Coherence of physics and problem solving approaches

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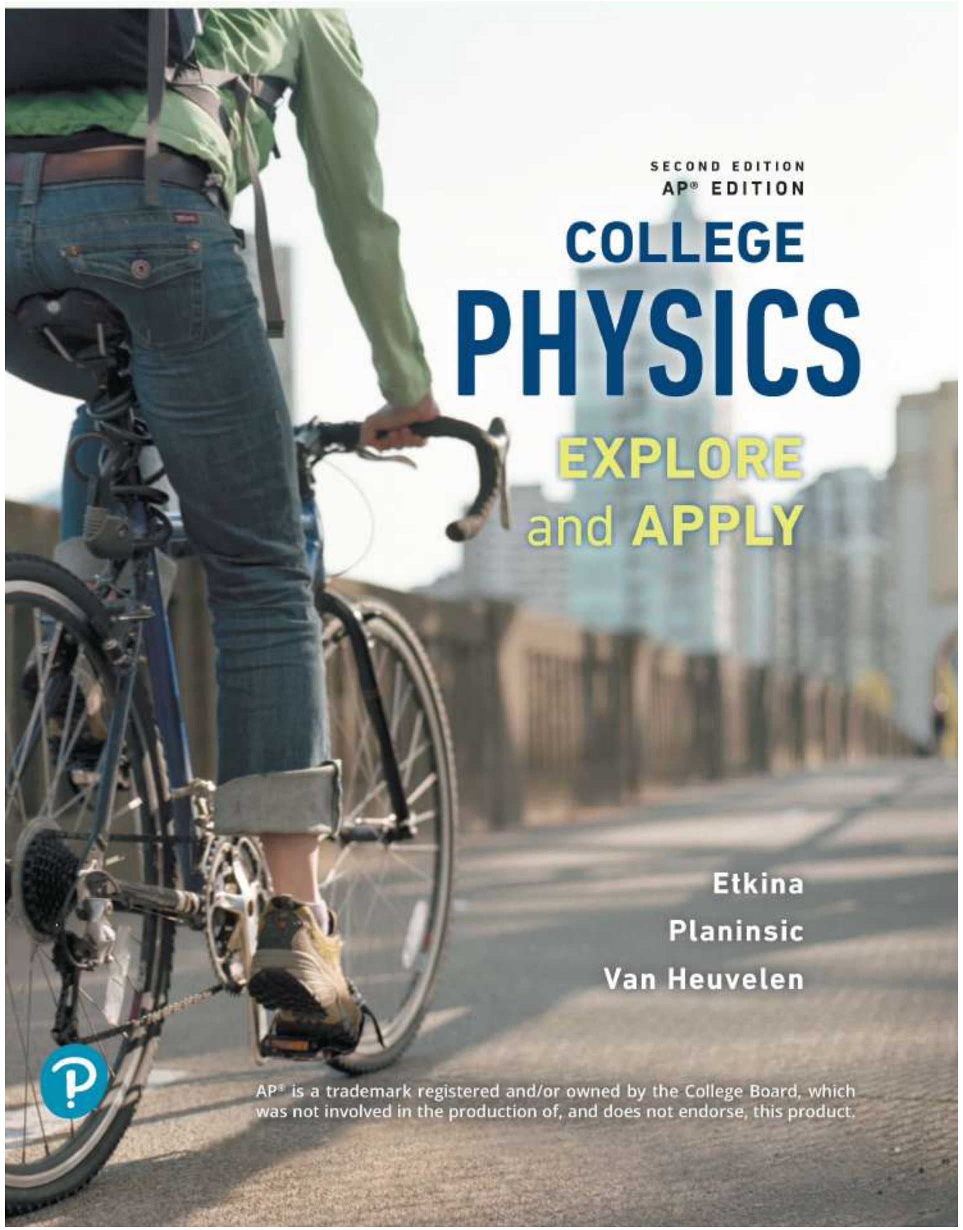
Organized by Yulia Turchaninova

Based on:



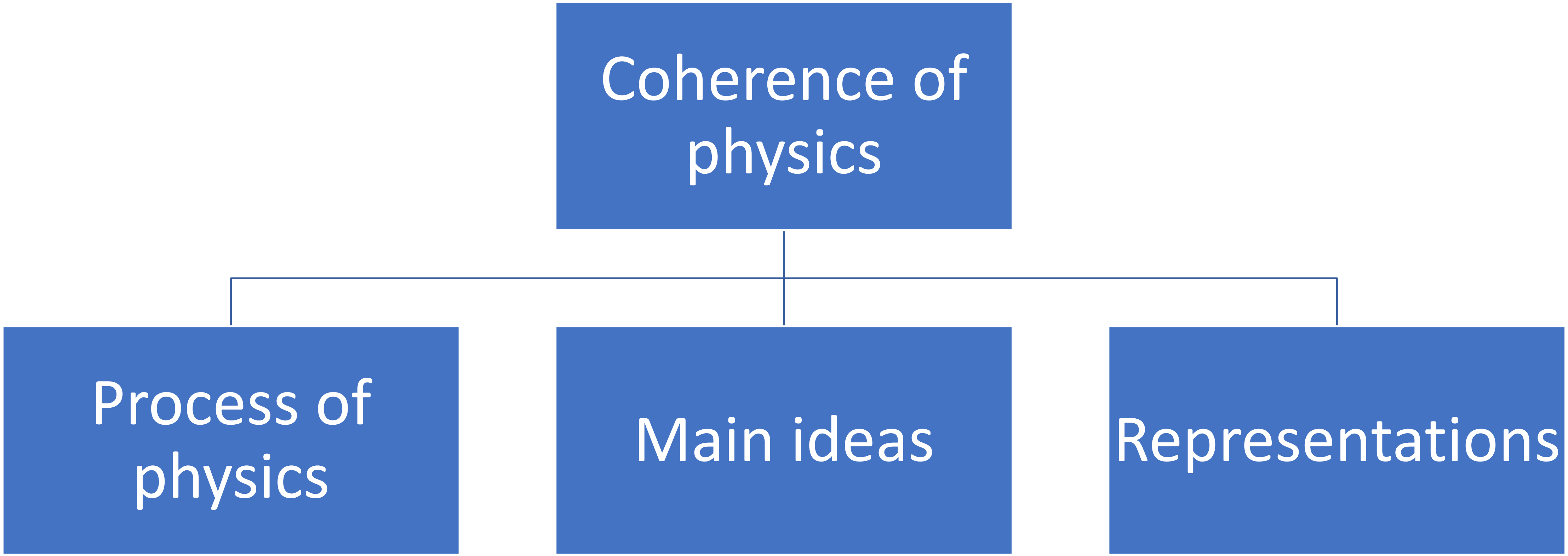
Join Facebook group “Exploring and applying Physics”, make sure you answer the question there.

What does the word “coherence” mean?

the quality of being logical and consistent.

the quality of forming a unified whole.

Types of coherence in physics



Process of physics (NGSS – science practices)

Elements of physics knowledge (what is physics made of? – bricks of physics)

Organization of the elements (what is holding these bricks together – the mortar of physics)

Elements of physics knowledge

Physical phenomena (observational experiments)

Physical quantities

Measuring instruments

Physical models (causal and mechanistic) – of objects, systems, processes

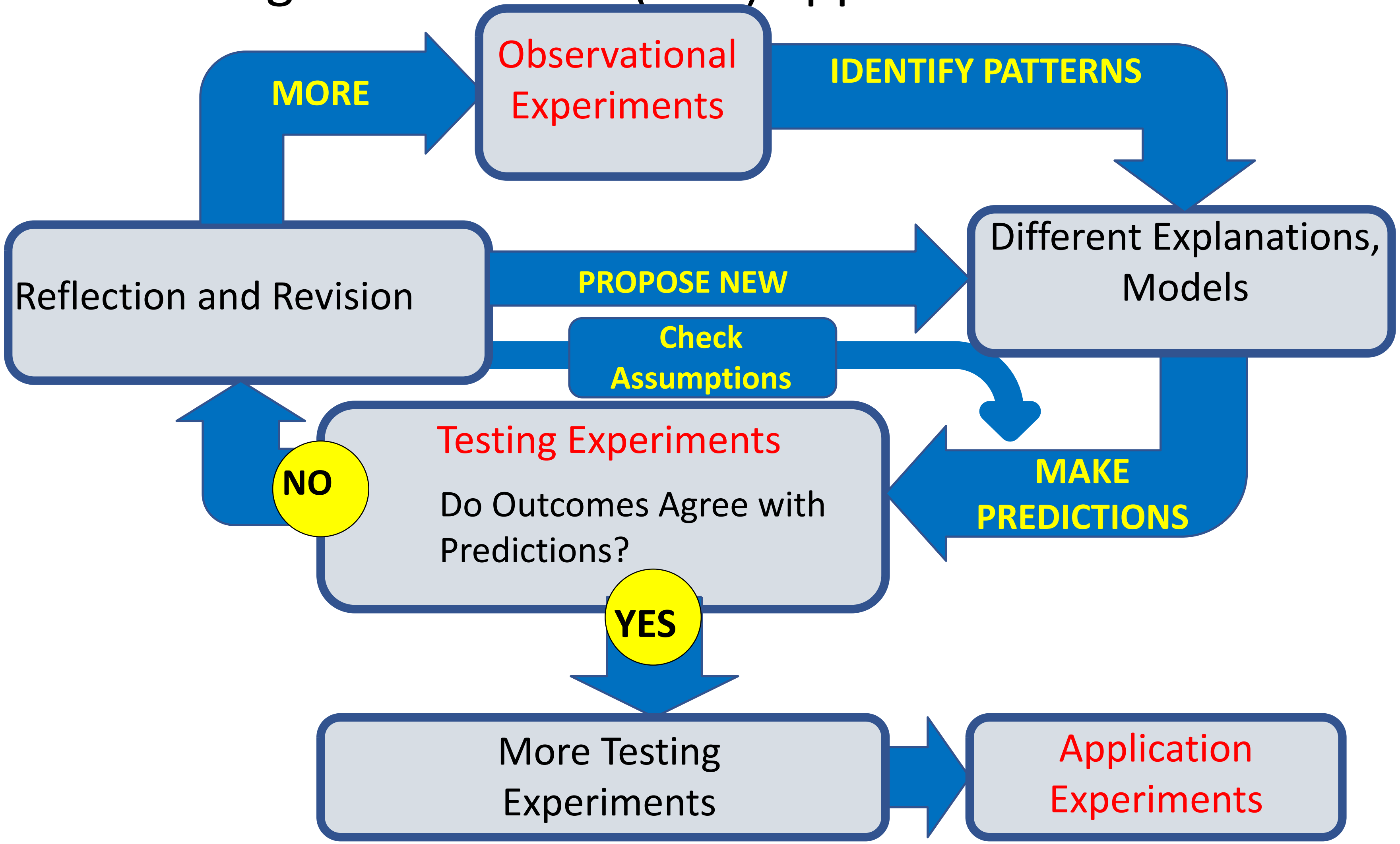
Experiments to test the models (testing experiments)

Physics devices

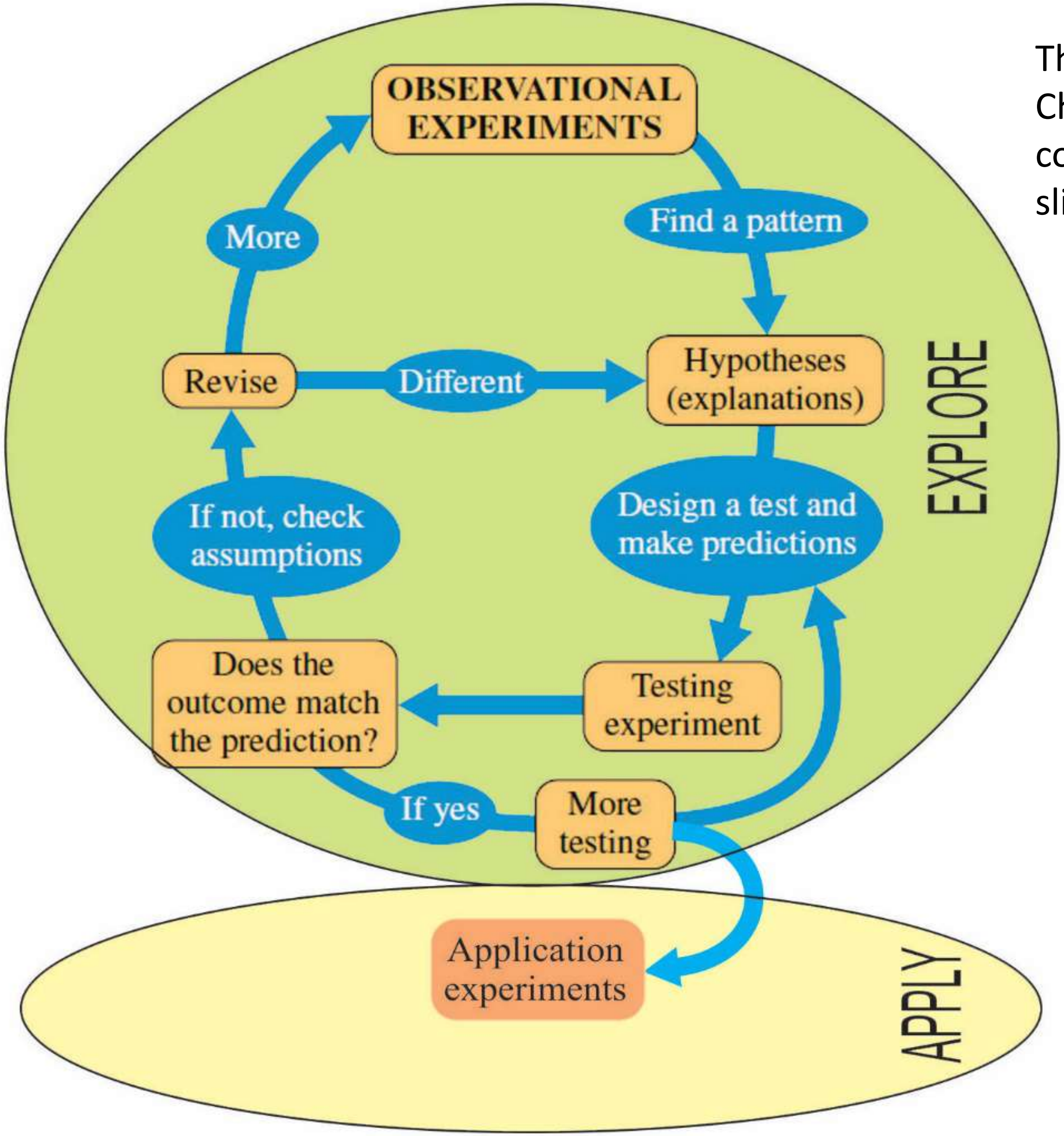
Anything else???

How are they organized?

Orgnization of the elements - The Investigative Science Learning Environment (ISLE) approach framework



Etkina and Van Heuvelen, 2001, 2007; Etkina, 2015, Etkina et al., 2019



This representation is in Chapter 1 in the textbook, compare it to the previous slide.

Content (NGSS – crosscutting concepts)

- The concept of a system and the environment
- The concept of causality
- The concept of conservation
- Occam razor concept

Multiple representations

- Pictorial (useful sketches)
- Mathematical: linear, quadratic, and trig functions
- Graphical (non-physics) – graphs of functional dependencies
- Graphical (physics) – motion diagrams, force diagrams, bar charts – momentum and energy, field representations (many), wave representations (many), electric circuits representations.

A different approach to problem solving

This problem is from Chapter 3 in the textbook.

Problem solving approaches

PROBLEM-SOLVING STRATEGY 3.1

Applying Newton's laws for one-dimensional processes

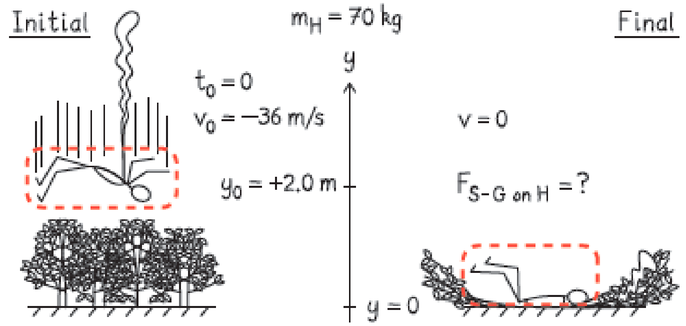
EXAMPLE 3.4 **Holmes's skydive**

Michael Holmes (70 kg) was moving downward at 36 m/s (80 mi/h) and was stopped by 2.0-m-high shrubbery and the ground. Estimate the average force exerted by the shrubbery and ground on his body while stopping his fall.

Sketch and translate

- Sketch the process.
- Choose the system.
- Choose a coordinate system.
- Label the sketch with everything you know about the situation.
- Identify the unknown that you need to find. Label it with a question mark on the sketch.

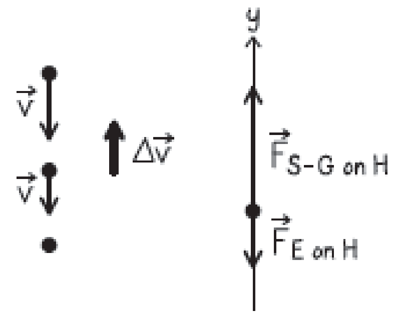
We sketch the process, choosing Holmes as the system (H). We want to know the average force that the shrubbery and ground (S-G) exert on him from when he first touches the shrubbery to the instant when he stops. We choose the *y*-axis pointing up and the origin at the ground where Holmes comes to rest. We use kinematics to find his acceleration while stopping and Newton's second law to find the average force that the shrubbery and ground exerted on him while stopping him.



Simplify and diagram

- Make appropriate simplifying assumptions about the process. For example, can you neglect the size of the system? Can you assume that forces or acceleration is constant?
- Then represent the process with a motion diagram and/or force diagram(s). Make sure the diagrams are consistent with each other.

We model Holmes as a point-like object and assume that the forces being exerted on him are constant so that they lead to a constant acceleration. A motion diagram for his motion while stopping is shown along with the corresponding force diagram. To draw the force diagram we first identify the objects interacting with Holmes as he slows down: the shrubbery and ground (combined as one interaction) and Earth. The shrubbery and ground exert an upward force $\vec{F}_{\text{S-G on H}}$ on Holmes. Earth exerts a downward gravitational force $\vec{F}_{\text{E on H}}$. The force diagram is the same for all points of the motion diagram because the acceleration is constant. On the force diagram the arrow for $\vec{F}_{\text{S-G on H}}$ must be longer to match the motion diagram, which shows the velocity change arrow pointing up.



Represent mathematically

- Convert these qualitative representations into quantitative mathematical descriptions of the situation using kinematics equations and Newton's second law for motion along the axis. Determine the signs for the force components in the equations. Add the force components (with either positive or negative signs) to find the sum of the forces.

The y-component of Holmes's average acceleration is

$$a_y = \frac{v_y^2 - v_{0y}^2}{2(y - y_0)}$$

The y-component of Newton's second law with the positive y-direction up is

$$a_y = \frac{\Sigma F_{\text{on H}\,y}}{m_\text{H}}$$

The y-component of the force exerted by the shrubbery-ground on Holmes is $F_{\text{S-G on H}\,y} = +F_{\text{S-G on H}}$, and the y-component of the force exerted by Earth is $F_{\text{E on H}\,y} = -F_{\text{E on H}} = -m_\text{H}g$. Therefore,

$$a_y = \frac{F_{\text{S-G on H}\,y} + F_{\text{E on H}\,y}}{m_\text{H}} = \frac{(+F_{\text{S-G on H}}) + (-F_{\text{E on H}})}{m_\text{H}} = \frac{+F_{\text{S-G on H}} - m_\text{H}g}{m_\text{H}}$$

$$\Rightarrow F_{\text{S-G on H}} = m_\text{H}a_y + m_\text{H}g$$

Solve and evaluate

- Substitute the known values into the mathematical expressions and solve for the unknowns.
- Finally, evaluate your work to see if it is reasonable (check units, limiting cases, and whether the answer has a reasonable magnitude). Check whether all representations—mathematical, pictorial, and graphical—are consistent with each other.

Holmes's average acceleration was

$$a_y = \frac{0^2 - (-36\ \mathrm{m/s})^2}{2(0 - 2.0\ \mathrm{m})} = +324\ \mathrm{m/s^2}$$

Holmes's initial velocity is negative, since he is moving in the negative direction. His initial position is +2.0 m at the top of the shrubbery, and his final position is zero at the ground. His velocity in the negative direction is decreasing, which means the velocity change and the acceleration both point in the opposite direction (positive). The average magnitude of the force exerted by the shrubbery and ground on Holmes is

$$F_{\text{S-G on H}} = m_{\mathrm{H}} a_y + m_{\mathrm{H}} g = (70\ \mathrm{kg})(324\ \mathrm{m/s^2}) + (70\ \mathrm{kg})(9.8\ \mathrm{N/kg})$$
$$= 22{,}680\ \mathrm{kg \cdot m/s^2} + 686\ \mathrm{N} = 23{,}366\ \mathrm{N} = 23{,}000\ \mathrm{N}$$

The force has a magnitude greater than the force exerted by Earth—thus the results are consistent with the force diagram and motion diagram. The magnitude is huge and the units are correct. A limiting case for zero acceleration gives us a correct prediction—the force exerted on Holmes by the shrubbery and ground equals the force exerted by Earth.

Try It yourself What process involving forces can be described by the equation $50\ \mathrm{kg} \times 2\ \mathrm{m/s^2} = 50\ \mathrm{kg} \times 9.8\ \mathrm{N/kg} + (-390\ \mathrm{N})$?

Answer

A 50-kg person is landing on a thick cushion that exerts a 390-N upward force on her but cannot slow her down. She continues to accelerate down, but her acceleration is less than g (only $2\ \mathrm{m/s^2}$). The vertical axis points down.

This rubric is from the Instructor Guideby Etkina, Brooks, Planinsic and Van Heuvelen. The IG accompanies the textbook. Chapter 1 (an additional chapter posted separately on Mastering Physics).

Rubric Item	Adequate	Needs improvement	Inadequate
…is able to clearly explain and justify the key steps of their reasoning process	Student verbally explains what they are doing and why. Explanation is clear, sufficiently detailed, easy to follow, and shows physical and conceptual understanding.	Student explains what they are doing, but missing why they are doing it. And/or there is some difficulty in following their explanation.	Explanation is incoherent, confusing, or missing; and/or invokes incorrect/irrelevant physics ideas; and/or is unrelated to that which is being explained.
…is able to create 2 or more consistent representations of the problem	Two or more representations are constructed according to accepted standards learned in class, and the representations are consistent with each other.	Two or more different representations are present and they are consistent, but there are mistakes or missing elements in the representations.	There are major (key) mistakes/missing elements in representations or different representations are inconsistent with each other.
…is able to choose and apply productive mathematical procedures for solving the problem	Mathematical procedure is productive for solving the problem. Implementation of procedure is free of major conceptual errors.	Productive mathematical procedures are chosen, but implementation reveals misunderstanding about how to implement them.	Mathematical procedures are unproductive/inappropriate and will not lead to a physically reasonable answer to the problem, even if implemented correctly.
…is able to evaluate the reasonableness of final result.	Evaluates reasonableness of the result, correctly applying all the steps of one of the possible evaluation techniques listed below: a. limiting/special case analysis, b. unit analysis, c. physical reasonableness of answer, d. two independent methods, e. cross substitution consistency, f. consistency of representations. A valid conclusion is drawn from the analysis	An appropriate evaluation technique is used, but there are mistakes in the implementation of the technique (wrong units, misunderstanding of how reasonable the numbers are) and/or student neglects to draw a conclusion from their analysis.	There is no evaluation, or evaluation technique is implemented in an incoherent way, and/or an invalid conclusion is drawn, such as concluding the answer is reasonable when evaluation analysis shows it is not reasonable.

A different approach to problem solving

- Think of representing instead of solving first.
- Give students the numerical answer if the problem asks for it, only grade on the reasoning.
- Focus on clarity of their explanations
- Make sure they systematically evaluate their answer.

We have developed a whole library of these new unique AP-style problems, see textbook.

TABLE 1: Novel problems and how they help students develop specific science practices

We have bolded the main practice that is addressed. A list of the novel problems by chapter is given in the *Instructor's Gu*

Type of problem	Description	Practices develop
Ranking tasks (RAT)	Students have to rank the values of a certain physical quantity for different situations, in descending or ascending order.	SP 1, **6**
Choose answer and explanation (CAE)	Students have to choose the correct answer *and* the correct matching explanation (cause-effect or mechanistic) in order to get full credit.	SP **6**
Choose measuring procedure (MEP)	Students have to choose (or propose) the correct (or the best) experimental procedure that will allow them to measure/determine a certain quantity.	SP **4**
Evaluate (reasoning, solution. . .) (EVA)	Students have to critically evaluate the reasoning of some (imaginary) people or evaluate the suggested solution to a problem (given either in words, graphs, diagrams, or as an equation). Students have to recognize productive ideas (even when they are embedded in incorrect answers) and differentiate them from unproductive ideas.	SP 1, 2, **3** and **6**
Make judgment (based on data) (MJU)	Students have to make a judgement about one or more hypotheses, based on data or other forms of evidence that are given in the problem, sometimes taking uncertainties into account.	SP 2, 4, **5**, **6**

Type of problem	Description	Practices developed
Linearization (LIN)	First, students have to write an equation that describes the relevant situation. Then they have to rearrange the equation to obtain a linear function (note that the independent and dependent variables in this function can be any function of the data given in the problem). Students then draw the graph and determine the unknown quantities using the best-fit line. These problems help students combine knowledge of physics, the ability to “read and write” with graphs, the ability to manipulate equations, and the ability to recognize linear dependence in non-standard situations.	SP 1, 2, 5
Multiple possibility and tell all (MPO)	Students have to list as many quantities as they can that can be determined based on data given in the problem, or tell everything they can about the physical attributes of the objects that appear in the text or the relations between them. Normally, students are required to determine the values for only few of the quantities that they identify. These problems allow all students to feel successful.	SP 1, 3 and 7
Jeopardy (JEO)	Students have to convert a representation of a solution into a problem statement. If the solution is given in the form of an equation, they need to understand the meaning of the quantities and their units. Such problems emphasize the value of units.	SP 1, 2 and 3
Design an experiment (or pose a problem) (DEX)	Students have to design an experiment, an experimental procedure, or a device that will allow them to measure/determine certain physical quantities or that would meet specific requirements. Students have to pose a problem that involves certain objects with given characteristics. Often there is an additional requirement that solving the problem should involve the use of a particular physics topic, law, or principle. Students may also need to do an additional literature search.	SP 3 and 4
Problem based on real data (RED)	Students have to solve problems that are based on real data, obtained in real-life situations, often using easily available equipment and/or equipment that is typically used in student labs. The types of problems may be traditional or any of the types presented above. Students need to deal with uncertainties, anomalous data, and assumptions, and to propose meaningful models.	SP 5, 7