagram)



Physical Representation (Kinematic Graphs)



Mathematical Representation

For $0 < x < x_1$ and $0 < t < t_1$	For $x_1 < x$ and $t_1 < t$
$x = 0 + 0 \bullet t + (1/2)(2\ \text{m/s}^2)\ t^2$	$x = x_1 + (10\ \text{m/s})\ t$
$v = 0 + (2\ \text{m/s}^2)\ t$	$v = +10$ m/s

Fig. 1. The kinematics process described in the problem can be represented by qualitative sketches and diagrams that contribute to understanding. The sketches and diagrams can then be used to help construct with understanding the mathematical representation.

A crate moves along a vertical wall. The application of Newton's second law in component form to that crate is shown below (the y-axis points up). Assume that g = 10 m/s^2.

$$F \cos 60^0 + \quad 0 \quad - N + \quad 0 \quad = 0$$

$$F \sin 60^0 + 0.40\, N + 0 - 200\ \text{N} = (20\ \text{kg})(-0.50\ \text{m/s}^2)$$

What is the object's mass? 20 kg

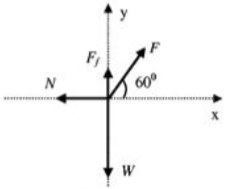
What is the object's weight? 200 N

How many forces act on the object? 4

Solve the equations for the unknowns.

$F = 178$ N, $N = 89$ N

Draw below a set of coordinate axes, one horizontal and the other vertically up. Then, examine the components of each force one at a time and draw arrows representing each force, thus constructing a free-body diagram.



Describe in words and/or in a drawing some real situation that might result in the diagram above.

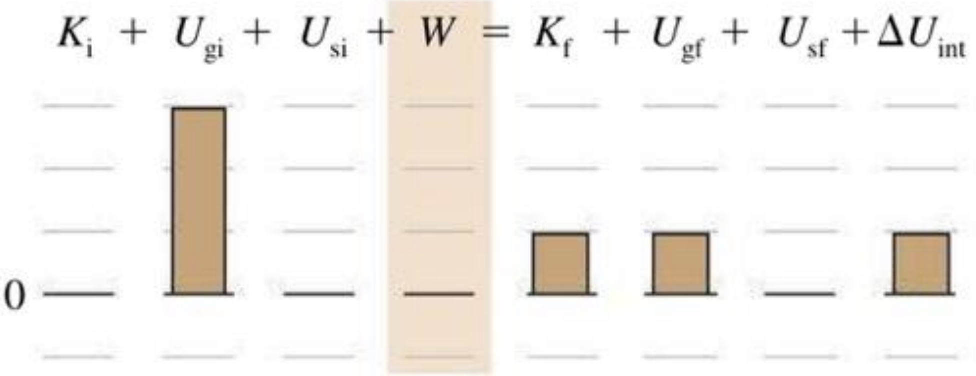
Fig. 2. The physical process described in the mathematical equations can be represented by diagrams, sketches, and words. The diagrams and sketches aid in understanding the symbolic notations, and help give meaning to the abstract mathematical symbols. (There could be more than one diagram and sketch consistent with the mathematical equations.)

Multiple Representations in Kinematics and Dynamics mean a wide usage and application of Jeopardy problems

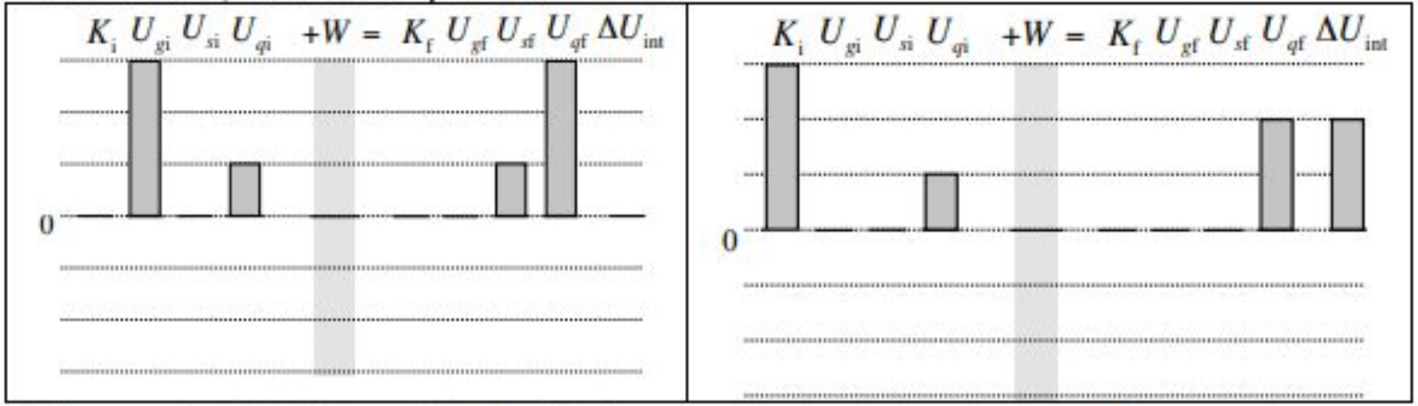
11. • **Jeopardy!** Contestants on the game show *Jeopardy!* depress spring-loaded buttons to "buzz in" and provide the question corresponding to the revealed answer. The force constant on these buttons is about 130 N/m. Estimate the amount of energy it takes—at a minimum—to buzz in.

39. * **Bar chart Jeopardy 1** Invent in words and with a sketch a process that is consistent with the qualitative work-energy bar chart shown in Figure P6.39. Then apply in symbols the generalized work-energy principle for that process.

Figure P6.39



4. Bar chart jeopardy: The two bar charts below could represent many processes. Separately, for each bar chart, answer the questions below.



a) Draw a sketch of a possible physical process that each bar chart could represent.
b) Describe the physical process in words.
c) Construct a work-energy equation that each bar chart could represent.

Main topics

Kinematics
Dynamics
Energy
Fluidodynamics
Calorimetry/thermodynamics
Optics
Electrostatics
Magnetism
Electromagnetism
Quantum Mechanics
Special & General relativity

Useful education tools in PER

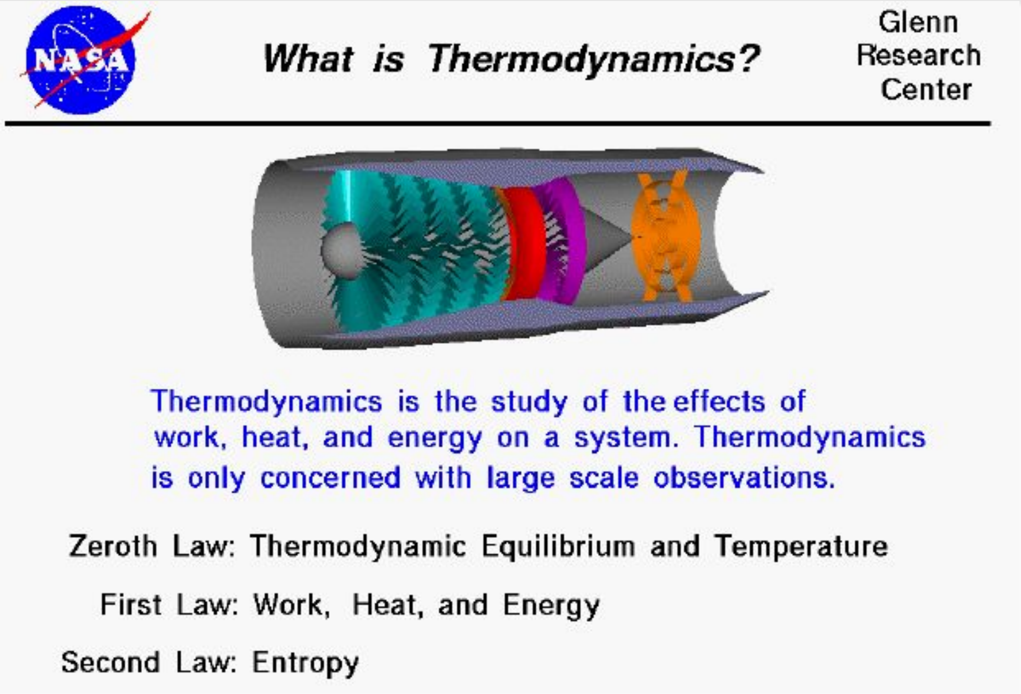
Early Physics
Multiple Representations in Physics
Historical approaches
Problem-solving activities
Jeopardy problems
Physics of everyday Thinking
Project Based Education
Modelling instruction
Simulation for Educational Physics
ISLE - Investigative Science Learning Environment
IBSE - Inquiry Based Science Education
Bayesian updating method
Assessment methods
On line educational toolkit (DESMOS)
Students with learning Disorders

Physics Education Laboratory
Lecture 10
Content Knowledge for Thermodynamics

Francesco Longo - 28/10/24

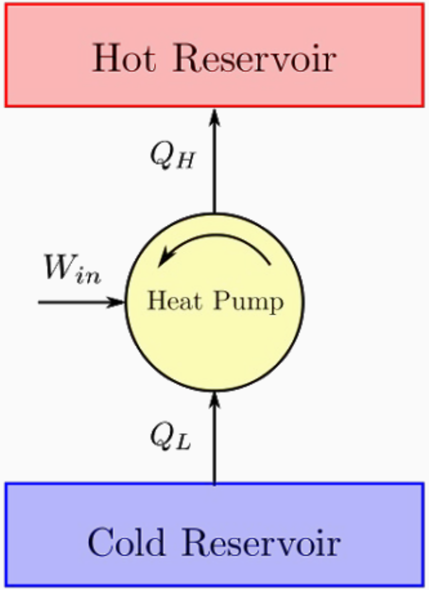

BIG BOWL: TOO HOT. MEDIUM BOWL: TOO COLD. SMALL BOWL: JUST RIGHT. THIS GOES AGAINST ALL OF THE THERMODYNAMICS I EVER LEARNED!
©1993 Tom Swanson
Tom

Key concepts in thermodynamics



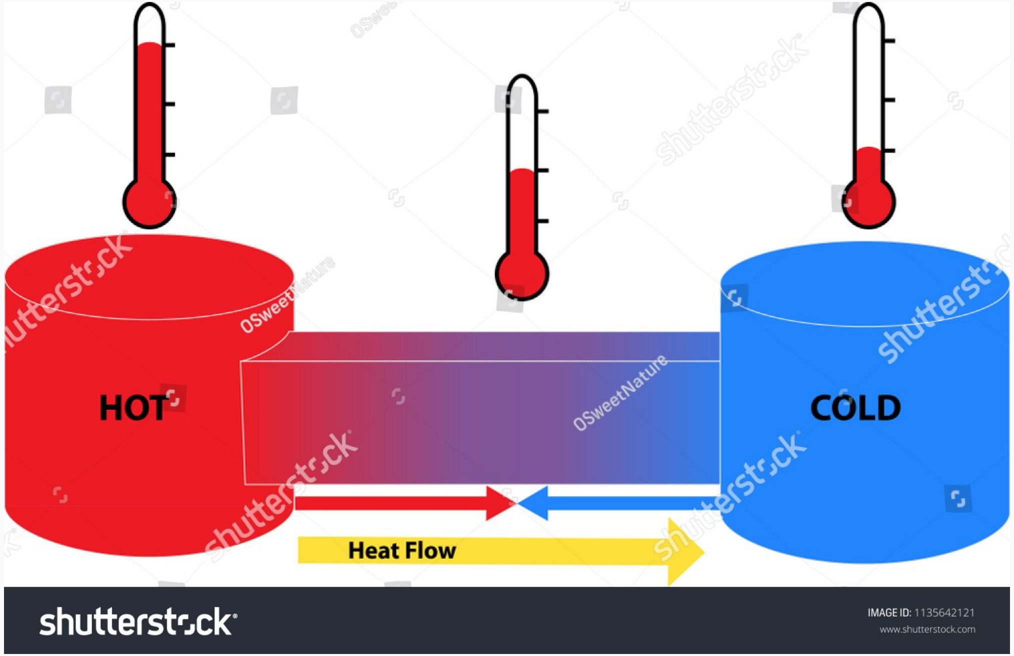
Key concepts in thermodynamics

- Temperature
- Thermodynamic state
- Thermodynamic Equilibrium
- State changes - Latent heat
- Heat - Heat exchange
- Work
- Internal energy
- Laws of gases - pV plane
- Reversibility / irreversibility
- Entropy



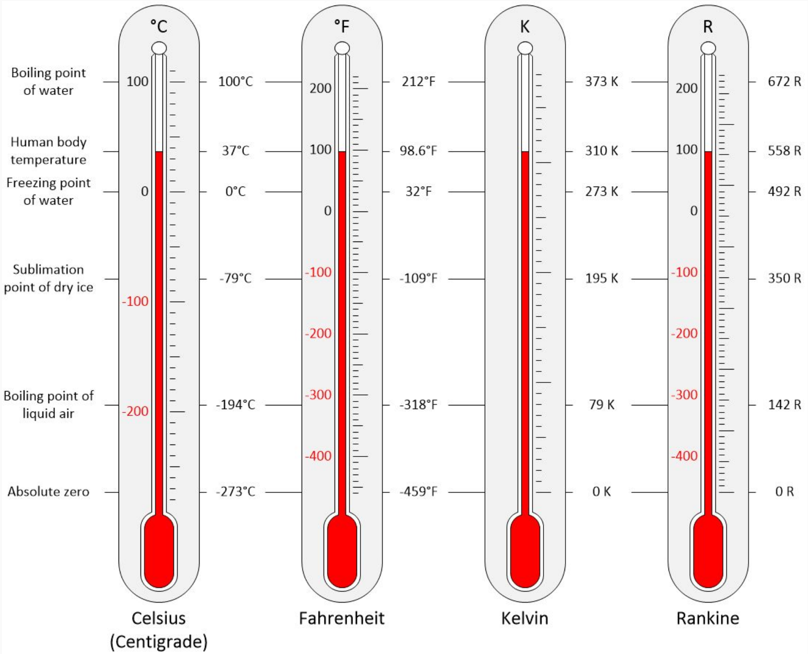
Key concepts in thermodynamics

- Temperature
- Hot vs Cold



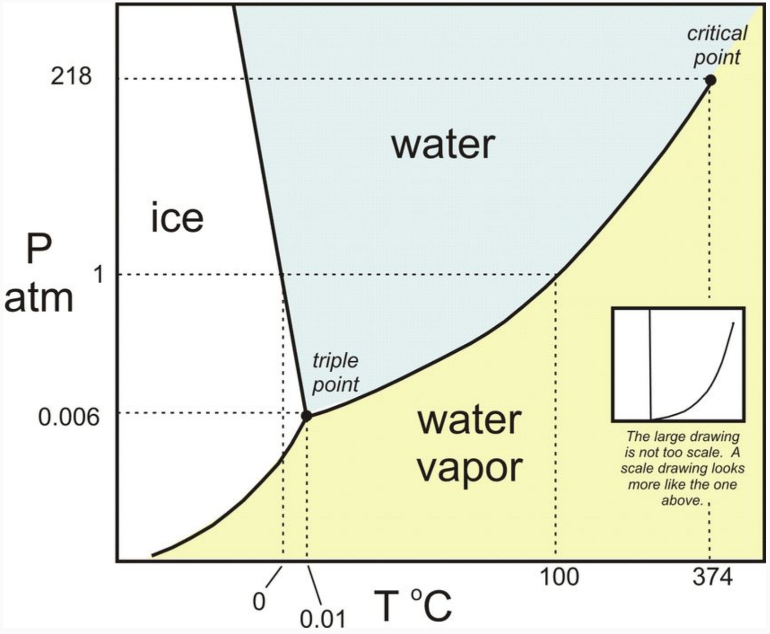
Key concepts in thermodynamics

- Temperature scales



Key concepts in thermodynamics

- State transitions
- Latent heat



Key concepts in thermodynamics

- Reversibility / irreversibility
- pV plane
- quasi-static phenomena

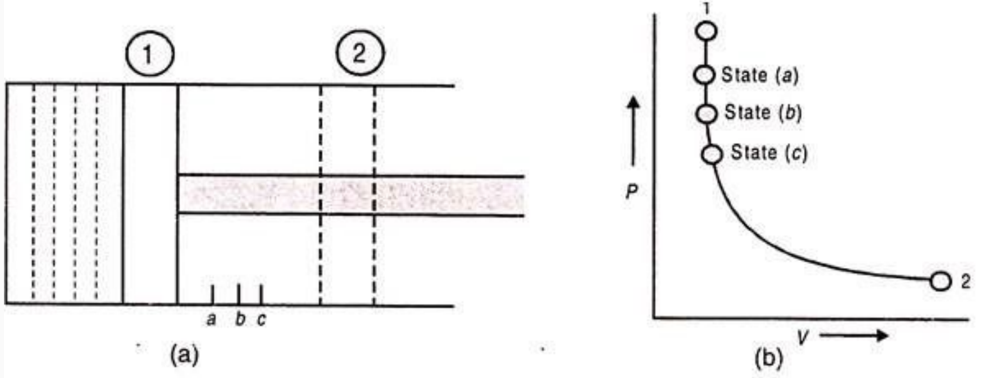
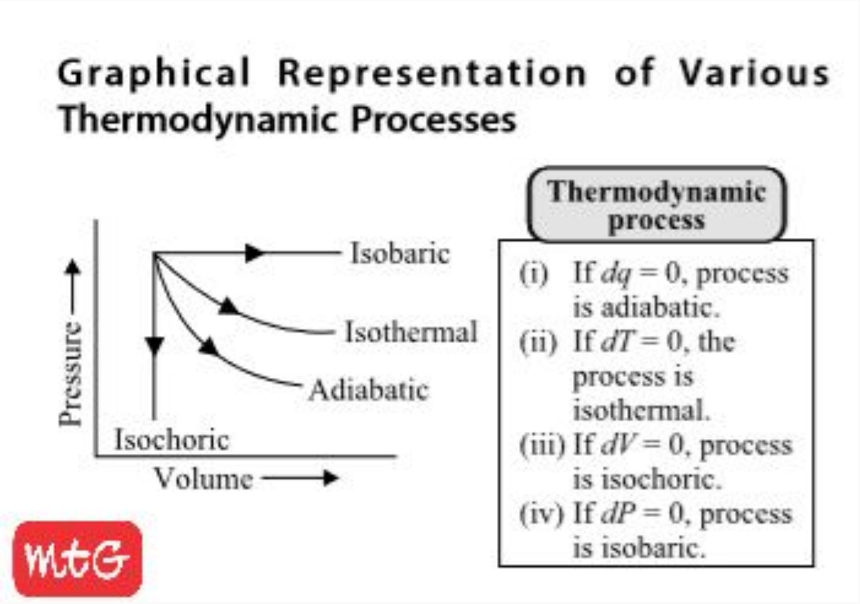


Fig. 1.8

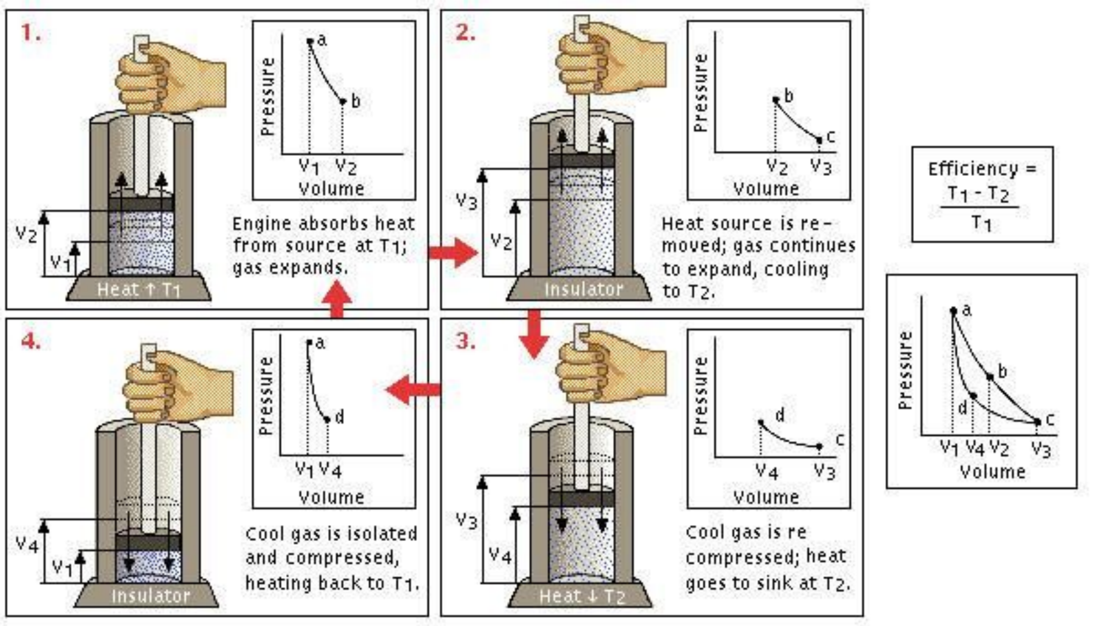
Key concepts in thermodynamics

- Processes in pV plane



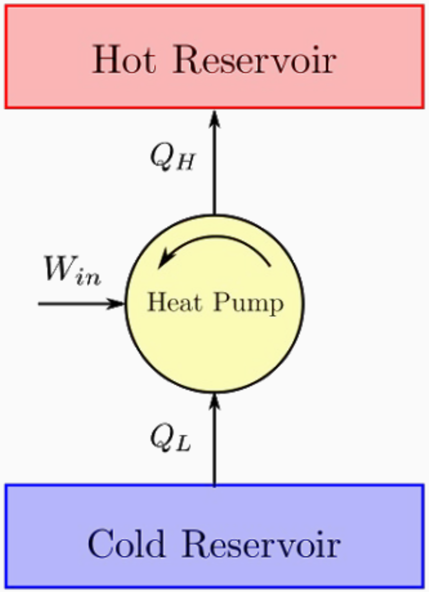
Key concepts in thermodynamics

- Thermodynamic cycles



Key concepts in thermodynamics

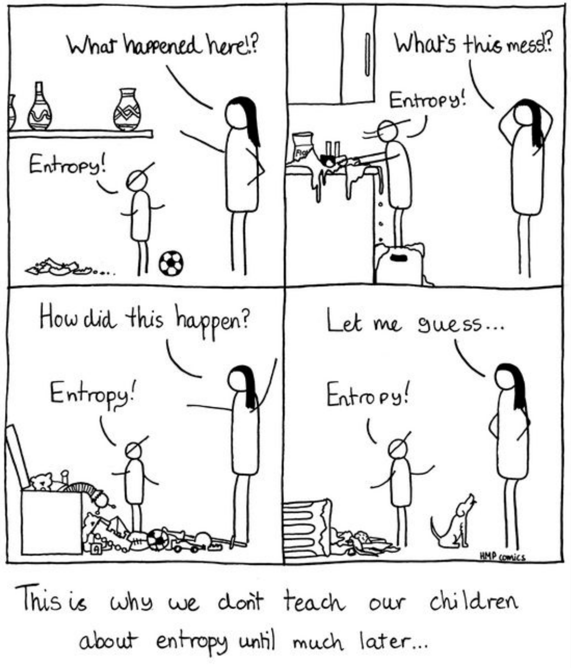
- Thermodynamics machines



Key concepts in thermodynamics

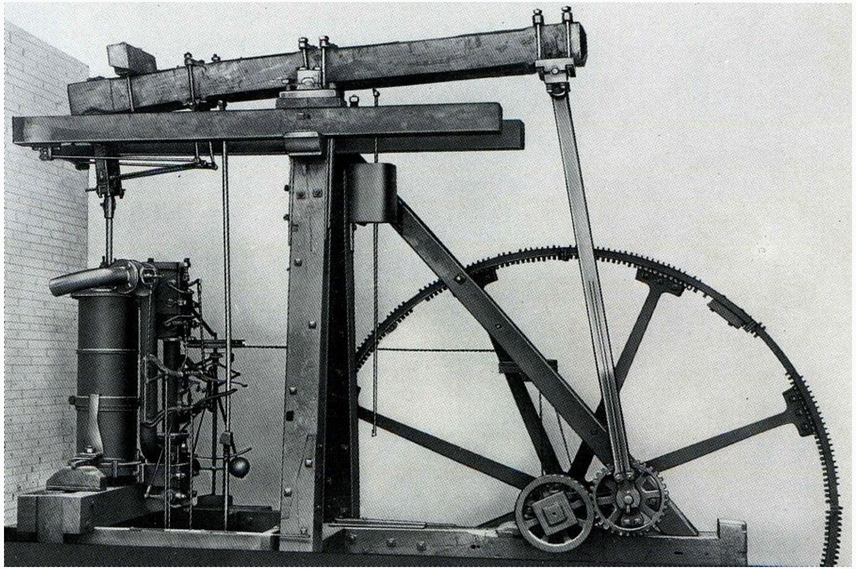
- Entropy as state variable
- Universe, System
- Closed or Open Systems
- Increase/Decrease of order

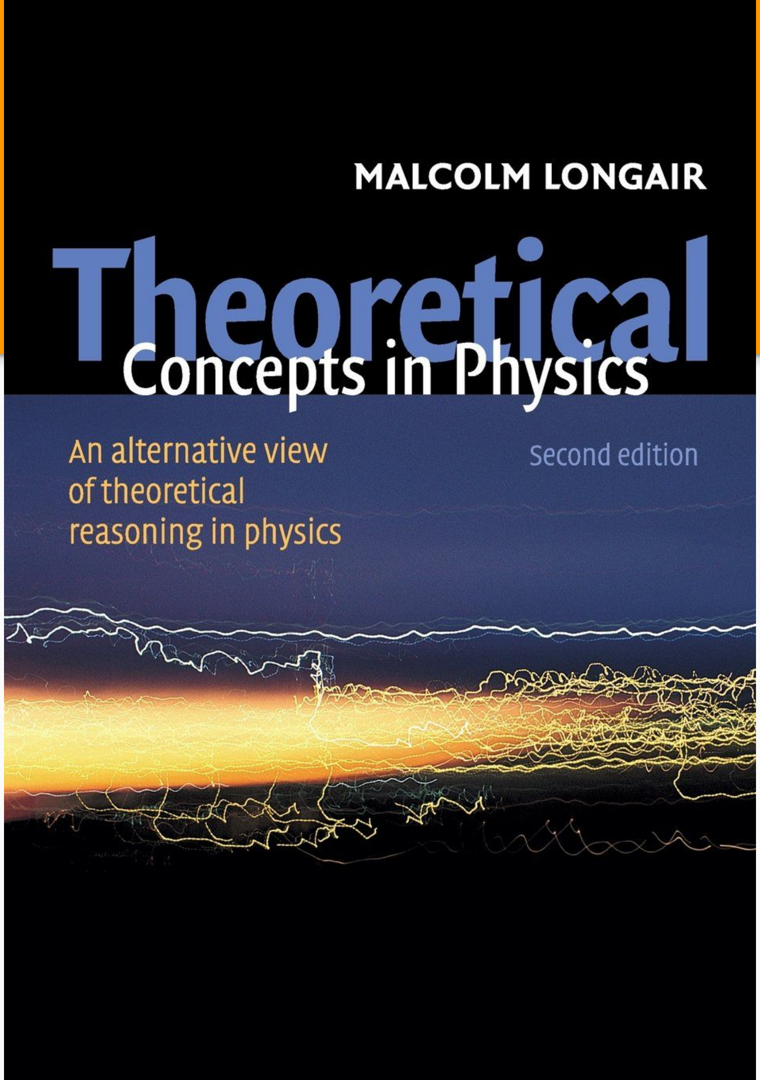
$$\Delta S = S_f - S_i = \int \frac{dq_{rev}}{T}$$



Knowledge of curricula

- Link to cultural needs …





Misconceptions

- Open vs. closed systems
- Evaluation of properties
- State concept
- Transient vs. steady state
- Realizing entropy is a thermodynamic property
- Reversibility
- Correct application of process equations vs. rate equations

(Karimi et al., 2014)

Misconception - example

Students often struggle to distinguish between isothermal and adiabatic processes. Students find it counter-intuitive that a system can absorb energy by a heat transfer, Q without a change in temperature during a process. In many cases the temperature increases with heating, but if the system undergoes a phase change at constant pressure the temperature remains constant. A classic example is boiling water trapped in a piston cylinder apparatus where the piston is free to rise in a gravitational field. In this example, the concept needs to be grasped is that temperature does not rise but the internal energy and volume will increase due to heating. Also the temperature and pressure in the two-phase region are not independent properties. **In a single-phase region, the student's intuition would lead to a correct evaluation that when there is a heat transfer into the system, the temperature of the system increases.**

(Karimi et al., 2014)

Misconception - examples

Students find it counter-intuitive that temperature can increase when there is no heat transfer into a closed system. This occurs when there is a work transfer into an adiabatic system. The work transfer causes an increase in the internal energy, and the internal energy of a single phase substance is dependent on temperature, so it increases. There appears to be no easy way to teach these concepts such that students easily grasp this subtly other than being explicit in highlighting when the anticipated intuition of the student will lead the student toward an incorrect response.

(Karimi et al., 2014)

Misconception - examples

To many students, it is counter-intuitive that pressure is independent of the height of a piston for a sealed vertical piston-cylinder apparatus. The students need to understand the concept that a force balance analysis on the piston shows that the gas pressure below the piston is related to the piston weight, cross-sectional area, and ambient pressure on top of piston. The height of the piston is not relevant to the force balance.

(Karimi et al., 2014)

Misconception - examples

It is counter-intuitive to students that no work is done by a gas trapped in a piston-cylinder apparatus when the position of the piston doesn’t change yet pressure does change. Students need to grasp the concept that boundary work is always zero when there is no change in volume of a closed system. This is analogous to determining the work done by a person pushing with increasing force on an immovable wall. No work is done on the wall because it doesn’t move.

(Karimi et al., 2014)

Traditional teaching

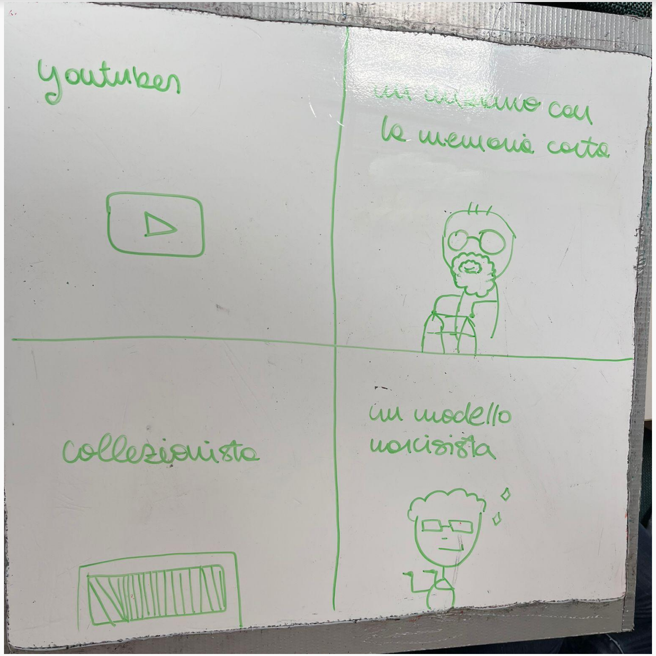
In the traditional approach to teaching and learning, the instructors are focused on what they will do to explain the material better, what experiments they will show, what problems they will assign and how they will grade student work. The students usually sit in a classroom with seats in rows facing the teacher and listen to the explanations taking notes. The students do not question the information that is supplied to them. The instructor grades them on how they understand this information and how they apply it to solve problems. The grades for student work are given once and those are recorded. The students do not have an opportunity to improve their work (in cases that they are allowed to do it, the second attempt receives a reduced grade for being second).

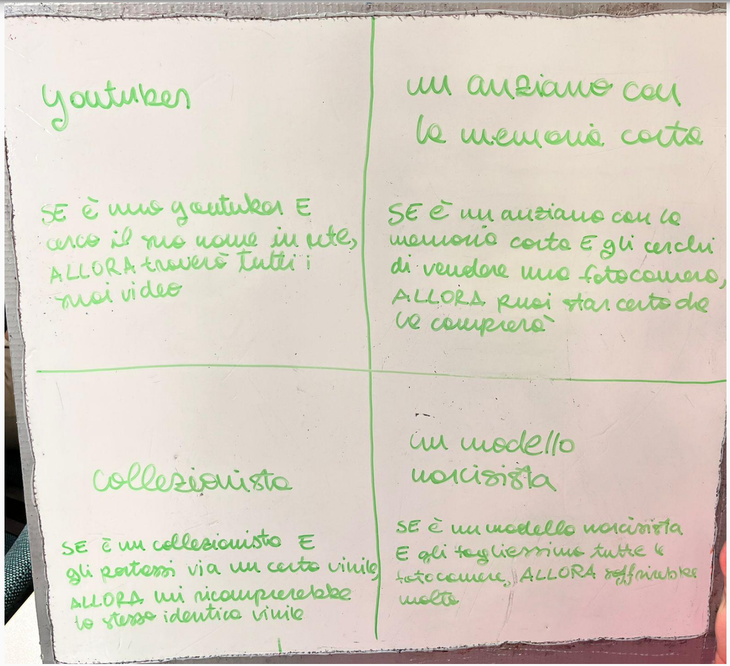
https://www.openaccessgovernment.org/investigative-science-learning-environment/74964/

Investigative Science Learning Environment

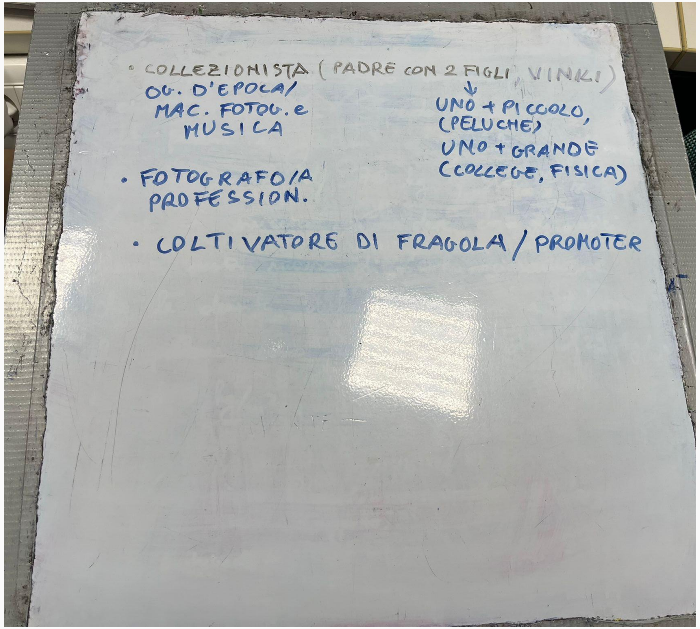
(ISLE approach)

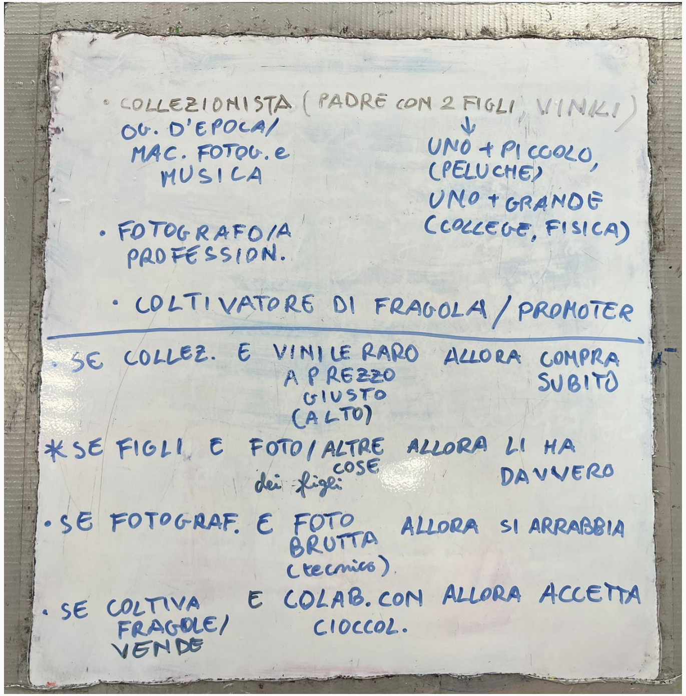
ISLE - Laboratory 1



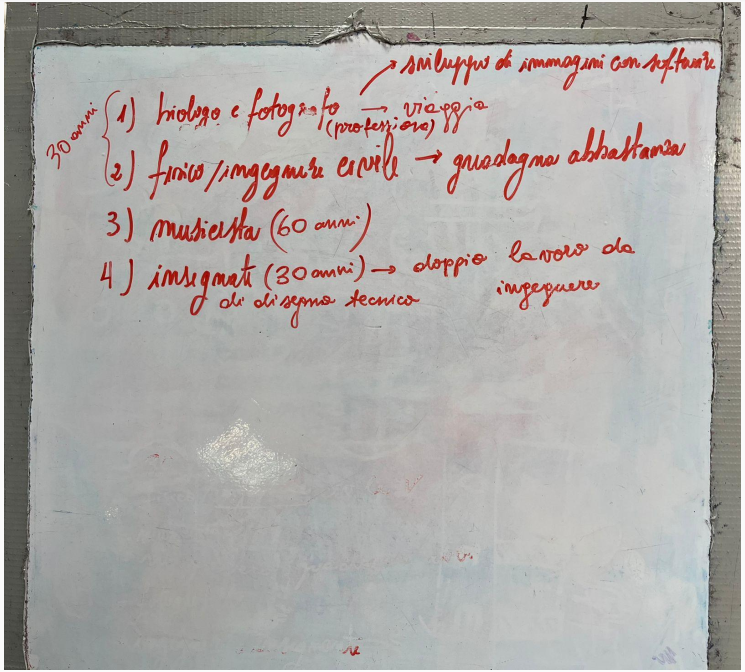


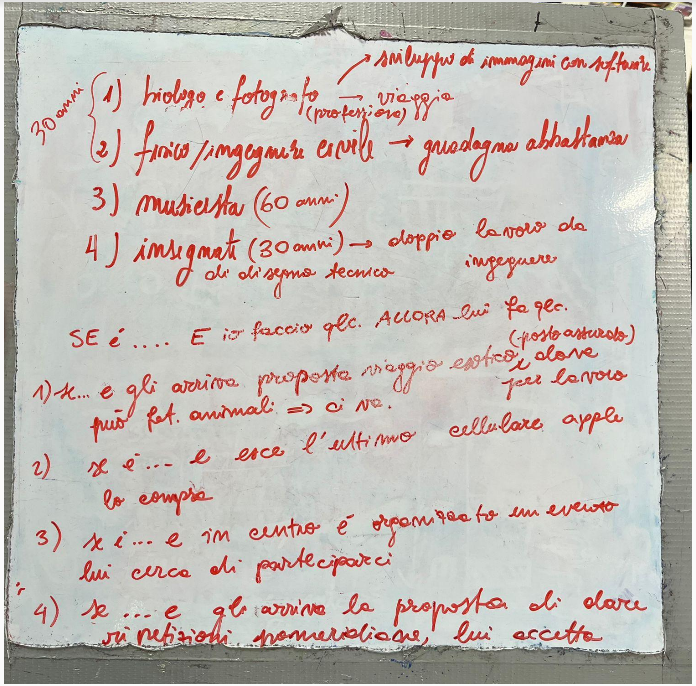
ISLE - Laboratory 1





ISLE - Laboratory 1





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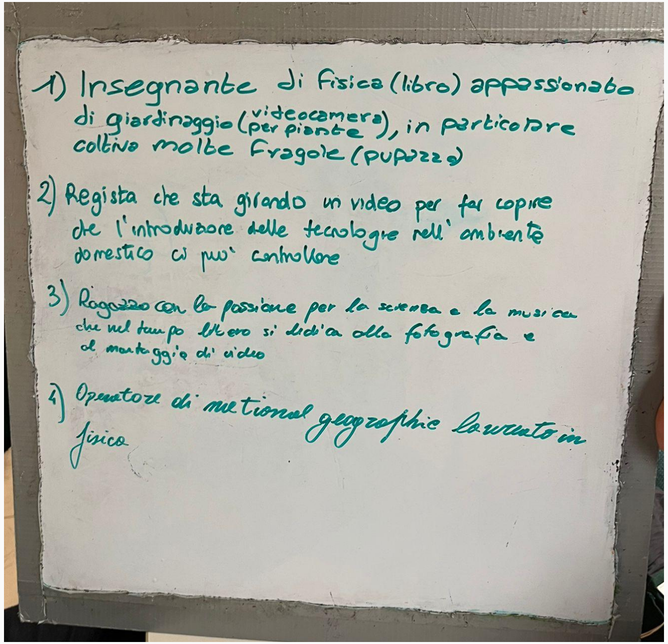
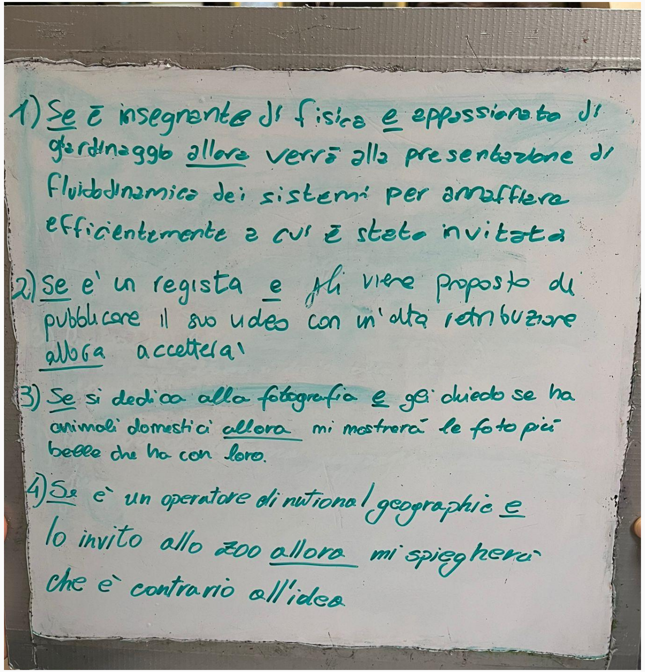
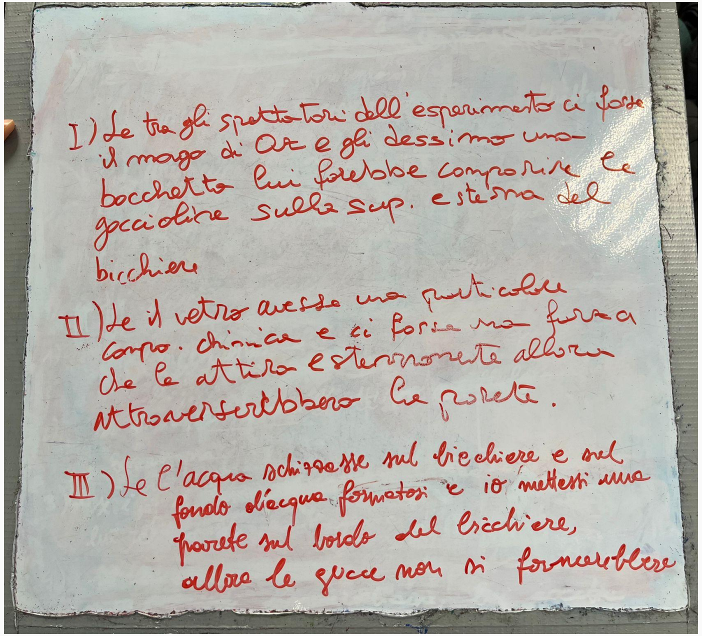
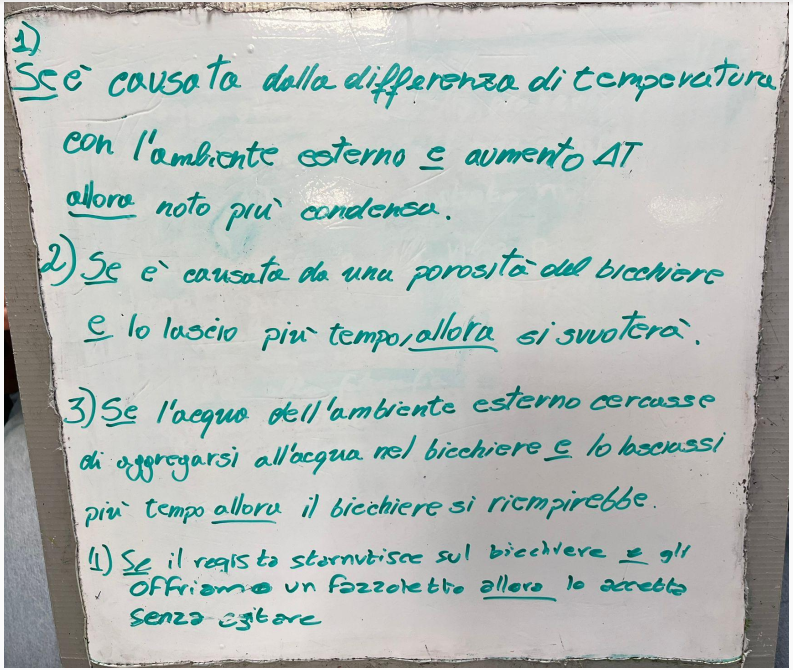




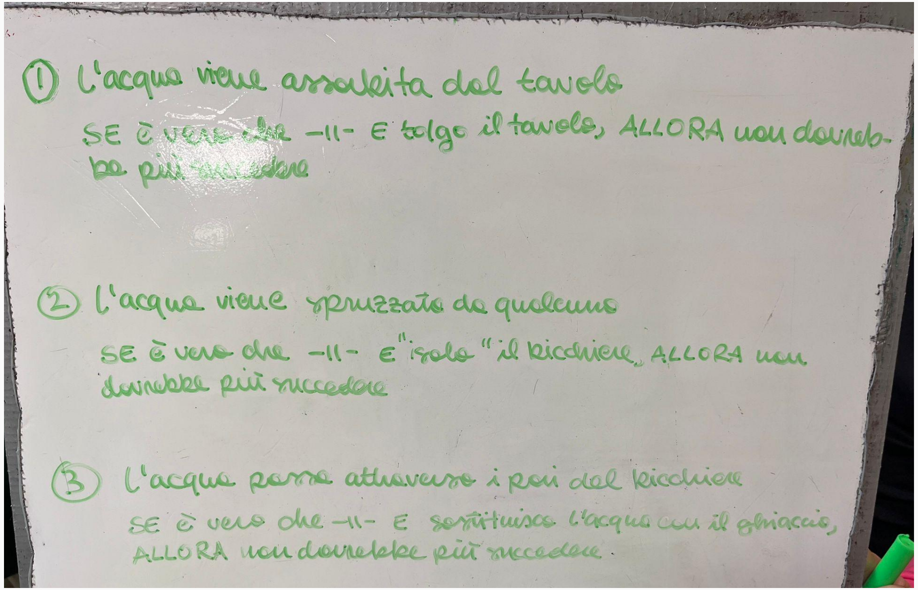
OBSERVATIONAL EXPERIMENT

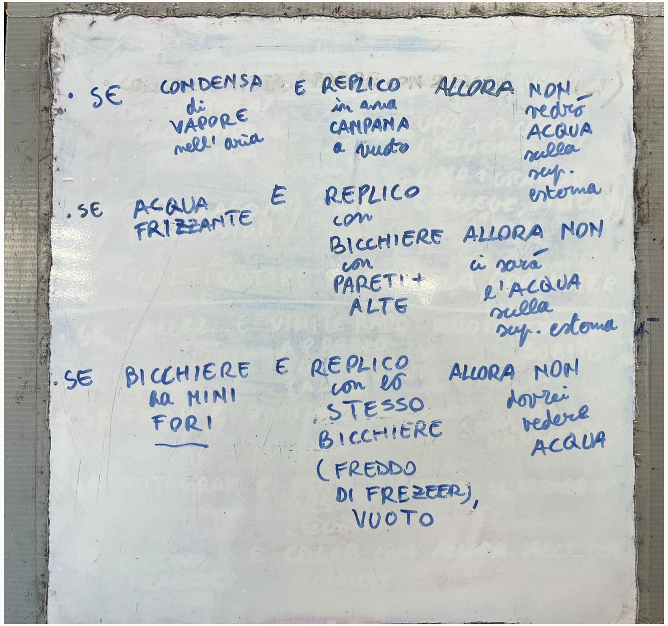
ISLE - Laboratory 2





ISLE - Laboratory 2





TESTING EXPERIMENT

As teachers, how do we create an environment in which students can discover and learn physics for themselves - to own it, so to speak?

ISLE approach involves students' development of their own ideas by

- Observing phenomena and looking for patterns,
- Developing explanations for these patterns,
- Using these explanations to make predictions about the outcomes of testing experiments,
- Deciding if the outcomes of the testing experiments are consistent with the predictions,
- Revising the explanations if necessary,
- Encouraging students to represent physical processes in multiple ways.

(Etkina et all, 2007-2010-2019)

The combination of these features is applied to every conceptual unit in the ISLE learning system, thus helping them develop productive representations for qualitative reasoning and for problem solving.

The ISLE Game

ISLE is a game that models the process by which physicists create their knowledge.

The key to what makes it non-threatening is that it is like a mystery investigation.

Students construct physics concepts and develop science process abilities emulating the processes that physicists use to construct knowledge.

The steps of the ISLE cycle proceed as follows:

1.Students come upon some interesting physical phenomenon that needs explaining.

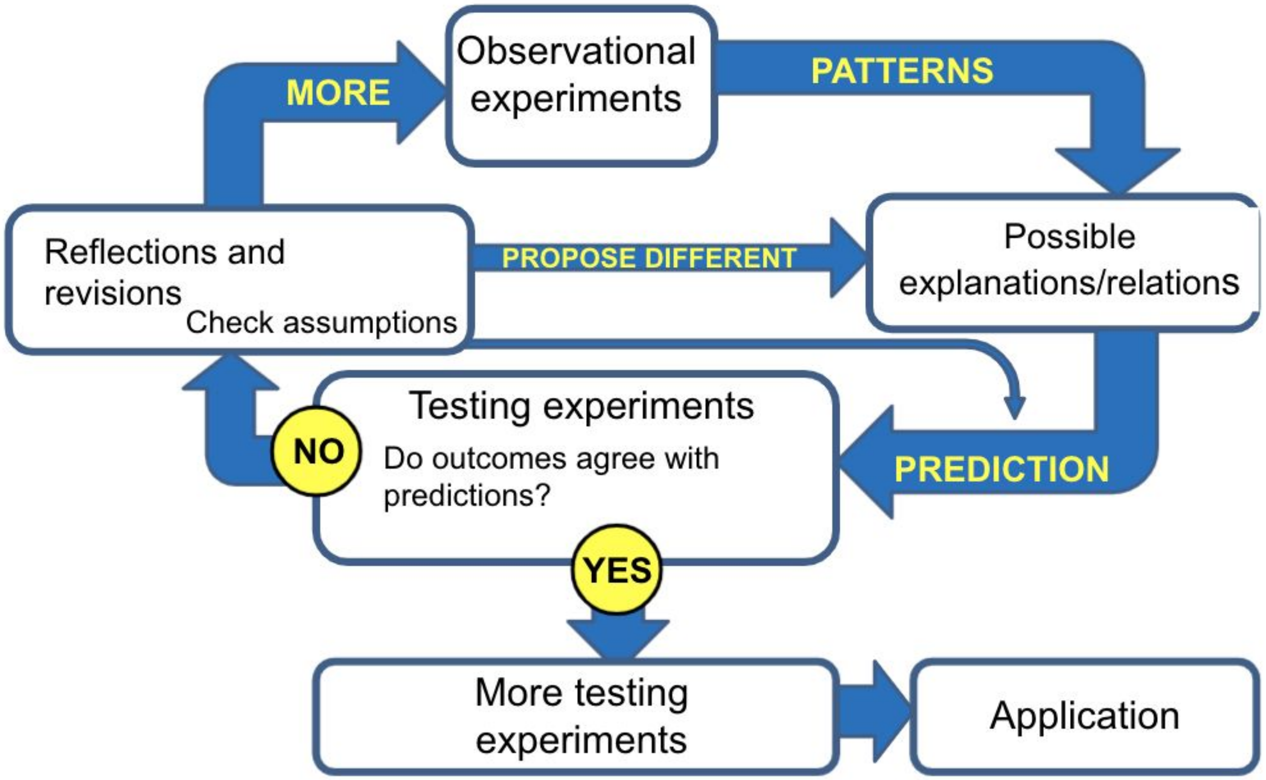
2. Students gather data about the phenomenon, identify interesting patterns and come up with multiple mechanistic explanations for why the phenomenon is happening.
We say “come up with any crazy idea that could explain this” because we DO NOT want students to feel deeply emotionally attached to their ideas.

3. They then test their explanations by conducting one or more testing experiments.

The primary goal is to eliminate explanations rather than “prove” them.
This is key to the non-threatening nature of the process. In ISLE, “predicting” means saying what would be the outcome of the testing experiment if a particular hypothesis were true. Ideas that are not eliminated are kept and re-tested with further experimentation.
Finally students apply the ideas they have established to solve real-world problems.

The cycle repeats twice, first qualitatively, then quantitatively.

Investigative Science Learning Environment - ISLE cycle



Etkina, 2015