Physics Education Laboratory
Lecture 09
Content Knowledge for Thermodynamics

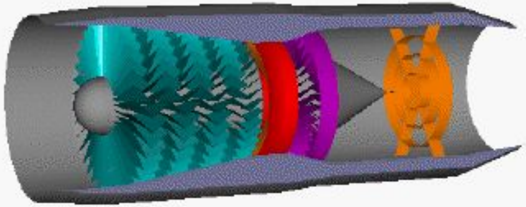
Francesco Longo - 17/11/22


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.

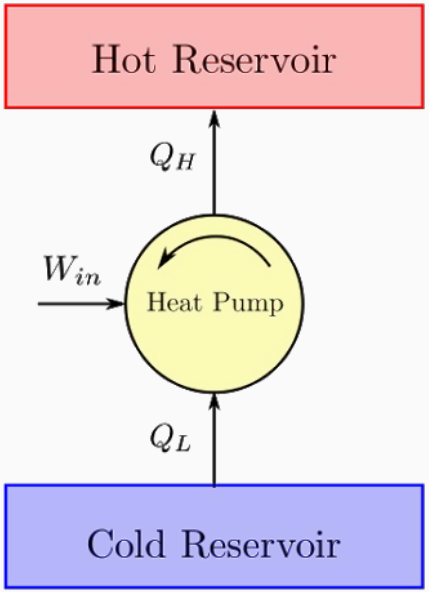
Zeroth Law: Thermodynamic Equilibrium and Temperature

First Law: Work, Heat, and Energy

Second Law: Entropy

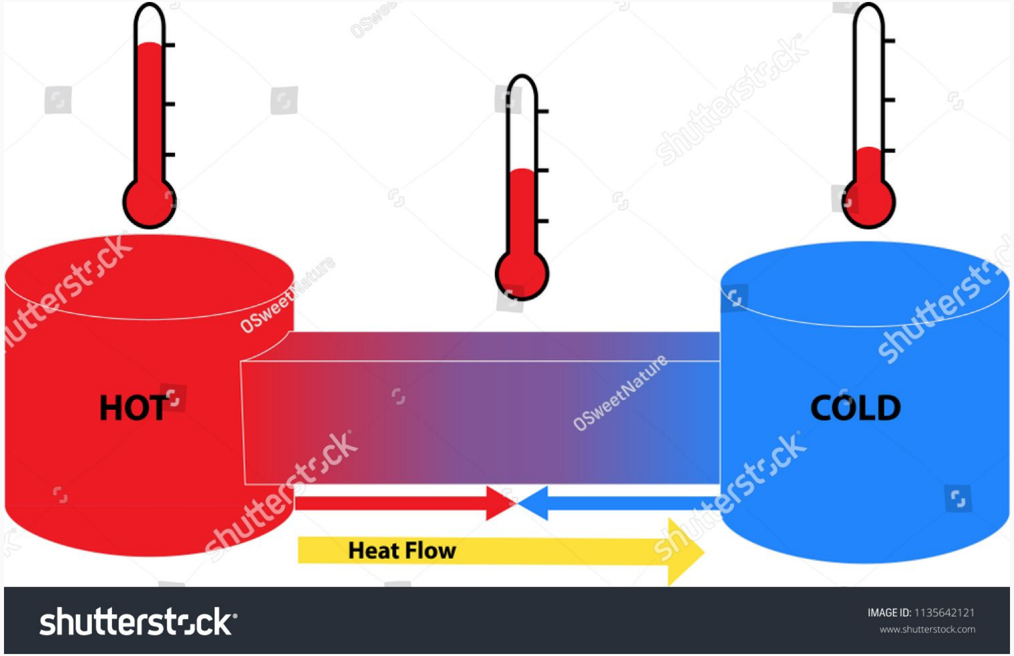
Key concepts in thermodynamics

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



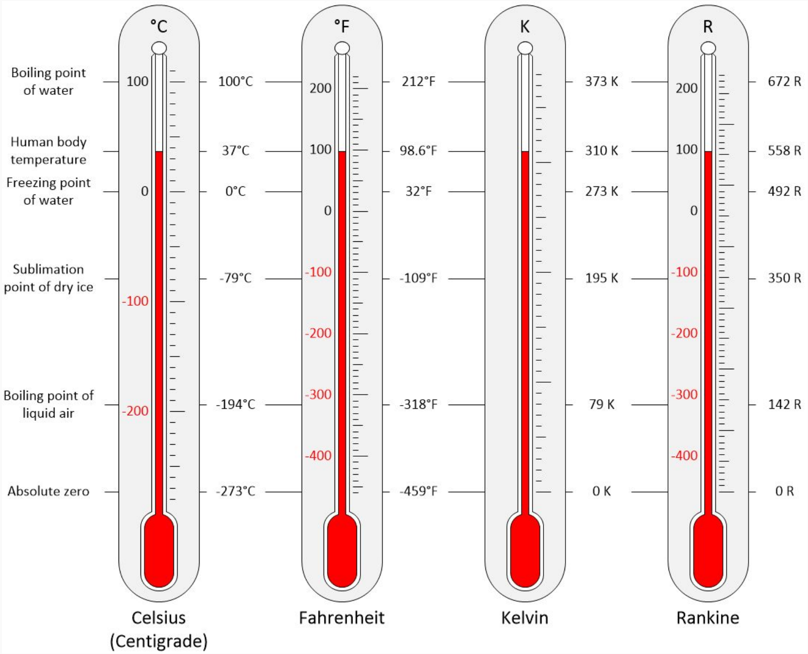
Key concepts in thermodynamics

- Temperature
- Hot vs Cold



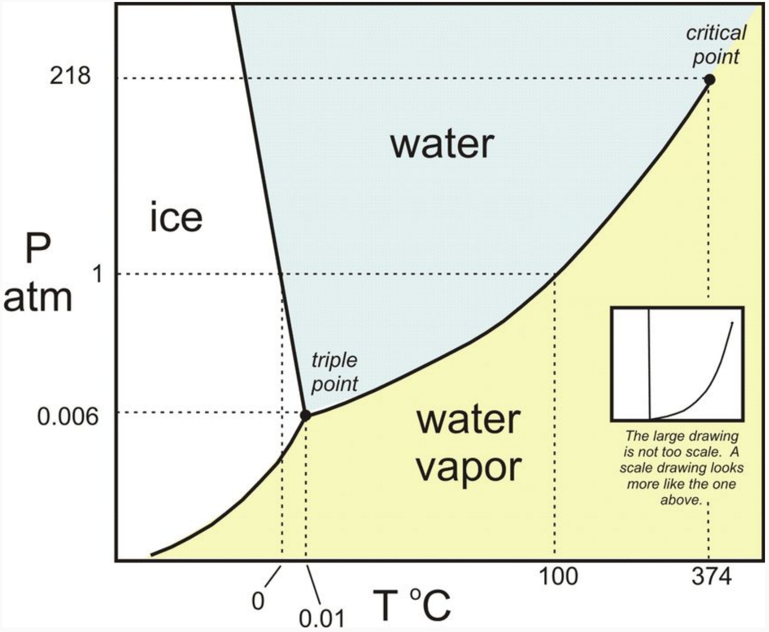
Key concepts in thermodynamics

- Temperature scales



Key concepts in thermodynamics

- State transitions
- Latent heat



Key concepts in thermodynamics

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

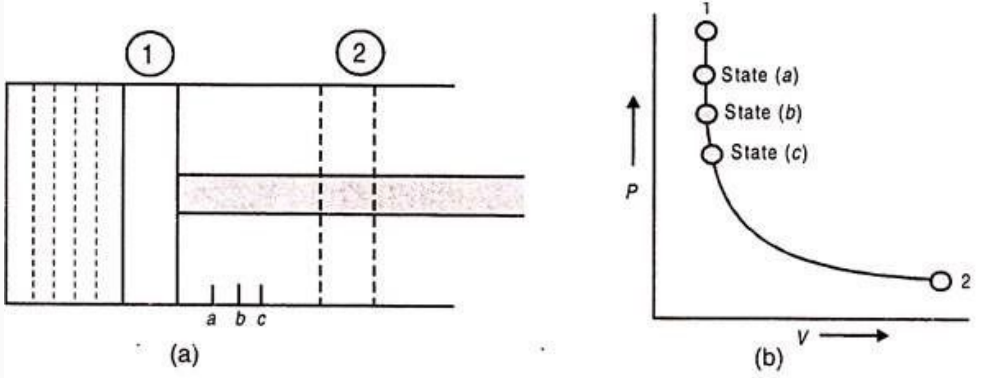
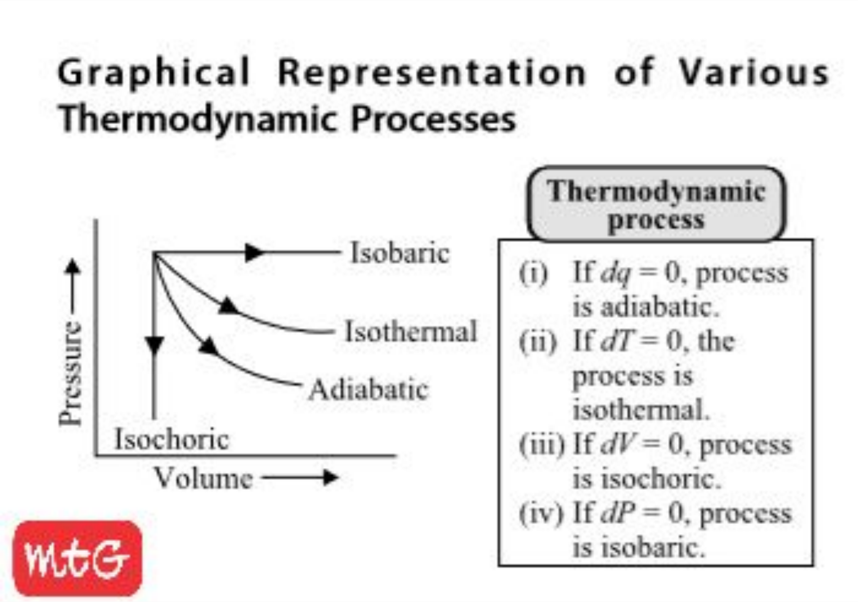


Fig. 1.8

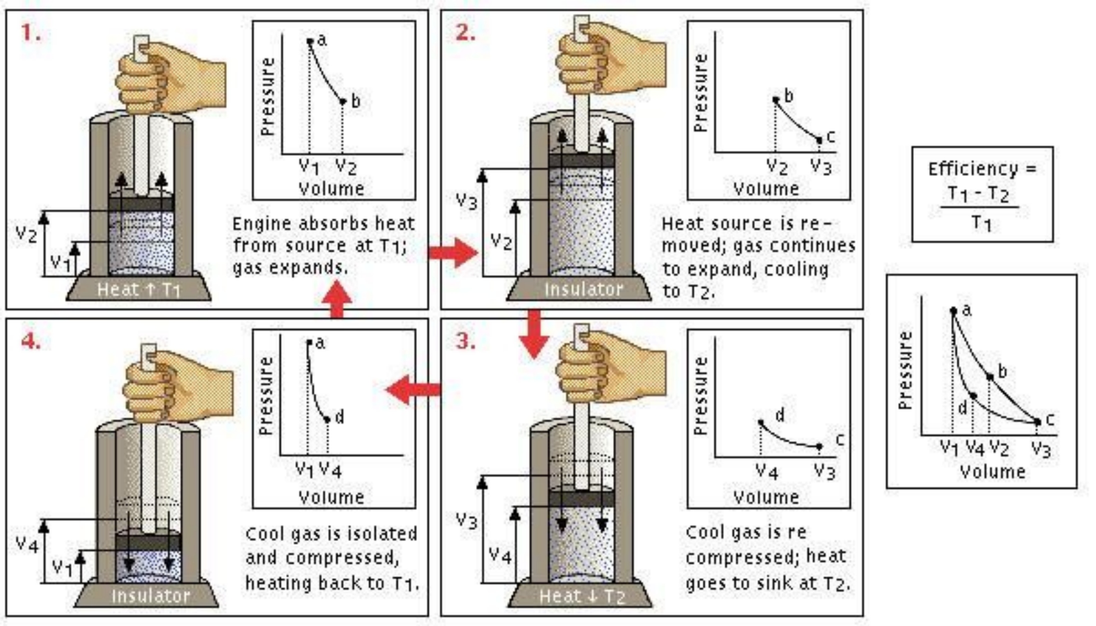
Key concepts in thermodynamics

- Processes in pV plane



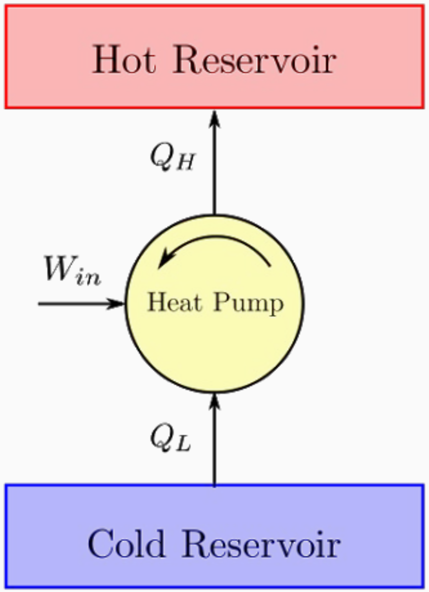
Key concepts in thermodynamics

- Thermodynamic cycles



Key concepts in thermodynamics

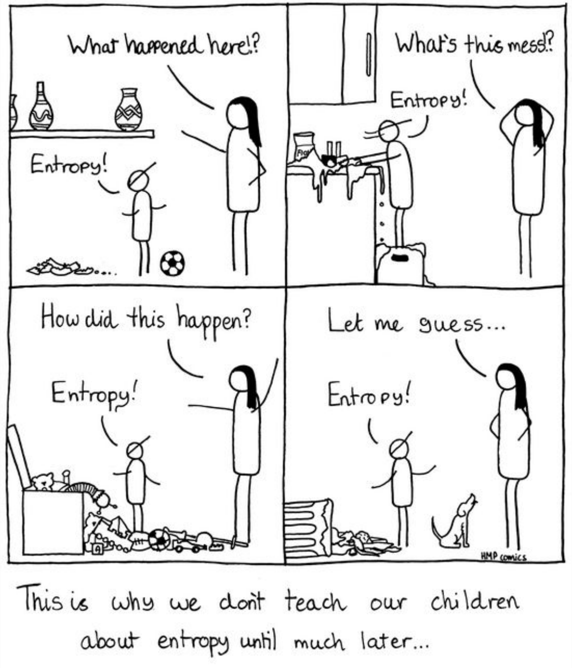
- Thermodynamics machines



Key concepts in thermodynamics

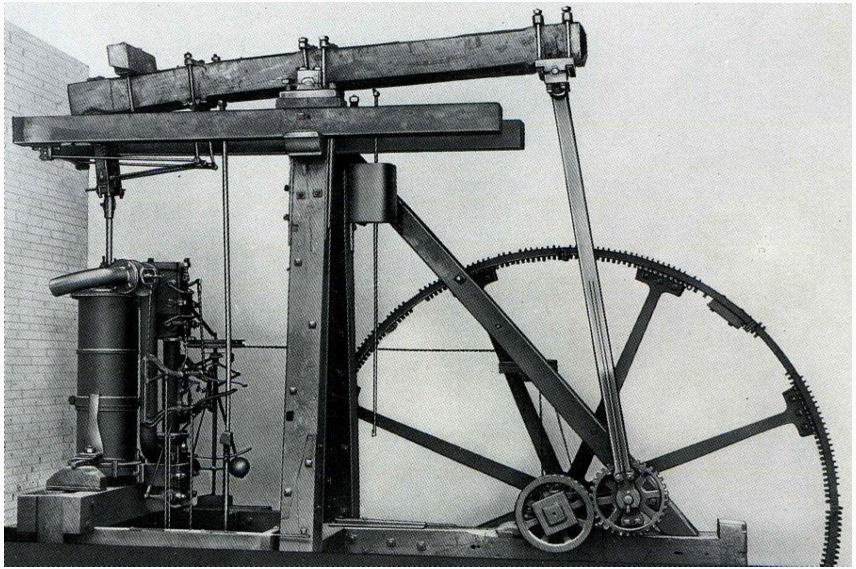
- Entropy as state variable
- Universe, System
- Closed or Open Systems
- Increase/Decrease of order

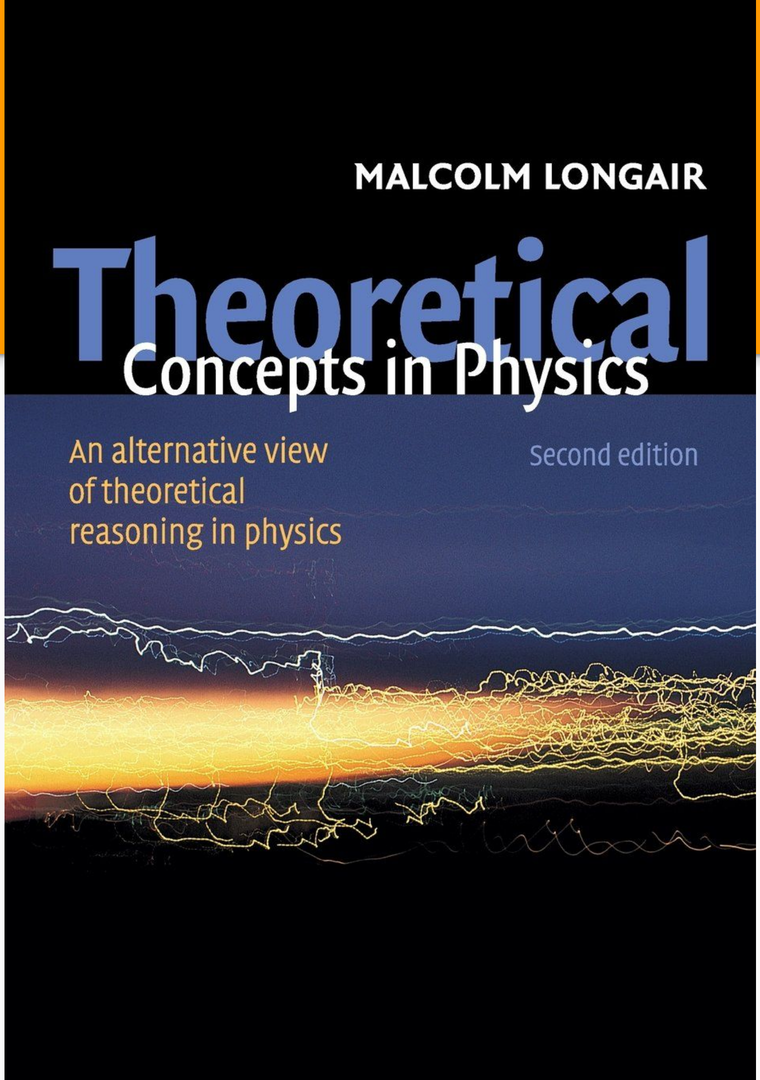
$$\Delta S = S_f - S_i = \int \frac{dq_{rev}}{T}$$



Knowledge of curricula

- Link to cultural needs …





Misconceptions

- Open vs. closed systems
- Evaluation of properties
- State 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 - 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/

OBSERVATIONAL EXPERIMENT

TESTING EXPERIMENT

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:

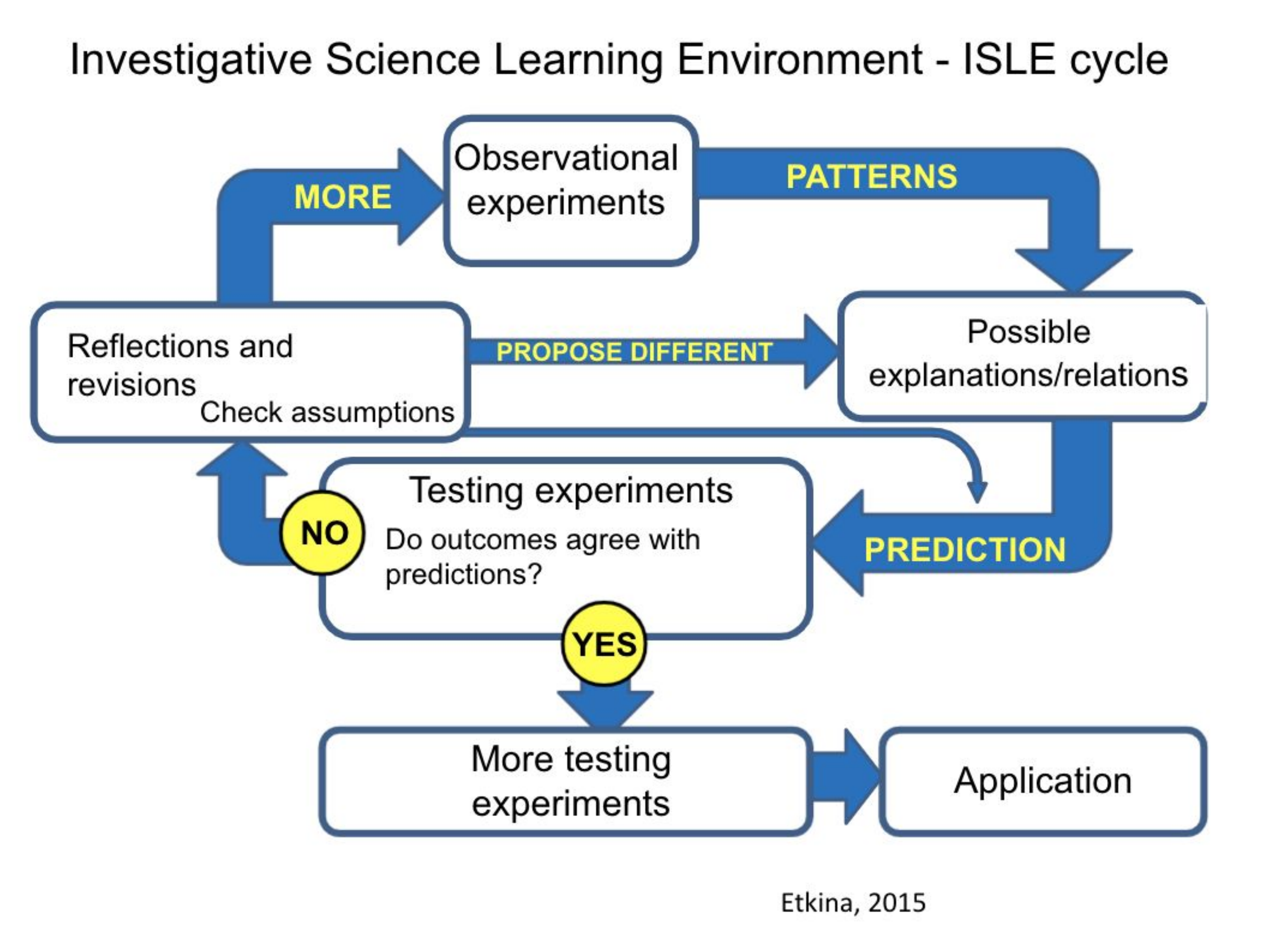
1.Students come upon some interesting physical phenomenon that needs explaining.

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.


Investigative Science Learning Environment - ISLE cycle
Observational experiments
PATTERNS
MORE
Reflections and revisions
Check assumptions
PROPOSE DIFFERENT
Possible explanations/relations
Testing experiments
Do outcomes agree with predictions?
NO
PREDICTION
YES
More testing experiments
Application
Etkina, 2015

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/u3Y4npFvlO4] 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.

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

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]. 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.

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.