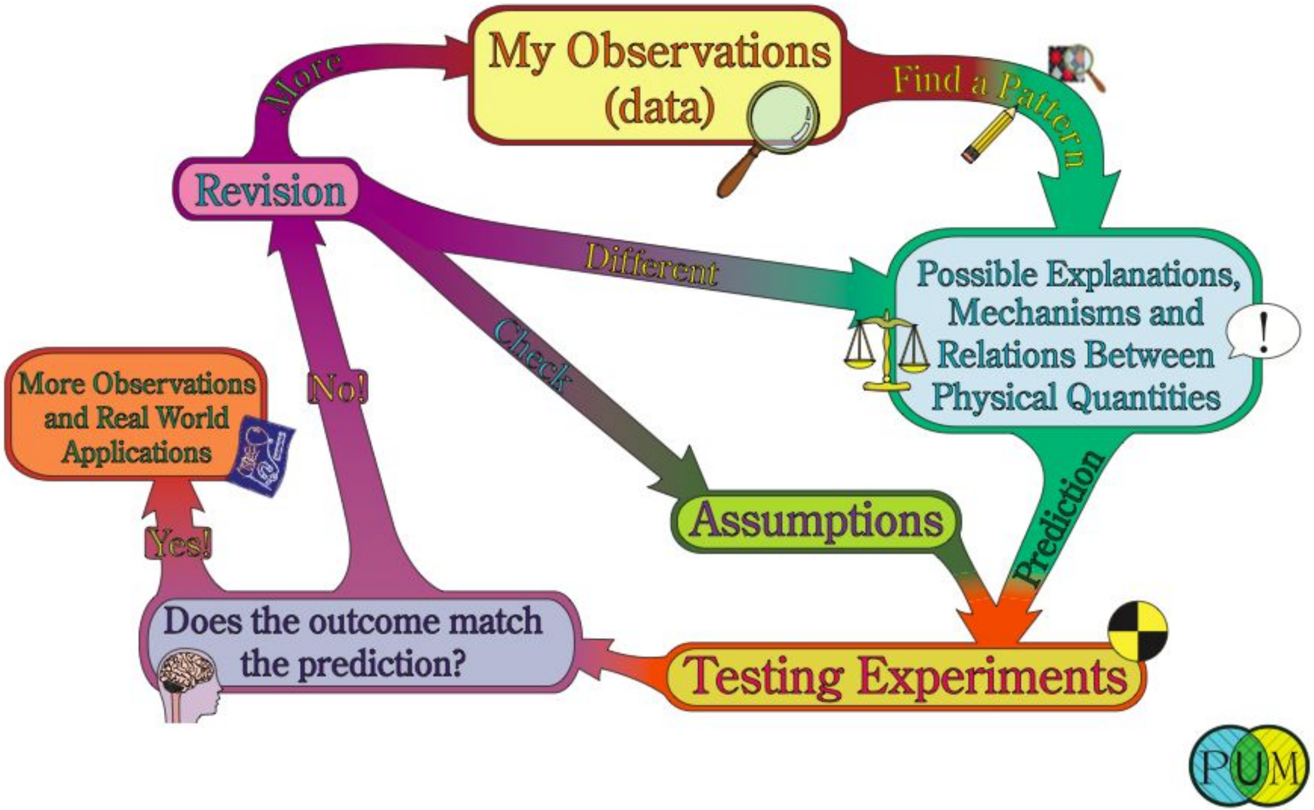
Physics Education Laboratory Lecture 10

Investigative Science Learning Environment

Francesco Longo - 06/11/23

Investigative Science Learning Cycle!

Etkina and Van Heuvelen (2001; 2007)



Example of ISLE at work ..

https://docs.google.com/document/d/1F7XA_jZz8bIhB4RxS6cWgDJn4DbUQknO/edit

Demonstrative experiment

A demonstrative experiment is an experiment that students watch when they are involved in the study of a phenomenon already explained. Thus, they do not make any measurements, nor they do not make predictions, nor make comparative analysis between measurements and prediction. Students do no construct by their own any qualitative or quantitative relationship.

Observational experiment

An observational experiment is an experiment that students perform when they are investigating a new phenomenon. Thus, they do not make predictions or have expectations about its outcome. Students need to collect data, analyze them and find a pattern in the data. They then need to explain the reasons for the pattern (if applicable), and/or construct a qualitative or quantitative relationship.

Esperimenti di osservazione: cosa sono?

Esperimenti nei quali gli studenti investigano un fenomeno nuovo.
Gli studenti non effettuano previsioni circa i risultati dell'esperimento, ma osservano e descrivono: raccolgono dati, li analizzano e trovano delle relazioni ricorrenti ("*patterns*") in essi.
Essi sono portati a elaborare una spiegazione per le relazioni trovate e/o a costruire una relazione qualitativa o quantitativa.

Esperimenti di osservazione: perché usarli?

Gli studenti:

- riceveranno esperienze *concrete* come parte del ciclo di apprendimento
- imparano ad interpretare i dati senza sapere se sono giusti o sbagliati (*open-mind*)
- imparano a effettuare *scelte* su come rappresentare i dati e su quali relazioni cercare
- procedono in situazioni dove non c'è una risposta giusta o sbagliata, imparando modi produttivi per investigare fenomeni complessi (*cognizione epistemica*)
- imparano a trattare la complessità di *dati reali*

Esperimenti di osservazione: come e dove usarli?

- a lezione: per sviluppare idee su un argomento nuovo. L’esperimento può essere svolto dal docente e gli studenti dovranno raccogliere ed elaborare i dati, decidere quali variabili sono importanti e trovare *patterns*. I dati o la loro analisi possono essere già forniti da terzi: in questo caso gli studenti dovranno solo trovare un pattern e fornire una spiegazione a riguardo;
- in laboratorio: dove gli studenti raccolgono ed elaborano i dati, trovano pattern e costruiscono spiegazioni o relazioni matematiche per descriverli;
- come compito per casa: si forniscono i dati agli studenti che dovranno analizzare e trovare patterns da soli.

Observational Experiment Table 2.1

Using dots to represent motion

Observational experiment	Analysis
Experiment 1. You push a bowling ball (the object of interest) and let it roll on a smooth linoleum floor. Each second, you place a beanbag beside the bowling ball. The beanbags are evenly spaced.	The dots in this diagram represent the positions of the beanbags you placed each second as the bowling ball slowly rolled on the floor. • • • •
Experiment 2. You repeat Experiment 1, but you push the ball harder before you let it roll. The beanbags are farther apart but are still evenly spaced.	The dots in this diagram represent the positions of the beanbags, which are still evenly spaced but separated by a greater distance than the bags in Experiment 1. • • •
Experiment 3. You push the bowling ball and let it roll on a carpeted floor instead of a linoleum floor. The distance between the beanbags decreases as the ball rolls.	The dots in this diagram represent the decreasing distance between the beanbags as the ball rolls on the carpet. • • • •
Experiment 4. You roll the ball on the linoleum floor and gently and continually push on it with a board. The distance between the bean-bags increases as the pushed ball rolls.	The dots in this diagram represent the increasing distance between beanbags as the ball is continually pushed across the linoleum floor. • • • •

Pattern

- The spacing of the dots allows us to visualize the motion of the object of interest.
- When the object travels without speeding up or slowing down, the dots are evenly spaced.
- When the object slows down, the dots get closer together.
- When the object moves faster and faster, the dots get farther apart.

a. What patterns did you notice in the placement of the dots?

b. How can you use the distances between the dots to describe the motion of the bowling ball?

Testing experiment

In a testing experiment, students use an explanation or relationship to make a prediction of the outcome of the experiment. They also decide what additional assumptions they are making. Then they perform the experiment, and record the outcome. Based on the (dis)agreement of the prediction and the experimental outcome, and taking into account theoretical assumptions and experimental uncertainties, students have to make a judgment about the explanation or relationship that they are testing.

Students learn that when their prediction agrees with the experimental outcome, it only means that the explanation/relationship cannot be rejected. On the other hand, if their prediction does not agree with the experimental outcome, they have to either reject the explanation/relationship they tested, or reconsider the additional assumptions they made. Thus, the emphasis is on trying to disprove an idea

Esperimenti di test: cosa sono?

Esperimenti nei quali gli studenti usano una spiegazione o una relazione per effettuare previsioni circa il risultato di un esperimento.

Gli studenti eseguono l'esperimento e registrano il risultato. Basandosi sull'accordo (o meno) della previsione con i risultati sperimentali, e tenendo conto delle assunzioni teoriche, dei modelli usati e delle incertezze sperimentali, essi devono effettuare giudizi circa la spiegazione o le relazioni che stanno testando.

Essi dunque imparano che se la loro previsione è d'accordo con l'esperimento, la spiegazione o la relazione pensata non può essere rifiutata, mentre se non c'è accordo essi devono rigettare la spiegazione o riconsiderare le loro assunzioni.

Esperimenti di test: perché usarli?

Gli studenti:

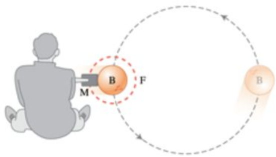
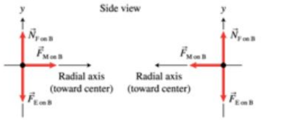
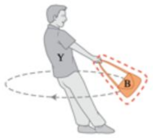
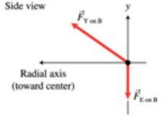
- imparano il ragionamento *ipotetico-deduttivo* (logica del “se”, “e”, ”ma” “allora”...)
- imparano a basare la loro conoscenza sull’evidenza e non sull’autorità
- imparano la differenza tra assunzione, previsione, spiegazione
- imparano che la discordanza tra previsioni e esperimento può essere dovuto a svariati fattori: assunzioni incomplete, spiegazioni errate, o tecniche sperimentali inadeguate
- imparano a scegliere quando rigettare una spiegazione per un fenomeno

Esperimenti di test: come e dove usarli?

- a lezione: il docente descrive l’apparato sperimentale e gli studenti effettuano previsioni dell’esperimento a seguito di una spiegazione precedentemente elaborata. Il docente (o un terzo) esegue l’esperimento e gli studenti decidono l’accordo o meno delle previsioni con i risultati dell’esperimento
- in laboratorio: gli studenti eseguono in prima persona l’esperimento dopo aver effettuato delle previsioni, e giudicano in seguito l’accordo o meno con i risultati dell’esperimento. L’esperimento può anche essere ideato dagli studenti in prima persona, a seconda del materiale a disposizione.

Observational Experiment Table 5.1

Forces exerted on an object moving in a circle at constant speed

Observational experiment	Analysis
Experiment 1. A bowling ball is rolled toward you over a smooth floor. You are asked to tap it with a mallet to make the ball roll in a circle with constant speed. You find that directing the mallet taps along the desired circular path doesn't work; the ball rolls wide. The only thing that works is to tap *directly toward the center of the desired circle.* 	There are three objects interacting with the bowling ball: Earth, the floor, and the mallet. We assume that the force exerted by the floor is perpendicular to the floor's surface. The force diagrams for the ball at two locations are shown below. We see that at each location the sum of the forces points toward the center of the circle. 
Experiment 2. You hold a bag by the handle and swing it in a horizontal circle at constant speed. You observe that your arms pulling the bag are angled down with respect to the horizontal. 	Two forces are exerted on the bag as it moves around the circle: Earth pulls downward, and you pull at an angle with the vertical. The vertical component of the force that you exert on the bag must balance the force that Earth exerts on it because the bag does not accelerate in the vertical direction. Consequently, the sum of these two forces again points toward the center of the circle. 

Pattern

In each case, as shown in the force diagrams, the sum of the forces exerted on the circling object points directly toward the center of the circle.

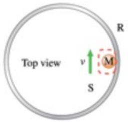
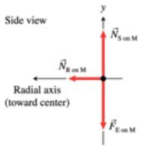
Watch *Circular motion*

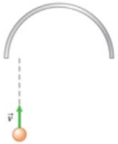
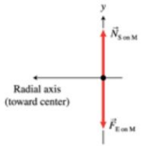
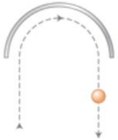
FIND A PATTERN

Experiment: the circling object is in bold.	List objects that interact with the circling object.	Draw a top view force diagram for the circling object.	List forces or force components that add to zero.	Indicate the direction of the sum of the forces exerted on the object.
a. Tapping a **bowling ball.** So it moves in a circle on the floor				
b. Swinging a **bucket** in a horizontal circle.				
c. Pulling a rope attached to a moving **rollerblader** so she moves in a circle.				

Testing Experiment Table 5.2

Does the sum of the forces exerted on an object moving at constant speed in a circle point toward the center of the circle?

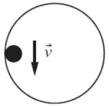
<table>
<tr><th>Testing experiment</th><th>Prediction</th><th>Outcome</th></tr>
<tr>
<td>Experiment 1. You roll a marble against the inside wall of a metal ring sitting on a smooth surface.

</td>
<td>The force diagram for the marble is shown below.


The vertical force components add to zero. The sum of the forces points along the radial axis toward the center of the circle. Thus we predict that the marble will roll along the wall of the ring following the circle.</td>
<td>As you can see in the video, this is exactly what happens. The marble rolls inside the ring following the circle.
</td>
</tr>
<tr>
<td>Experiment 2. You roll a marble at constant speed toward a semicircular metal ring sitting on a smooth surface.

</td>
<td>When the marble rolls toward the ring, the sum of the forces exerted on it is zero, so we predict that it will move in a straight line with constant velocity. When it reaches the ring, the sum of the forces will point toward the center of the ring, so we predict it will follow the ring as in Experiment 1. Once the marble reaches the end of the ring, it should continue in a straight line as before.

</td>
<td>The video of the experiment shows that our prediction matches the outcome.
</td>
</tr>
</table>

Conclusion

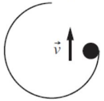
The outcomes of both experiments are consistent with the pattern of the sum of the forces exerted on an object moving at constant speed in a circle pointing toward the center.

For the following testing experiment, use the pattern that you formulated in Activity 5.1.2 and Newton's laws to predict the outcome of the experiment. Do not watch the video until you finish part **b** of this activity.



a. Inside a metal ring, a person rolls a small ball or a marble on a smooth horizontal surface. The marble rolls along the ring. Is the motion of the ball consistent with the pattern formulated in Activity 5.1.2? Explain.

b. Use the pattern you found in Activity 5.1.2 (not your intuition) to predict what will happen to the ball if, after the ball rolls for a couple of turns, the person removes a quarter of the ring as shown in the figure. Justify your prediction in words and with a force diagram before you watch the video of the experiment.



c. After you make your prediction, watch the video, and compare the outcome to your prediction. What judgment can you make about the idea that you're testing? Does the outcome support, prove, or disprove the idea you're testing?

Application experiment

An application experiment typically involves solving a practical problem or determining an unknown quantity by performing experiments. Students need to solve these experimental problems using at least two different methods and then compare the results. Often they need to perform additional experiments or make informed estimates to determine some physical quantities.

Esperimenti di applicazione: cosa sono?

Esperimenti che includono il risolvere un problema pratico o determinare una quantità sconosciuta mediante un esperimento.
Agli studenti può venire chiesto di usare più metodi sperimentali per determinare una stessa quantità e confrontare i risultati.

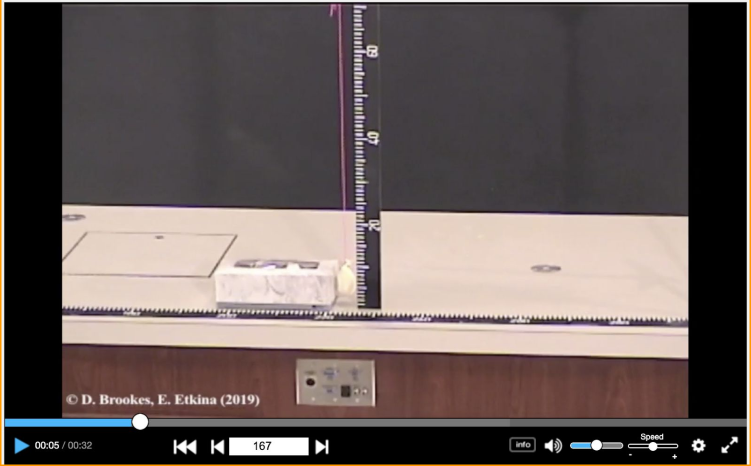
Esperimenti di applicazione: perché usarli?

Gli studenti:

- imparano ad affrontare problemi realistici
- imparano ad affrontare un problema da più punti di vista, usando più idee e confrontandole
- imparano a scegliere quali assunzioni effettuare per risolvere un problema e cosa tralasciare
- imparano ad applicare la fisica nella vita di tutti i giorni usando strumentazioni semplici
- imparano a confrontare risultati di diversi esperimenti

Esperimenti di applicazione: come e dove usarli?

- in laboratorio: agli studenti è richiesto di calcolare una quantità fisica effettuando un esperimento con degli strumenti a loro disposizione
- come problema-video: gli studenti possono raccogliere dati guardando un video di un esperimento e risolvere il problema richiesto (si può fare anche in classe o come compito per casa)



OALG 7.7.3 Application experiment: Measuring the coefficient of kinetic friction

The goal is to use your knowledge of energy and momentum to determine the coefficient of kinetic friction between a tissue box and the table in the following video. [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-7-7-3].

The flour-filled balloon has a mass of 54.7g, the tissue-box has a mass of 161.1g.

Observing the experiments

Observe two experiments that can be used to determine the coefficient of kinetic friction. For each experiment:

Constructing the mathematical model

Start with the experiment with the flower balloon hitting the box and the box sliding to a stop. Think of how you can analyze the process conceptually (using energy and momentum bar charts) to find the coefficients of kinetic friction and then how you can convert these bar charts into mathematical representations. The following steps might help you:

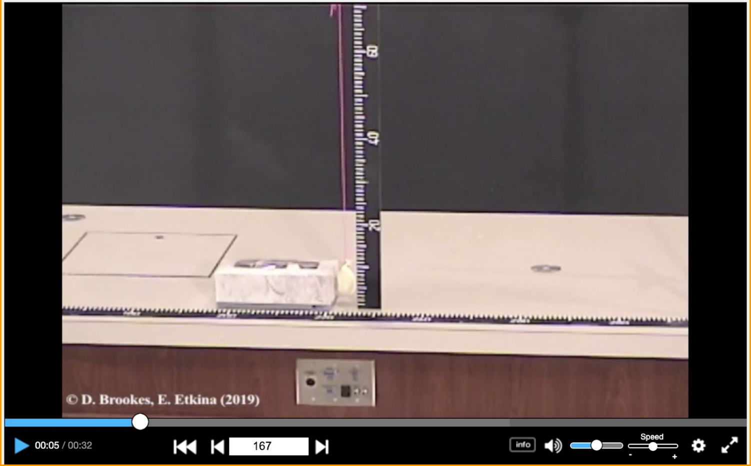
a. Divide the process into three smaller processes that each involves one central physics idea. Represent each smaller process with a relevant bar chart (think of whether energy bar chart of momentum bar chart will be easier to analyze mathematically). Carefully choose your system for every sub-process.

b. Once you have the bar charts, convert them into mathematical representations (models). Check if what you wrote will help you determine the coefficient of kinetic friction.

c. Identify the physical quantities you will need to measure in order to determine the coefficient of kinetic friction.

d. Repeat the process for the second experiment (pulling the box with the scale). Here you might want to use the force diagram to construct the mathematical model.

e. What assumptions did you make in your mathematical models? Specifically, what is the effect making each of them will have on the result produced by your mathematical model (will it make the calculated value smaller, larger, or randomly different than the real-world value)? Explain your reasoning.



Collecting data

a. Measure the physical quantities you identified in parts **c** and **d** in the previous step.

c. Record the data. What is the uncertainty in each measurement?

d. Use the mathematical procedure you devised to determine the coefficient of kinetic friction in both experiments. Estimate the uncertainty in your results.

e. Decide if the results of the two experiments are consistent or not. What is your judgment about the model you used to represent the situation shown in the video?

If you need to improve the mathematical model

a. Think about assumptions you made in your mathematical models. Which of your assumptions is least likely to be valid? Describe how you will revise part of your mathematical procedure to deal with this. What additional measurements will you need to make?

b. Construct force diagrams, and energy and/or momentum bar charts for your revised mathematical method.

c. Come up with a new equation for the coefficient of kinetic friction that incorporates your revisions. Again, do not plug in numbers.

d. Make any additional measurements you need, and then use your new equation to determine a revised value of the coefficient of kinetic friction.

e. Now are the results of the two independent methods consistent? Now what is your judgment about the mathematical model?

f. Are any of the other assumptions in your revised mathematical model questionable? How could you revise your mathematical procedure further to deal with these?

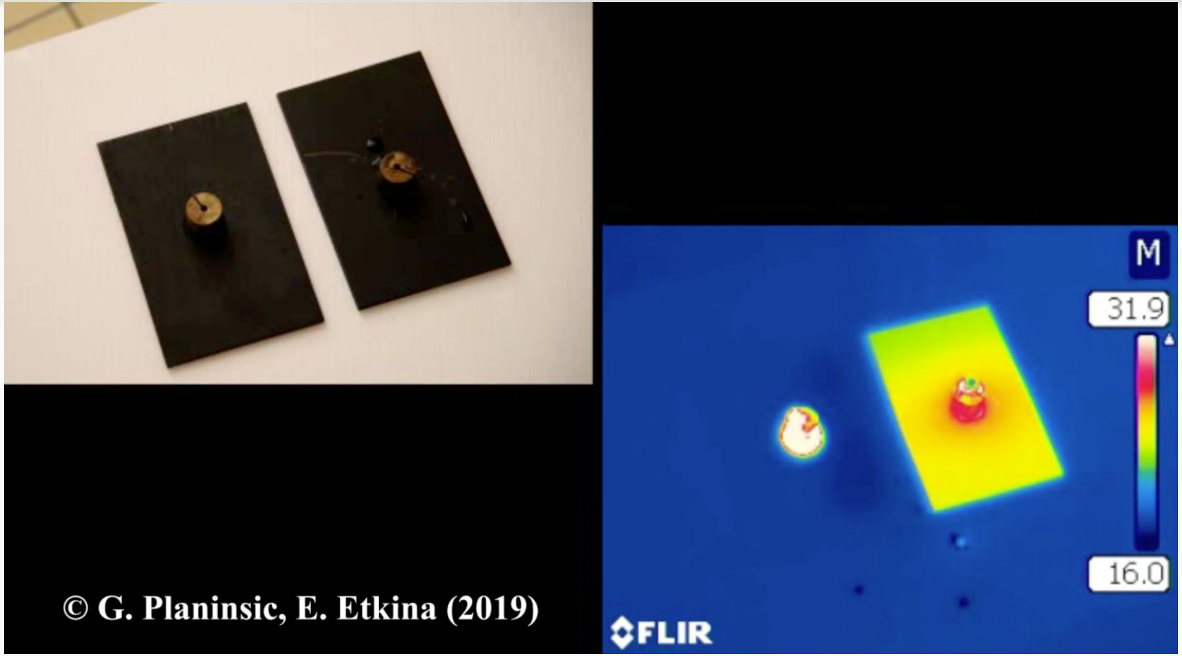
Video problems as Application experiment

A video problem is a subset of the category “application experiment”. From each video one can determine a physical quantity such as the coefficient of friction between two surfaces, the height of a table, etc. . . by two independent methods. The results determined from each method should agree with each other.

https://drive.google.com/file/d/1YOWDDJujMnD_BY5gw60eDNtxqjeiPXjN/view?usp=sharing

Example 1:
First law of thermodynamics

Example of Observation Experiment



In the experiment, two identical metal objects (made of brass) are taken from the same hot water bath and placed on two identically-shaped (same height, length, and width) plates. The plates are made of wood and aluminum (colored with the same black paint to reduce the reflective properties of aluminum) and have been sitting on the table for a long time.

a. Describe what you observe.

b. Devise one or more explanations for your observation.

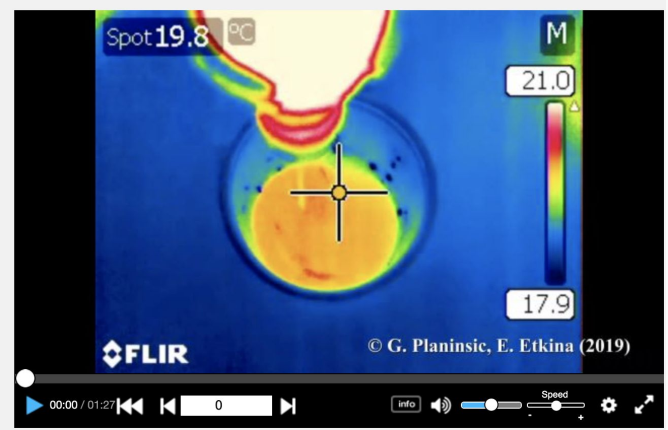
https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-15-7-2

Example of Testing Experiment

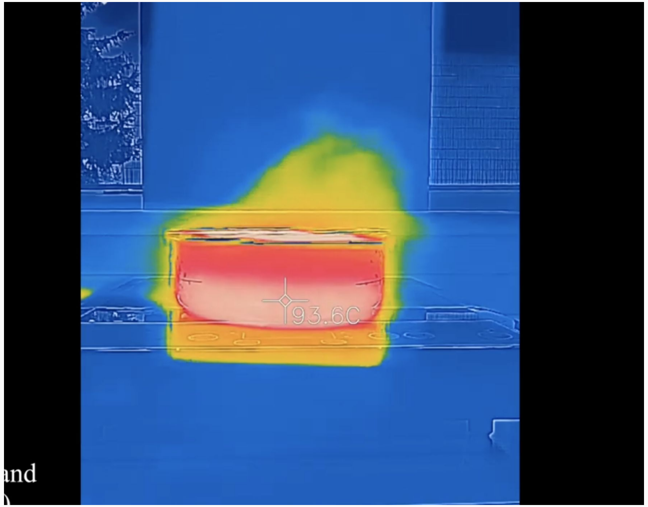
a. Use the explanations you made in Observational Experiment to predict what you will observe.
b. View the video [https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-15-7-3] and compare the outcome to your predictions. Do you need to revise your explanation?

Example of Application Experiment

https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-15-5-7



https://youtu.be/hLcYCzMgSzc



Example of Video- Application Experiment

[https://mediaplayer.pearsoncmg.com/assets/_frames.true/sci-phys-egv2e-alg-15-5-7].

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

a. Use the data provided in the video to estimate how much energy provided by the mixer went into warming up the glycerin.

b. Could this experiment be used to test the equivalence of work and heating as a means for energy transfer? Justify your answer.

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.

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.

Scientific abilities for formative assessment

The term “scientific abilities” describes some of the most important procedures, processes, and methods that scientists use when constructing knowledge and when solving experimental problems. These are not AUTOMATIC SKILLS, but are instead PROCESSES that students need to use REFLECTIVELY and CRITICALLY.

1. an ability to represent knowledge in multiple ways;
2. an ability to design experiments to investigate new phenomena, test hypotheses and solve experimental problems;
3. an ability to collect and analyze experimental data;
4. an ability to devise and test relationships and explanations;
5. an ability to evaluate reasoning and experimental design;
6. an ability to communicate.

- Ability to represent information in multiple ways
- Ability to design and conduct an observational experiment
- Ability to design & conduct an experiment to test an idea/hypothesis/explanation or mathematical relation
- Ability to design & conduct an application experiment
- Ability to communicate scientific ideas
- Ability to collect and analyze experimental data
- Ability to evaluate models, equations, solutions, and claims