Physics Education Laboratory
Lecture 10
PCK for Thermodynamics

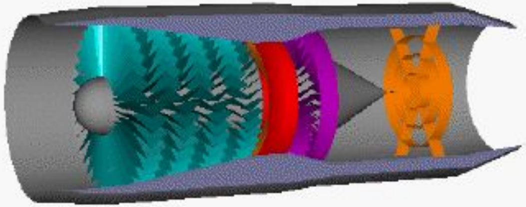
Francesco Longo - 10/11/20


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

What is Thermodynamics?

Glenn
Research
Center



Thermodynamics is the study of the effects of work, heat, and energy on a system. Thermodynamics is only concerned with large scale observations.

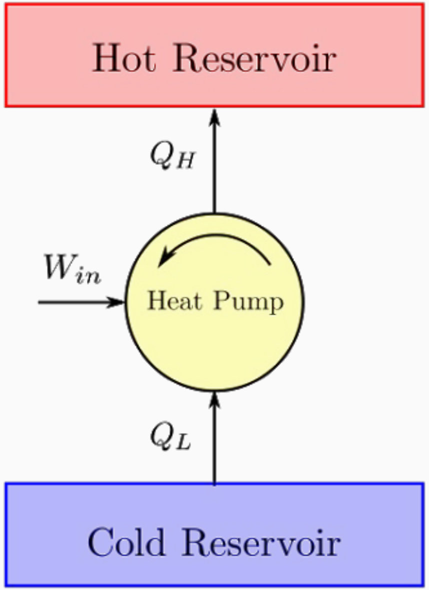
Zeroth Law: Thermodynamic Equilibrium and Temperature

First Law: Work, Heat, and Energy

Second Law: Entropy

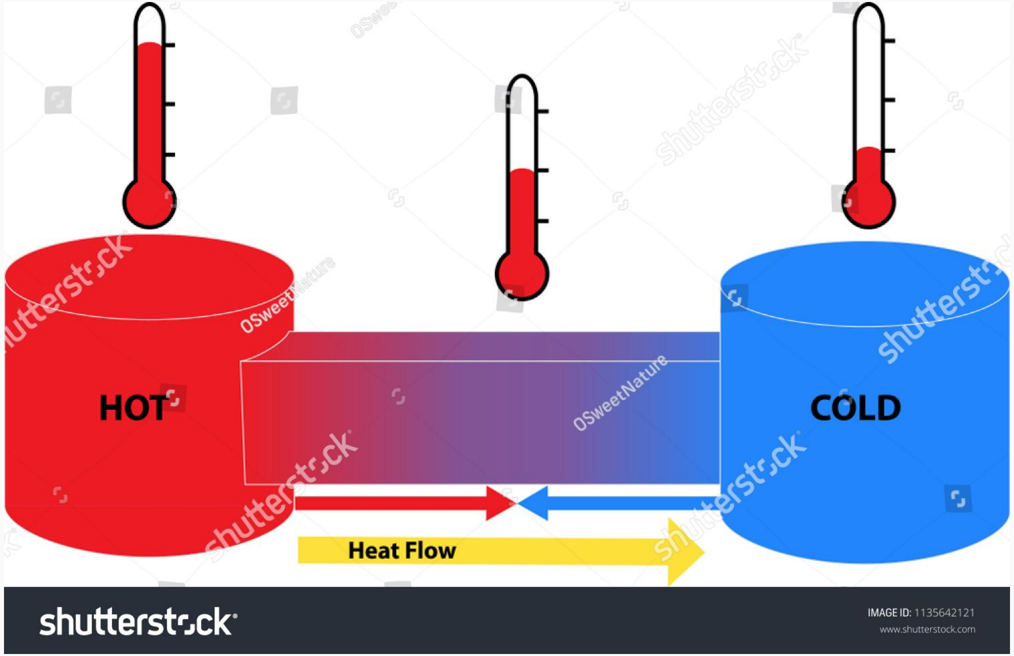
Key concepts in thermodynamics

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



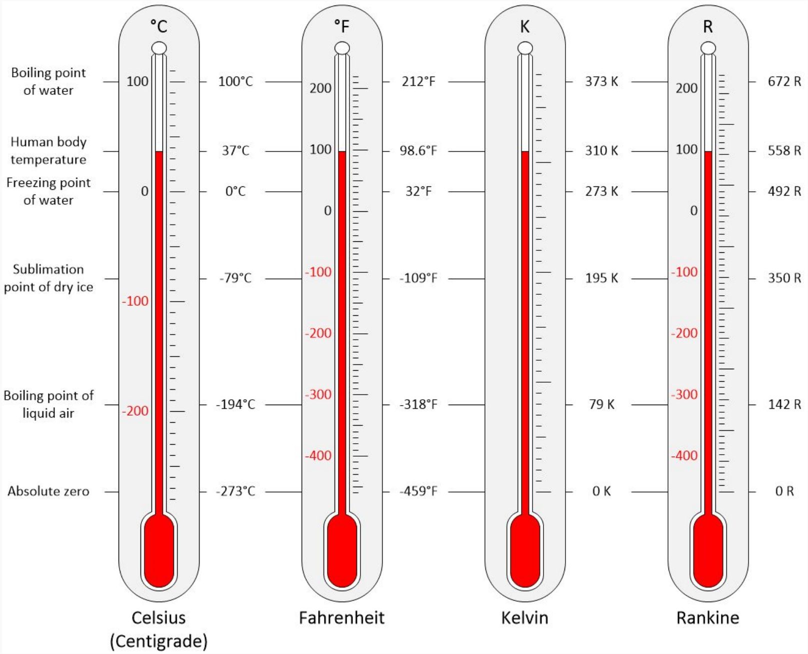
Key concepts in thermodynamics

- Temperature
- Hot vs Cold



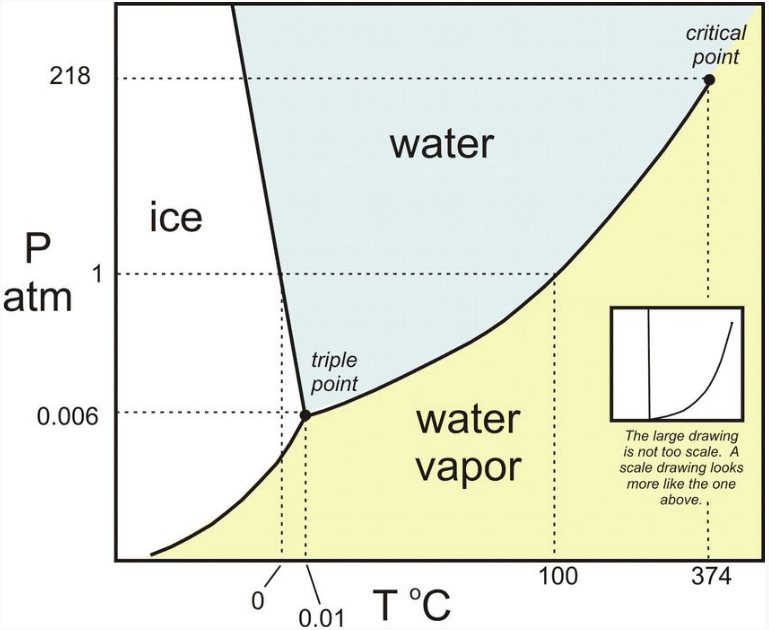
Key concepts in thermodynamics

- Temperature scales



Key concepts in thermodynamics

- State transitions
- Latent heat



Key concepts in thermodynamics

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

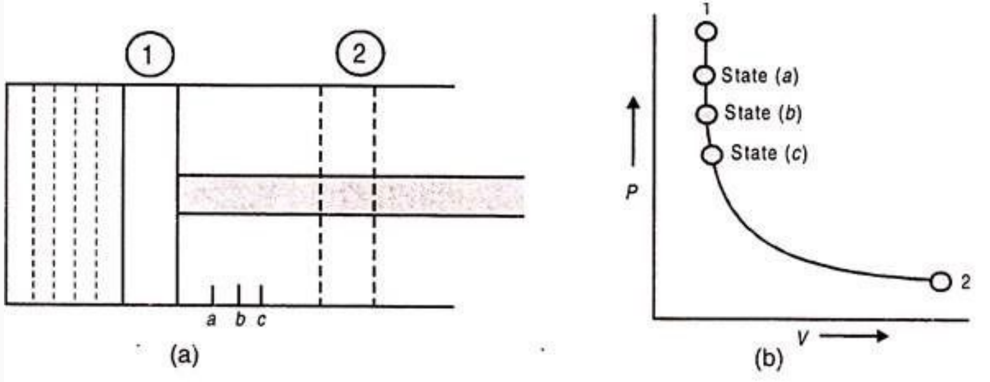
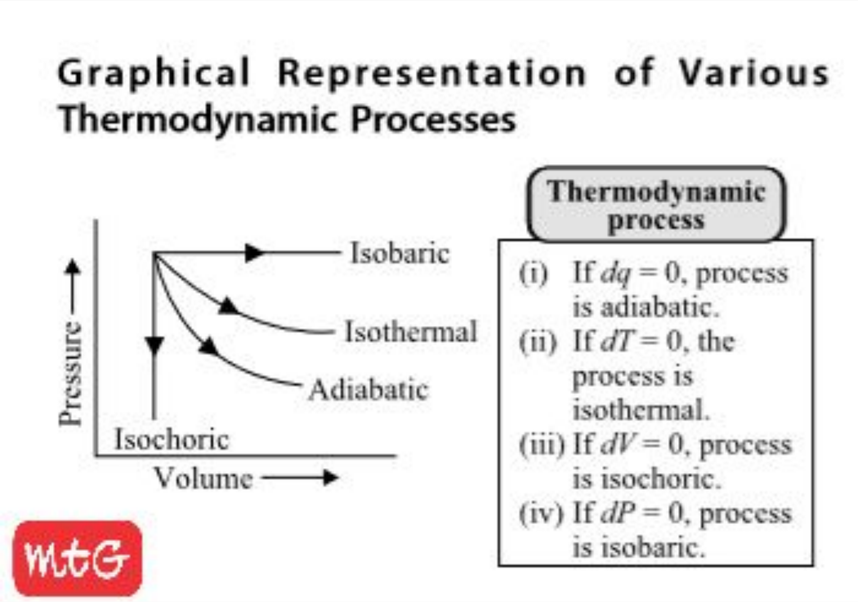


Fig. 1.8

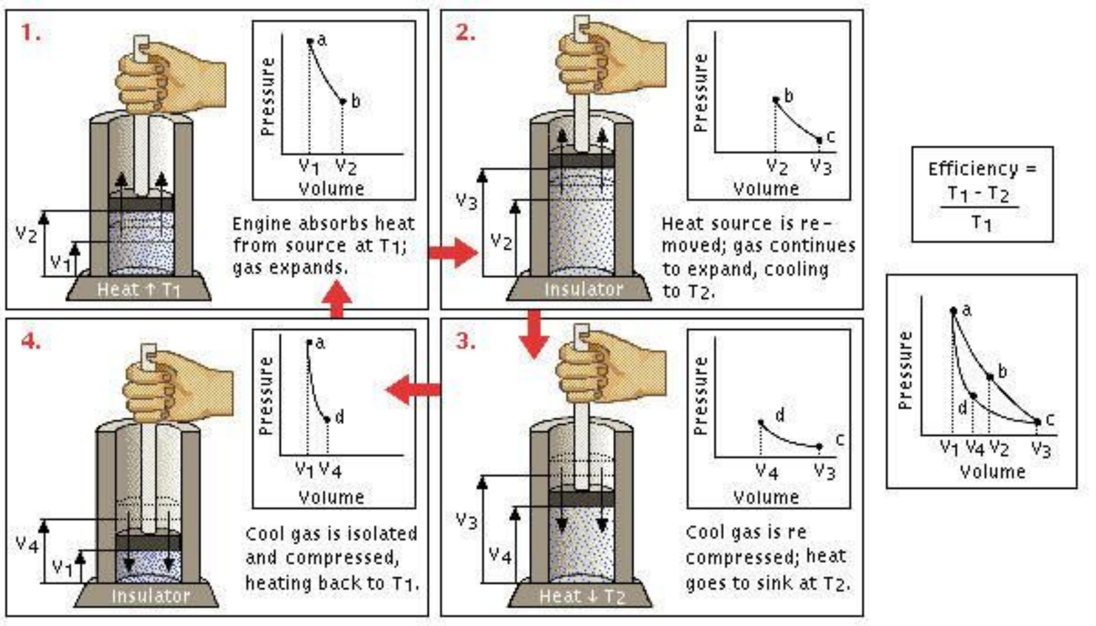
Key concepts in thermodynamics

- Processes in pV plane



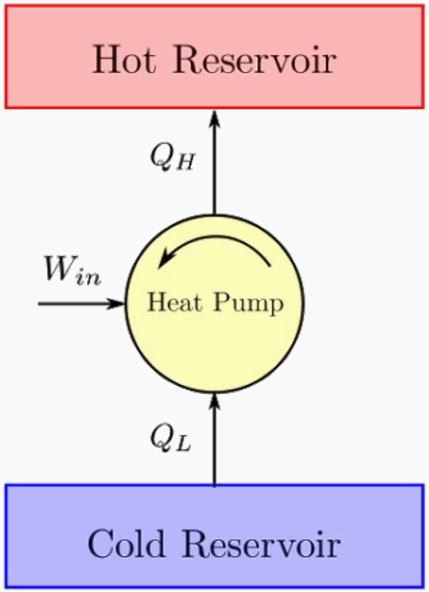
Key concepts in thermodynamics

- Thermodynamic cycles



Key concepts in thermodynamics

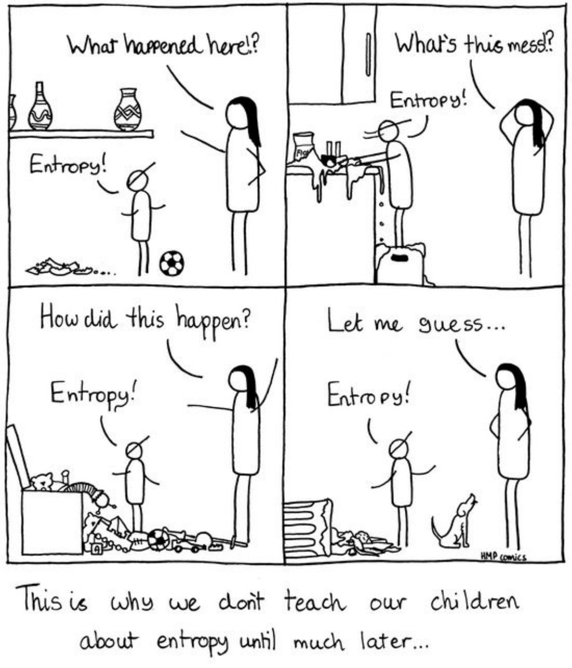
- Thermodynamics machines



Key concepts in thermodynamics

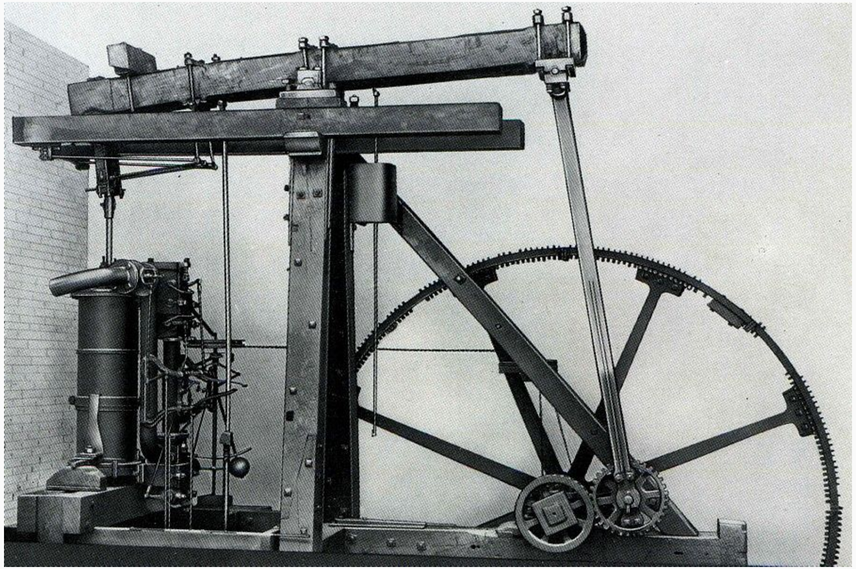
- Entropy as state variable
- Universe, System
- Closed or Open Systems
- Increase/Decrease of order

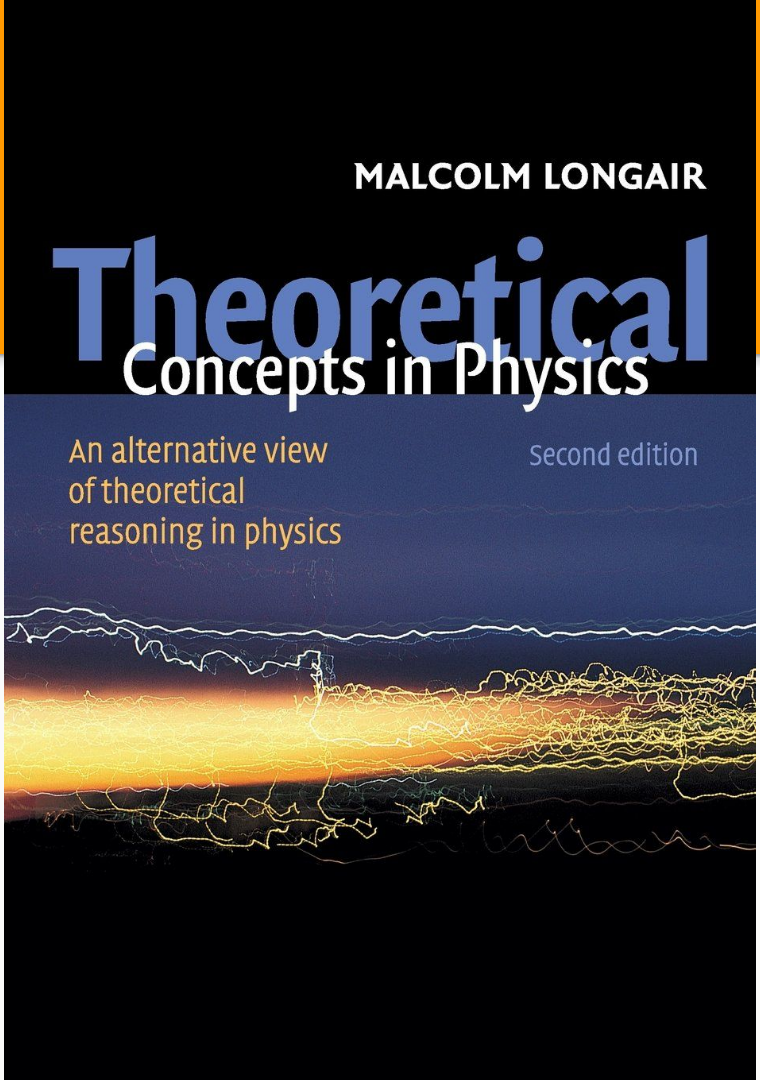
$$\Delta S = S_f - S_i = \int \frac{dq_{rev}}{T}$$



Knowledge of curricula

- Link to cultural needs …





Misconceptions

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

(Karimi et al., 2014)

Misconception - examples

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)

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:

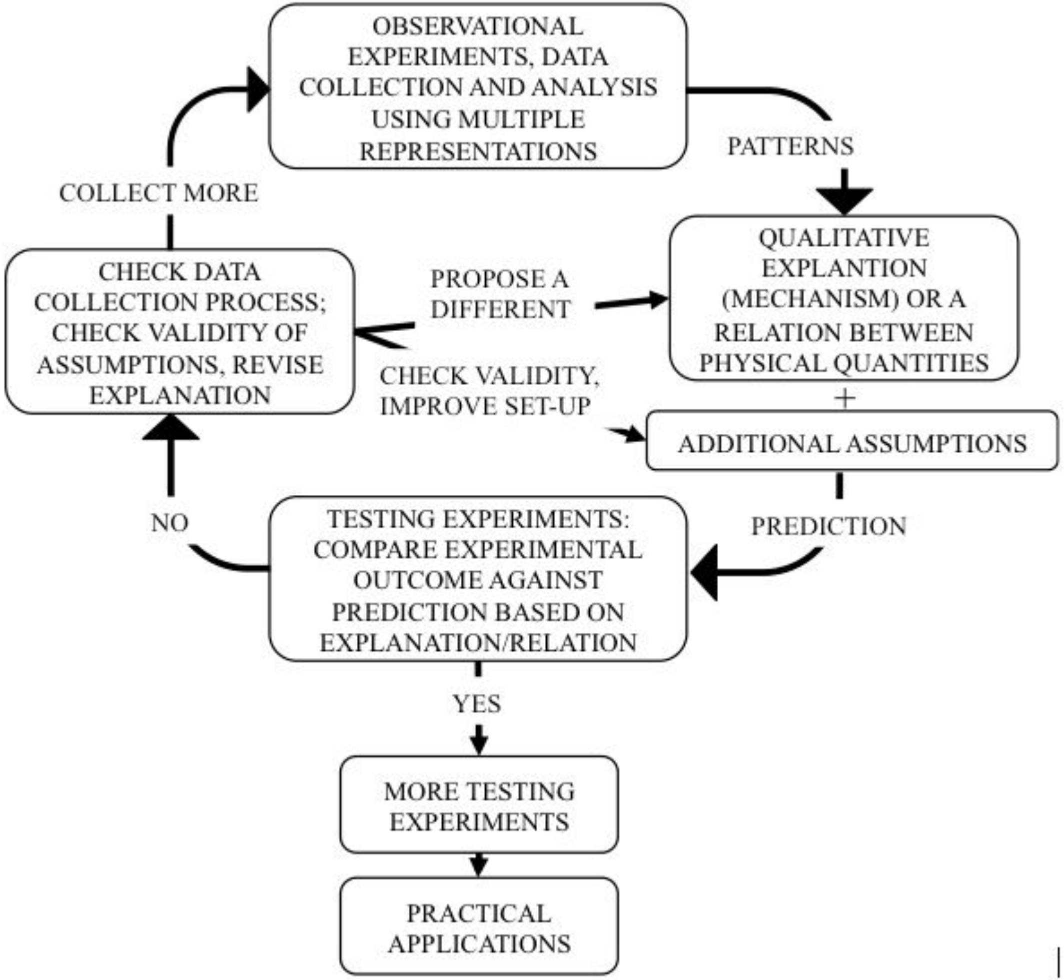
1.Students come upon some interesting physical phenomenon that needs explaining.

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.


OBSERVATIONAL EXPERIMENTS, DATA COLLECTION AND ANALYSIS USING MULTIPLE REPRESENTATIONS
PATTERNS
QUALITATIVE EXPLANTION (MECHANISM) OR A RELATION BETWEEN PHYSICAL QUANTITIES
+
ADDITIONAL ASSUMPTIONS
PREDICTION
TESTING EXPERIMENTS: COMPARE EXPERIMENTAL OUTCOME AGAINST PREDICTION BASED ON EXPLANATION/RELATION
YES
MORE TESTING EXPERIMENTS
PRACTICAL APPLICATIONS
NO
CHECK DATA COLLECTION PROCESS; CHECK VALIDITY OF ASSUMPTIONS, REVISE EXPLANATION
COLLECT MORE
PROPOSE A DIFFERENT
CHECK VALIDITY, IMPROVE SET-UP

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.

Types of quantitative reasoning activities.

Type of activity	Short description
Contextually interesting problems	Relatively standard problems which have interesting contexts
Multiple representation prob-lems	Students represent a word problem in different ways (such as, a sketch, graph, diagram, and equation)
Equation Jeopardy problems	Students are given an equation and are asked to construct other representations of a physical process that are consistent with the equation.
Problem-posing problems	A physical situation is described in one way and students are to in-vent a problem involving the situation.
Evaluation problems	Students are provided a solution for a problem and are asked to evaluate it for errors or in other ways.
Design and analyze problems	More complex problems where students need to design an experi-ment to achieve some goal and to development an appropriate mathematical solution to answer the question. The problems often involve concepts from different conceptual areas (for example, energy and circular motion).

Problem solving strategy.

General steps of the problem solving strategy	Modifications of the steps for the circular motion chapter
Picture and translate	Sketch the situation described in the problem statement. Choose a system when the object is at one particular position along its circular path. Draw an axis in the radial direction toward the center of the circle.
Simplify	Decide if you can consider the system as a particle Determine if you can ignore any interactions of objects outside the system with the system object. Determine if the constant speed approach is appropriate.
Represent physically	Indicate with an arrow the direction of the acceleration when passing the previously determined position Draw a free-body diagram for the object at the instant it passes that position.
Represent mathematically	Convert the free-body diagram into the radial component form of Newton's second law. For objects moving in the horizontal plane, you may also need to apply the vertical component form of Newton's second law to solve the problem
Solve and evaluate	Solve the equations formulated in the previous two steps and evaluate the results to see if they are reasonable (the magnitude of the answer, its units, how the solution changes in limiting cases, and so forth.

https://drive.google.com/file/d/1foYc9_g9Rr27W4iXb5kjJUDp0j0oDJgm/view?usp=sharing

Gas on line laboratory

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
A1	**Is able to extract the information from representation correctly**	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.
A2	**Is able to construct new representations from previous representations**	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.
A3	**Is able to evaluate the consistency of different representations and modify them when necessary**	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.
A4	**Is able to use representations to solve problems**	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)
A5	**Force Diagram**	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.
A6	**Motion Diagram**	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.

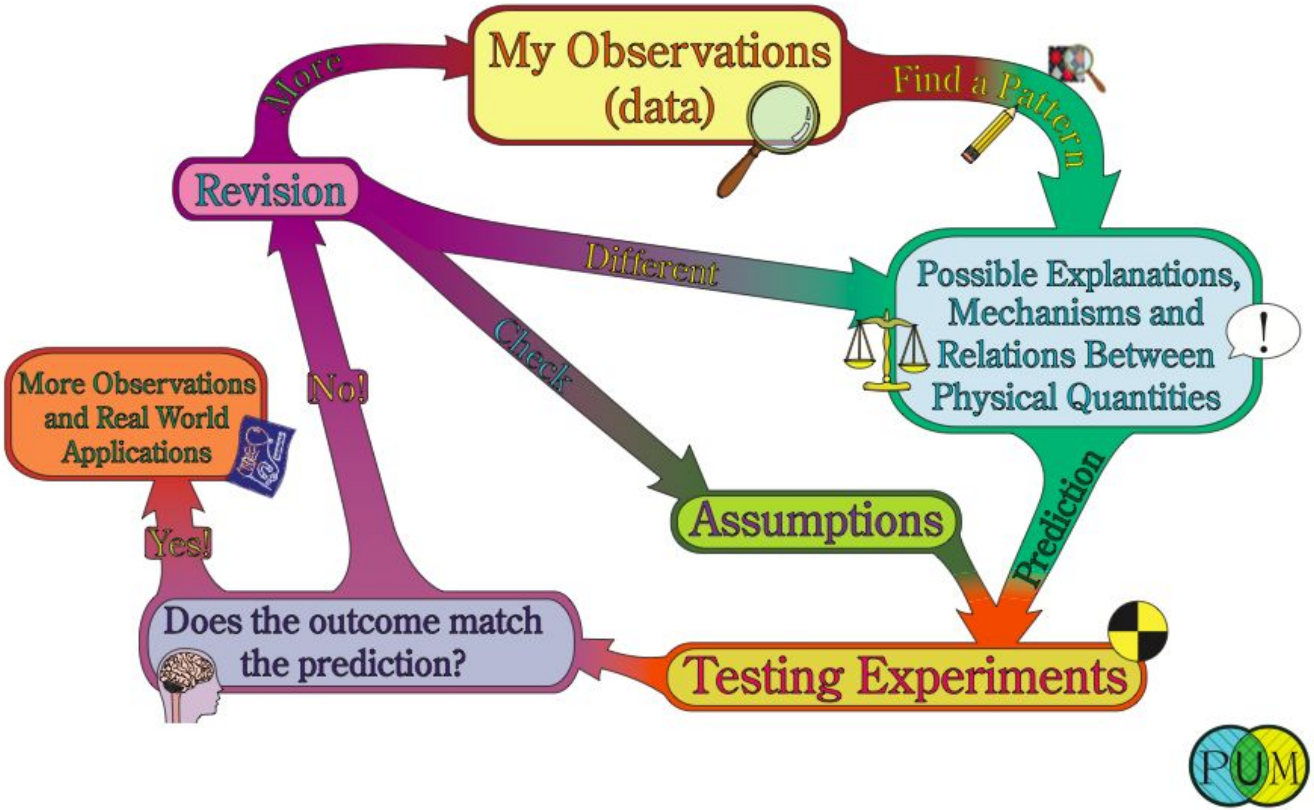
A7	**Sketch**	No representation is constructed.	Sketch is drawn but it is incomplete with no physical quantities labeled, or important information is missing, or it contains wrong information, or coordinate axes are missing.	Sketch has no incorrect information but has either no or very few labels of 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.
A8	**Energy bar chart**	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.
A9	**Mathematical**	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.
A10	**Ray diagram**	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.
A11	**Graph**	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

RUBRIC B: Ability to design & conduct an observational experiment					
	Scientific Ability	Missing	Inadequate	Needs improvement	Adequate
B1	**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.
B2	**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.
B3	**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.
B4	**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.
B5	**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).
B6	**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.
B7	**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.
B8	**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.
B9	**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.

Investigative Science Learning Cycle!

Etkina and Van Heuvelen (2001; 2007)



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First law of thermodynamics