

**Physics Education**

**Laboratory**

**Lecture 12**

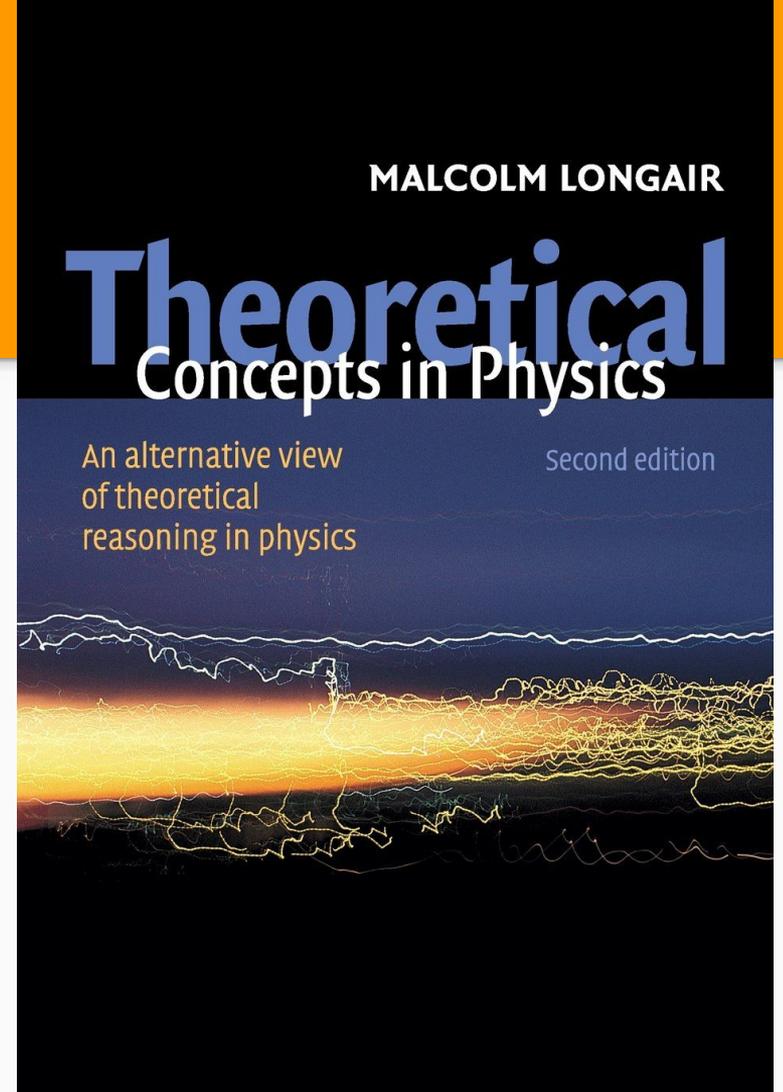
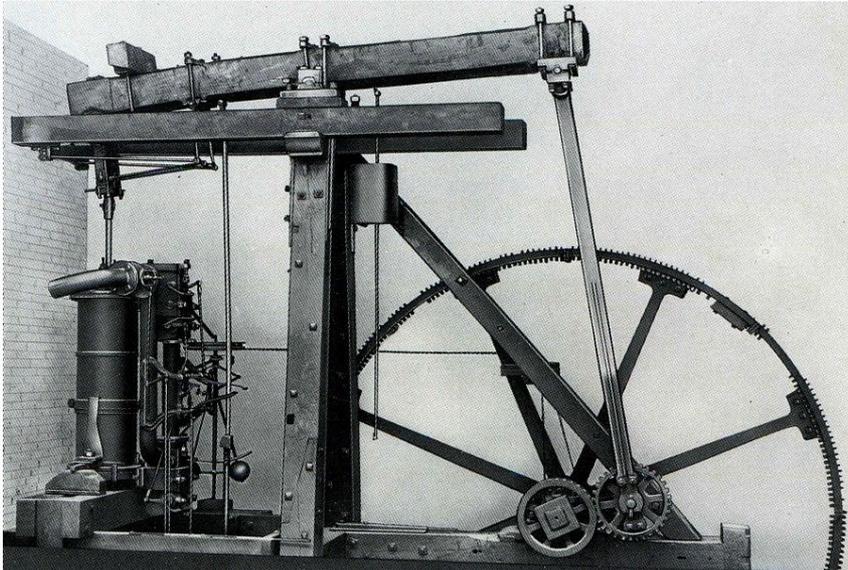
**Content Knowledge for  
Thermodynamics**

Francesco Longo - 30/10/25



# Knowledge of curricula

- Link to cultural needs ...

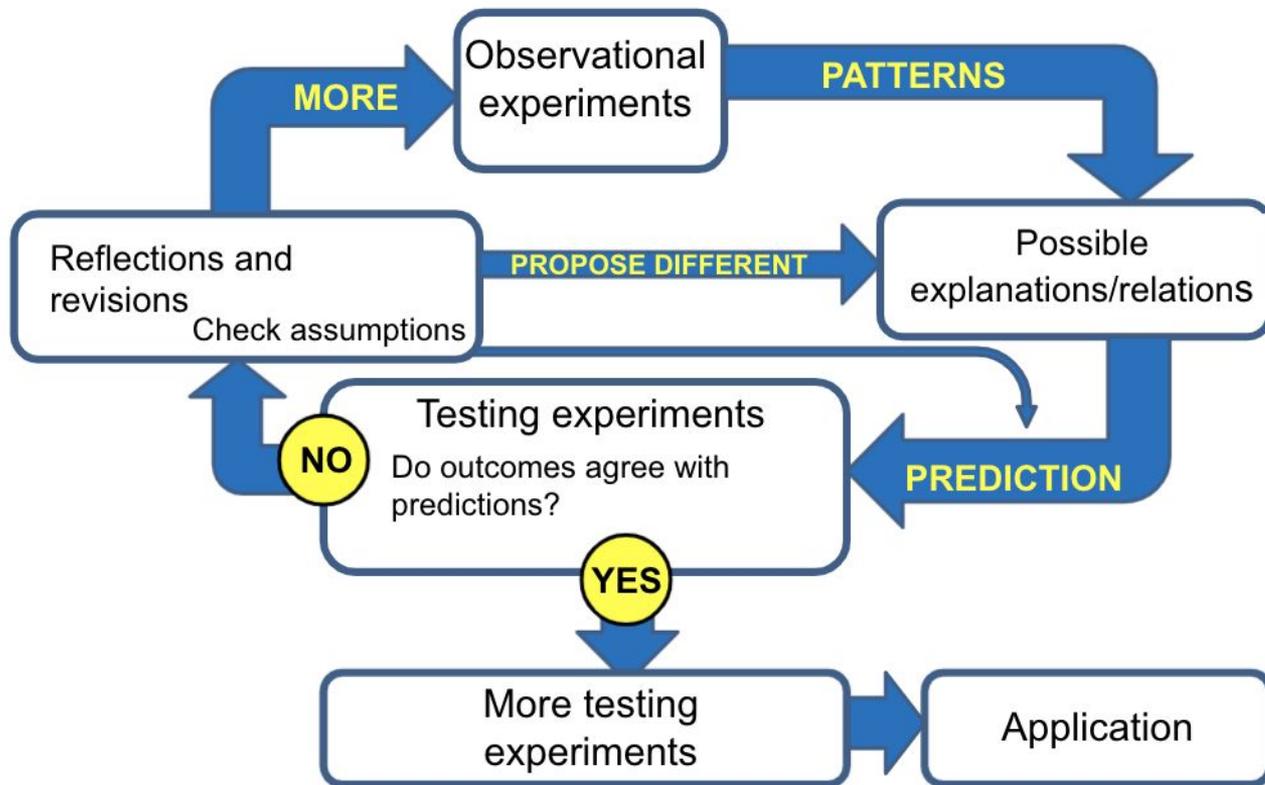


# Investigative Science Learning Environment (ISLE approach)

# 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.

## Investigative Science Learning Environment - ISLE cycle





APPLICATION EXPERIMENT

## *The Three Components ISLE*

The first component is a cycle of logical reasoning that repeats for every new topic that is learned. The reasoning logic is a marriage of inductive and hypothetico-deductive reasoning:

**Inductive:** Observational experiments provide students with interesting data (and patterns) that need to be explained. Students generate multiple explanations based on prior knowledge and analogical reasoning.

**Hypothetico-deductive:** If this explanation is correct, and I do such and such (perform a testing experiment), then so and so should happen (prediction based on explanation). But it did not happen, therefore my idea is not correct (judgment). Or and it did happen therefore my idea has not been disproved yet (judgment).

## *The Three Components ISLE*

The second component of ISLE is an array of representational tools that students learn to use to travel around the ISLE cycle and solve real-world problems (applications).

pictures

motion  
diagrams

graphs

force  
diagrams

impulse-momentum  
bar charts

electric circuit  
diagrams

work-energy bar  
charts

ray diagrams

## *The Three Components ISLE*

**The third component of ISLE is the development of a set of scientific abilities or scientific habits of mind that allow students to travel around the ISLE cycle and solve real-world problems (applications) by thinking like a physicist.**

Students are able to identify assumptions they are making and how those assumptions affect a result. Notice that this ability applies in multiple contexts. Assumptions are made in designing a testing experiment and may affect the outcome of that experiment or the conclusions that are drawn from that experiment.

Assumptions are made when applying physics knowledge to solve a real-world problem (e.g., figure out how far a projectile will travel). The assumptions made will affect the result of the calculation when compared with the actual outcome (i.e., firing the projectile and seeing how far it actually went). The full set of scientific abilities and the multiple contexts in which they occur are codified in the scientific abilities rubrics.

# Rubrics for assessment

The Rutgers Physics and Astronomy Education (PAER) group has developed rubrics for assessment of scientific abilities. The rubrics contain descriptors for individual scientific sub-abilities. One can use the descriptors to assign either a numerical score or a descriptive score for a portion of student writing related to a certain sub-ability. The relationship between the scores is shown in the table below. We prefer to give students rubric description with a descriptive score as numerical scores were found to have a negative effect on student learning. A score of 0 describes a write-up in which the sub-ability is 'Missing', 1 stands for a write-up where the sub-ability is 'Not adequate', 2 describes a write-up with the sub-ability that 'Needs some improvement' and 3 describes a write-up in which is 'Adequate'.

# Ability to represent information in multiple ways

RUBRIC A: Ability to represent information in multiple ways				
Scientific Ability	Missing	Inadequate	Needs improvement	Adequate
<b>A1 Is able to extract the information from representation correctly</b>	No visible attempt is made to extract information from the problem text.	Information that is extracted contains errors such as labeling quantities incorrectly, mixing up initial and final states, choosing a wrong system, etc. Physical quantities have no subscripts (when those are needed).	Some of the information is extracted correctly, but not all of the information. For example physical quantities are represented with numbers there are no units. Or directions are missing. Subscripts for physical quantities are either missing or inconsistent.	All necessary information has been extracted correctly, and written in a comprehensible way. Objects, systems, physical quantities, initial and final states, etc. are identified correctly and units are correct. Physical quantities have consistent subscripts.
<b>A2 Is able to construct new representations from previous representations</b>	No attempt is made to construct a different representation.	Representations are attempted, but use incorrect information or the representation does not agree with the information used.	Representations are created without mistakes, but there is information missing, i.e. labels, variables.	Representations are constructed with all given (or understood) information and contain no major flaws.
<b>A3 Is able to evaluate the consistency of different representations and modify them when necessary</b>	No representation is made to evaluate the consistency.	At least one representation is made but there are major discrepancies between the constructed representation and the given one. There is no attempt to explain consistency.	Representations created agree with each other but may have slight discrepancies with the given representation. Or there is no explanation of the consistency.	All representations, both created and given, are in agreement with each other and the explanations of the consistency are provided.
<b>A4 Is able to use representations to solve problems</b>	No attempt is made to solve the problem.	The problem is solved correctly but no representations other than math were used.	The problem is solved correctly but there are only two representations: math and words explaining the solution.	The problem is solved correctly with at least three different representations (sketch, physics representation and math or sketch, words and math, or some other combination)
<b>A5 Force Diagram</b>	No representation is constructed.	FD is constructed but contains major errors such as incorrect mislabeled or not labeled force vectors, length of vectors, wrong direction, extra incorrect vectors are added, or vectors are missing.	FD contains no errors in vectors but lacks a key feature such as labels of forces with two subscripts or vectors are not drawn from single point, or axes are missing.	The diagram contains no errors and each force is labeled so that it is clearly understood what each force represents.
<b>A6 Motion Diagram</b>	No representation is constructed.	Diagram does not show proper motion: either lengths of arrows (both velocity and velocity change) are incorrect or missing and or spacing of dots are incorrect.	Diagram has correct spacing of the dots but us missing velocity arrows or velocity change arrows.	The diagram contains no errors and it clearly describes the motion of the object. Dots, velocity arrows and velocity change arrows are correct.

<b>A7</b>	<b>Sketch</b>	No representation is constructed.	Sketch is drawn but it is incomplete with no physical quantities labeled, or important information is missing, or it contains wrong information, or coordinate axes are missing.	Sketch has no incorrect information but has either no or very few labels of given quantities. Subscripts are missing or inconsistent. Majority of key items are drawn.	Sketch contains all key items with correct labeling of all physical quantities have consistent subscripts; axes are drawn and labeled correctly.
<b>A8</b>	<b>Energy bar chart</b>	No representation is constructed.	Bar chart is either missing energy values, bars drawn do not show the conservation of energy or are drawn in the wrong places. Bars could also be labeled incorrectly. The system is not identified.	Bar chart has the energy bars drawn correctly, but some labels are missing or the system is not identified. The bar chart matches the process described with some other representation.	Bar chart is properly labeled and has energy bars of appropriate magnitudes. The system is clearly identified.
<b>A9</b>	<b>Mathematical</b>	No representation is constructed.	Mathematical representation lacks the algebraic part (the student plugged the numbers right away) has the wrong concepts being applied, signs are incorrect, or progression is unclear. The first part should be applied when it is appropriate.	No error is found in the reasoning, however they may not have fully completed steps to solve problem or one needs effort to comprehend the progression. No evaluation of the math in the problem is present.	Mathematical representation contains no errors and it is easy to see progression of the first step to the last step in solving the equation. The solver evaluated the mathematical representation.
<b>A10</b>	<b>Ray diagram</b>	No representation is constructed.	The rays that are drawn in the representation do not follow the correct paths. Object or image may be located at wrong position.	Diagram is missing key features but contains no errors. One example could be the object is drawn with the correct lens/mirror but rays are not drawn to show image. Or the rays are too far from the main axis to have a small-angle approximation. Or the diagram is drawn without a ruler.	Diagram has object and image located in the correct spot with the proper labels. Rays are correctly drawn with arrows and contain at least two rays. The ruler was used to draw the images.
<b>A11</b>	<b>Graph</b>	No graph is present.	A graph is present but the axes are not labeled. There is no scale on the axes. The data points are connected.	The graph is present and axes are labeled but the axes do not correspond to the independent and dependent variable or the scale is not accurate. The data points are not connected but there is no trendline.	The graph has correctly labeled axes, independent variable is along the horizontal axis and the scale is accurate. The trendline is correct.

# Ability to design and conduct an observational experiment

<b>RUBRIC B: Ability to design &amp; conduct an observational experiment</b>				
<b>Scientific Ability</b>	Missing	Inadequate	Needs improvement	Adequate
<b>B1</b> Is able to identify the phenomenon to be investigated	No phenomenon is mentioned.	The description of the phenomenon to be investigated is confusing, or it is not the phenomena of interest.	The description of the phenomenon is vague or incomplete.	The phenomenon to be investigated is clearly stated.
<b>B2</b> Is able to design a reliable experiment that investigates the phenomenon	The experiment does not investigate the phenomenon.	The experiment may not yield any interesting patterns.	Some important aspects of the phenomenon will not be observable.	The experiment might yield interesting patterns relevant to the investigation of the phenomenon.
<b>B3</b> Is able to decide what physical quantities are to be measured and identify independent and dependent variables	The physical quantities are irrelevant.	Only some of physical quantities are relevant.	The physical quantities are relevant. However, independent and dependent variables are not identified.	The physical quantities are relevant and independent and dependent variables are identified.
<b>B4</b> Is able to describe how to use available equipment to make measurements	At least one of the chosen measurements cannot be made with the available equipment.	All chosen measurements can be made, but no details are given about how it is done.	All chosen measurements can be made, but the details of how it is done are vague or incomplete.	All chosen measurements can be made and all details of how it is done are clearly provided.
<b>B5</b> Is able to describe what is observed without trying to explain, both in words and by means of a picture of the experimental setup.	No description is mentioned.	A description is incomplete. No labeled sketch is present. Or, observations are adjusted to fit expectations.	A description is complete, but mixed up with explanations or pattern. The sketch is present but is difficult to understand.	Clearly describes what happens in the experiments both verbally and with a sketch. Provides other representations when necessary (tables and graphs).
<b>B6</b> Is able to identify the shortcomings in an experimental and suggest improvements	No attempt is made to identify any shortcomings of the experimental.	The shortcomings are described vaguely and no suggestions for improvements are made.	Not all aspects of the design are considered in terms of shortcomings or improvements.	All major shortcomings of the experiment are identified and reasonable suggestions for improvement are made.
<b>B7</b> Is able to identify a pattern in the data	No attempt is made to search for a pattern	The pattern described is irrelevant or inconsistent with the data	The pattern has minor errors or omissions. Terms proportional are used without clarity- is the proportionality linear, quadratic, etc.	The patterns represents the relevant trend in the data. When possible, the trend is described in words.
<b>B8</b> Is able to represent a pattern mathematically (if applicable)	No attempt is made to represent a pattern mathematically	The mathematical expression does not represent the trend.	No analysis of how well the expression agrees with the data is included, or some features of the pattern are missing.	The expression represents the trend completely and an analysis of how well it agrees with the data is included.
<b>B9</b> Is able to devise an explanation for an observed pattern	No attempt is made to explain the observed pattern.	An explanation is vague, not testable, or contradicts the pattern.	An explanation contradicts previous knowledge or the reasoning is flawed.	A reasonable explanation is made. It is testable and it explains the observed pattern.

# Observational experiments: energy conversions - part 1

Goals: Explain a series of experiments using the knowledge of energy

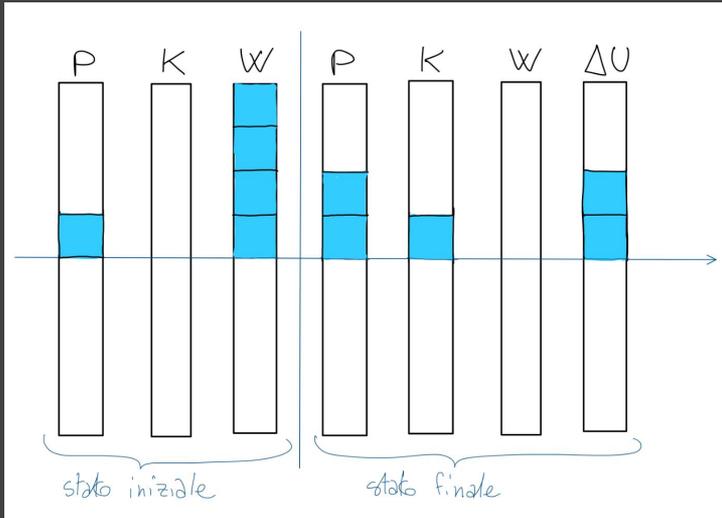
Equipment: none

1. Watch the video [<https://youtu.be/u3Y4npFvI04>] Answer the following questions:

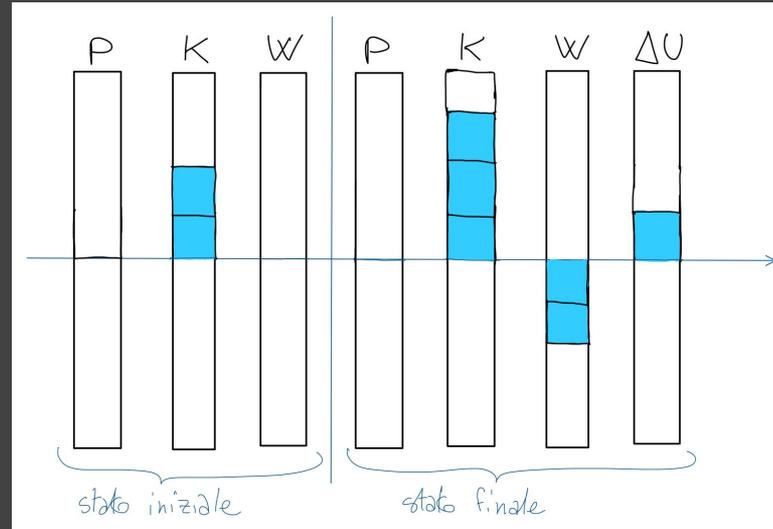
- A. Construct a microscopic explanation for how the hot gas pushes out the stopper. Remember what you learned about molecules of gas, their motion, and the pressure that they exert.
- B. Choose the gas inside the test tube, the stopper, and Earth (not the flame) as the system, and use the concepts of work and energy to explain the experiment. If you need a new physical quantity or quantities for your explanation, define them qualitatively.
- C. Draw an energy bar chart to explain the experiment using this new physical quantity. The system is the gas and the cork. The initial state is before we started warming up the gas and the final state is when the cork is flying out.

# Energy Bar Charts Laboratory - Group 1

- 1) La fiamma scalda il gas all'interno della provetta, aumentando l'energia cinetica delle molecole. Questo aumenta la pressione all'interno della provetta finché la forza che le molecole esercitano sul tappo vince la forza di attrito tra il tappo e il collo della provetta, causando l'apertura della provetta.



2) sistema composto da: terra, provetta, gas e tappo

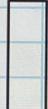
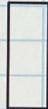
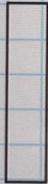


3) sistema composto da: provetta, gas e tappo

# Energy Bar Charts Laboratory - Group 2

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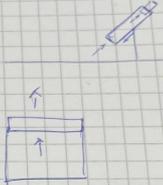
$$W + K + Q = w + K + Q$$



# Energy Bar Charts Laboratory - Group 2

**Esercizio 1**

A) Immagino un cannone di gas nell'atmosfera. Quando l'energia cinetica del gas viene ad applicarsi sul cannone, una pressione si genera e quella atmosfera che porta il cannone a partire come un proiettile. Il cannone non viene arrestato indietro perché lo stopper in completa di vincolo.



B) Energy bar chart



Consideriamo l'energia cinetica iniziale pura e se il lavoro fatto dal sistema si trasforma interamente in energia cinetica e potenziale.

C



In questo caso non ritorna nel nostro bar chart l'energia potenziale perché non c'è più la terra. Il lavoro fatto sul sistema, come risultato completamente di energia cinetica, il solo aumento dell'energia cinetica.

# Energy Bar Charts Laboratory - Group 3

① Le molecole del gas contenute nella provetta aumentano la loro energia cinetica iniziale data dalla temperatura del sistema ~~all'inizio dell'esperimento~~ a causa del calore ricevuto.

La temperatura aumenta e di conseguenza anche la pressione per via degli urti tra le molecole. Il gas tende a espandersi, ma essendo confinato aumenta la pressione esercitata sulle pareti. Il tappo, soggetto a tale pressione, viene spinto.

② Il gas all'inizio ha una certa energia interna data dalle sue caratteristiche iniziali. A questa viene aggiunto del calore, che aumenta la sua energia interna. Ricordiamo infatti che il calore è l'energia trasferita da un corpo ~~caldo~~ a un altro di temperatura minore ~~per mezzo~~. Il gas effettua un lavoro sul tappo ~~diminuendo~~ utilizzando l'energia in eccesso e aumentando così l'energia cinetica e potenziale del tappo.

③ INIZIO:

energia cinetica

energia interna

calore  
(E<sub>q lavoro</sub>)  
~~lavoro~~

FINE:

energia cinetica

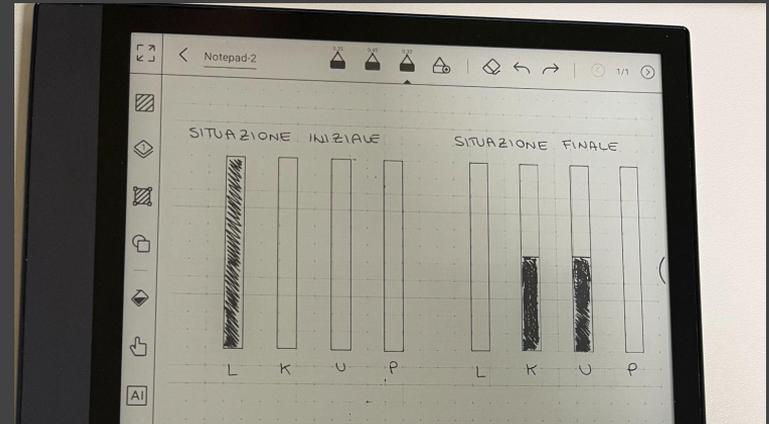
energia interna

calore

~~lavoro~~

# Energy Bar Charts Laboratory - Group 4

- a) Con la fiamma aumenta la temperatura che fa incrementare la velocità delle particelle all'interno della provetta, che causa un accrescimento della forza che viene esercitata dalle particelle sul tappo. Si esce dallo stato di equilibrio (la forza esercitata dalle particelle sarà maggiore rispetto alla forza di attrito presente tra il vetro e il tappo), quindi il tappo viene sparato via.
- b) Considerando l'opportuno sistema di riferimento, notiamo che dal punto di vista energetico l'unica variazione è dovuta all'aumento della velocità delle particelle che porta ad un aumento di energia cinetica, mentre l'energia potenziale non sarà di nostro interesse. Per quanto invece riguarda il lavoro partendo da un certo valore e considerando l'istante finale esattamente quando il tappo si allontana dalla provetta, il lavoro sarà nullo. Quindi concludiamo dicendo che dallo stato iniziale allo stato finale, il lavoro viene convertito in energia cinetica ed energia interna.



## Observational experiment - part 2

2. Watch the video of a cup of cold water in an aluminum container being placed in a container with warm water

[https://mediaplayer.pearsoncmg.com/assets/\\_frames.true/sci-phys-egv2e-alg-15-2-2](https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-15-2-2)

The video is taken with a thermal camera and allows you to see the change of temperature of the water.

- A. Describe what you observe (choose the initial state to be when the cup is outside the container and the final state when cup is inside and the temperature reaches some intermediate value).
- B. Consider the water in the cup as the system and explain this observed process using your knowledge of molecules and their motion. Then use the generalized work–energy principle to explain what happened to the cold water. If you cannot explain this process with this principle, try to modify the principle (for example, introduce a new physical quantity) to account for your observations.
- C. Repeat part b., only this time consider the water in the container as the system.
- D. Use your knowledge of molecules and their motion to explain the reasoning behind when two liquids of different temperatures mix together, the mixture will eventually reach some intermediate temperature (called the equilibrium temperature).

## Observational experiment - part 3

3. Watch the video of a cup of glycerin being stirred by a mixer used to whip cream

[\[https://mediaplayer.pearsoncmg.com/assets/\\_frames.true/sci-phys-egv2e-alg-15-3-1\]](https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-15-3-1).

The video is taken with a thermal camera and allows you to follow the temperature of the glycerin at the spot marked by cross hairs.

- a. Describe what you observe.
- b. Draw a bar chart to represent the process. Indicate any assumptions that you made.