

TEACHING PHYSICS THROUGH THE SCIENCE OF LEARNING

Understand
how students
learn

FROM RESEARCH TO CLASSROOM PRACTICE

Apply it
in the Physics
classroom



RESEARCH-BASED

What works in
how we learn.



CLASSROOM-FOCUSED

Practical strategies
you can use.



PHYSICS EXAMPLES

Real contexts.
Real understanding.



LASTING IMPACT

Build confidence
and curiosity.



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UNDERSTANDING HOW WE LEARN



The Brain and Learning

Neurons: The Brain's Communication Cells

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STRATEGIES IN PRACTICE



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Part 1

UNDERSTANDING HOW WE LEARN

The science behind learning



**The Brain
and Learning**



**Neurons:
The Brain's
Communication Cells**



**Neural Pathways
and Learning**

How does the brain build, connect and strengthen knowledge?

THE BRAIN AND LEARNING

The parts of the brain and their role in how we learn

1 PREFRONTAL CORTEX

(Front of the brain)

The “think and plan” center

- Focuses attention
- Makes decisions
- Solves problems
- Plans and monitors our learning strategies



2 PARIETAL LOBE

(Top of the brain)

The “process and understand” area

- Processes sensory information
- Understands numbers, symbols
- Makes sense of relationships



3 OCCIPITAL LOBE

(Back of the brain)

The “visual” center

- Processes what we see
- Supports reading and visual understanding



4 CINGULATE CORTEX

(Middle of the brain)

The “connection and regulation” hub

- Links emotions and thinking
- Helps with motivation
- Supports flexible learning

5 TEMPORAL LOBE

(Side of the brain)

The “memory and sound” center

- Forms memories
- Helps us understand meaning



6 HIPPOCAMPUS

(Deep in the brain)

The “memory maker”

- Creates new memories
- Turns short-term memories into long-term ones
- Helps with spatial learning



7 AMYGDALA

(Deep in the brain)

The “emotion detector”

- Processes emotions
- Attaches importance to experiences
- Helps strengthen memories



8 CEREBELLUM

(Back, lower part of the brain)

The “practice and refine” center

- Refines skills and movements
- Supports timing and coordination
- Helps with learning through practice and repetition



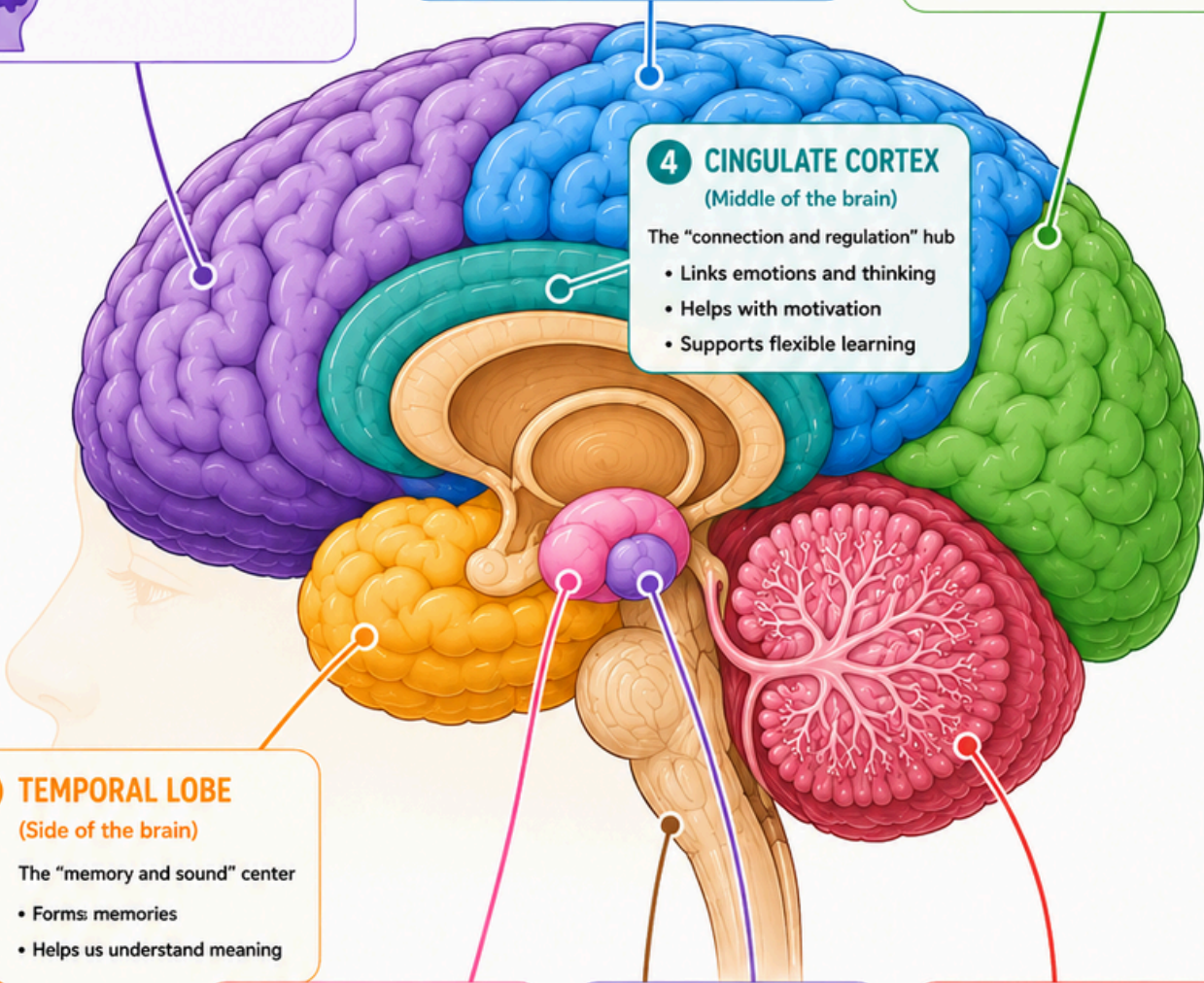
9 BRAINSTEM

(Base of the brain)

The “body manager”



- Controls basic body functions (breathing, heart rate)
- Keeps us alert and awake



NEURONS:

THE BRAIN'S COMMUNICATION CELLS

WHAT IS A NEURON?

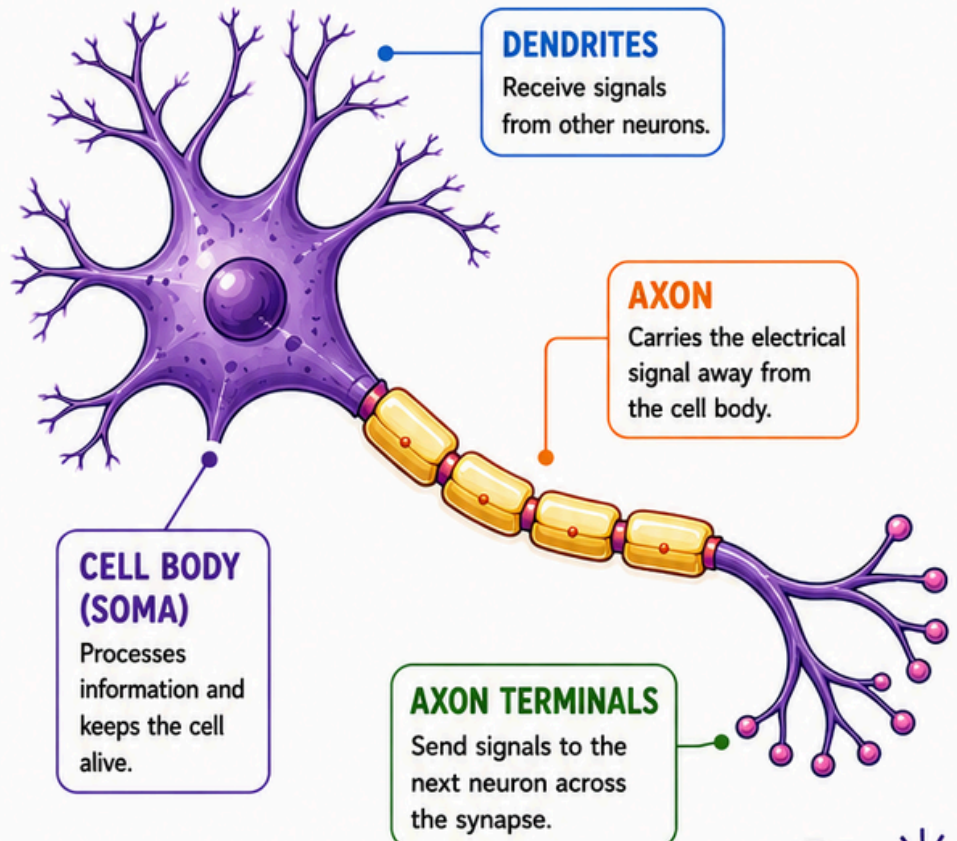
A neuron is a specialised cell that carries information throughout the brain and nervous system.



The human brain contains approximately
86 BILLION NEURONS.



Learning occurs when neurons communicate and form connections with one another.

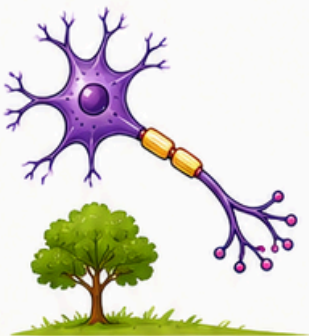


Neurons are the messengers of the brain. They allow us to think, feel, move, remember, and learn.



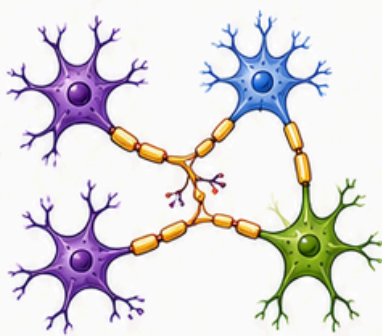
FROM ONE NEURON TO A POWERFUL NETWORK

ONE NEURON



A single neuron is like a tree standing alone.

A FEW NEURONS



Neurons connect with each other to share information.

A NETWORK OF NEURONS



Billions of connected neurons work together to create thoughts, skills, memories, and learning.



KEY IDEA: Neurons are already in your brain from birth. Learning happens when these neurons connect and communicate with each other.



NEURAL PATHWAYS AND LEARNING

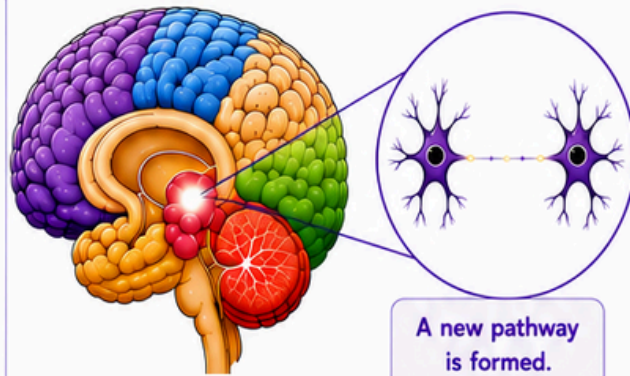
➤ Learning changes the brain. The more we use a pathway, the stronger it becomes. ➤

1 FIRST EXPOSURE

You are introduced to something new.

Example: FORCES

Today we learn what a force is.



LIKE A NEW TRAIL IN THE FOREST



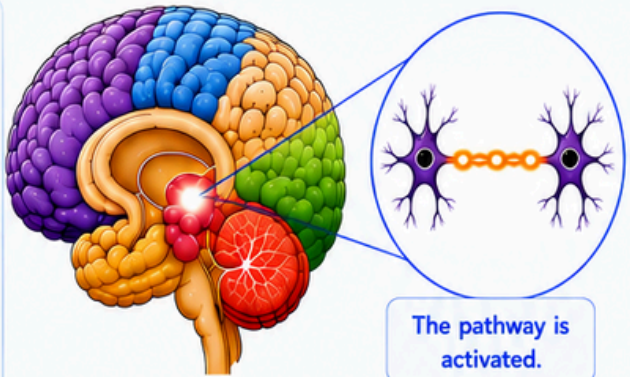
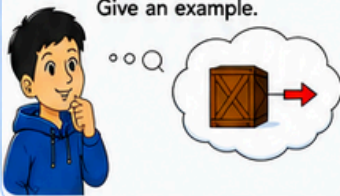
The path exists, but it is faint and easy to lose.

2 RETRIEVAL

You try to recall the information.

Example: FORCES

What is a force?
Give an example.



THE TRAIL IS USED



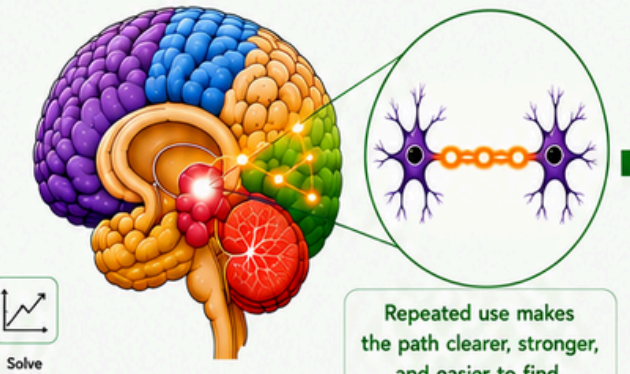
Using the path makes it easier to walk again.

3 REPEATED PRACTICE

You practice again and again over time.

Example: FORCES

Students encounter different types of questions related to the same concept (interleaving).



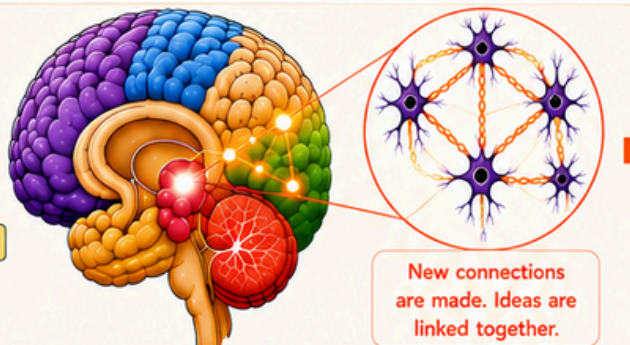
THE TRAIL BECOMES CLEARER



Repeated use makes the path clearer, stronger, and easier to find.

4 CONNECTIONS GROW

You connect the new learning to related concepts (Elaboration).



NEW PATHS CONNECT TO OTHER PATHS



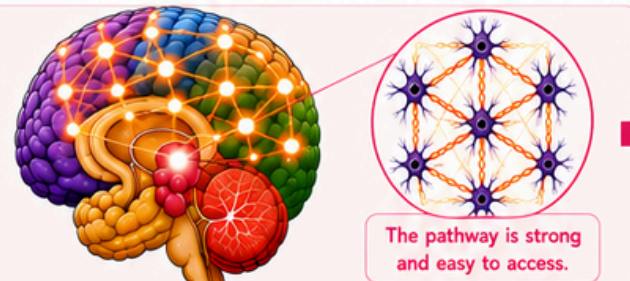
Ideas connect to each other and build a strong network.

5 STRONG NETWORK

The pathway is strong, fast and easy to use.

Example: FORCES

You can apply your knowledge to new and real-world situations.



A WELL-USED HIGHWAY SYSTEM



Information can be recalled quickly and used in many different situations.

Part 2

FROM SCIENCE OF LEARNING TO TEACHING

Turning Research into Classroom Practice

Research



Evidence



Teaching Practice

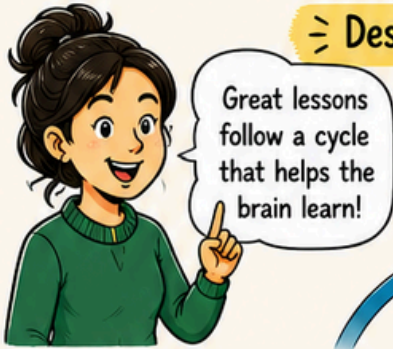


Same
Research.
Real
Impact
in the
Classroom.

Good teaching is informed by how we learn.

STRUCTURING AN EFFECTIVE LESSON

≡ Designing lessons that strengthen neural pathways ≡



1 DO NOW

Activate prior knowledge.



Retrieval practice wakes up the brain and activates existing pathways.

2 QUESTION TIME

Retrieve and connect previous learning.



Retrieval and interleaving strengthen and connect neural pathways.

6 EXIT TICKET

Check understanding and reflect.



Retrieval + feedback consolidate learning and close the loop.



Each step builds, strengthens and connects neural pathways. The more we use them, the stronger learning becomes!

5 INDEPENDENT PRACTICE

Apply your learning on your own.



Deliberate practice strengthens pathways and builds fluency.

4 GUIDED PRACTICE

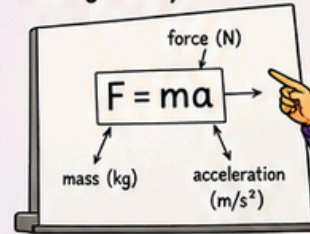
Work through examples together.



Guidance reduces mistakes and builds understanding.

3 EXPLANATION

Introduce new learning clearly.



Clear instruction helps create new neural pathways.

HOW EACH STEP SUPPORTS LEARNING

1 Do Now



Activates existing knowledge.

2 Question Time



Strengthens and connects pathways.

3 Explanation



Creates new neural connections.

4 Guided Practice



Builds confidence and accuracy.

5 Independent Practice



Makes learning stronger and more automatic.

6 Exit Ticket



Consolidates and reflects on learning.



REMEMBER:

We are not just teaching content.
We are building **strong brains** for life.



Retrieve



Connect



Apply



Succeed



STRATEGIES THAT IMPROVE LEARNING

Evidence-based strategies to help students learn deeper and remember longer.

A stronger brain builds brighter futures!

Different strategies work together to help students learn better!

6 CONCRETE EXAMPLES



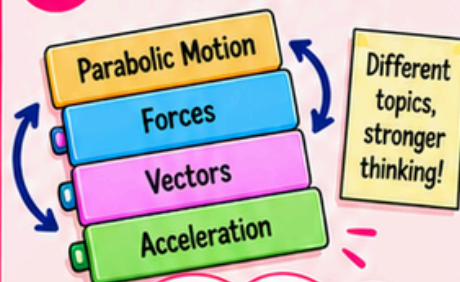
Concrete examples involve using clear, relatable situations to help students understand a concept before moving to abstract formulas.

1 SPACED PRACTICE



Spaced practice is the intentional distribution of learning over time, where previously taught material is revisited after a delay to strengthen long-term memory.

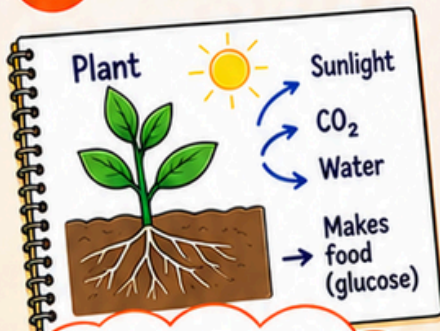
2 INTERLEAVING



Interleaving is the practice of mixing different types of problems or concepts during practice to improve discrimination, strategy selection, and transfer.

EVIDENCE-BASED LEARNING STRATEGIES

5 DUAL CODING



Dual coding involves teaching concepts using both words and visuals together, so students can process information in more than one way.

4 RETRIEVAL PRACTICE



Retrieval practice is the active recall of information from memory without relying on notes, strengthening storage and improving long-term retention.

3 ELABORATION



Elaboration is the process of asking students to explain their reasoning, describe how concepts are connected, and justify why a solution works, in order to deepen understanding and strengthen long-term learning.



When we use these strategies together, our brains make stronger connections and learning becomes deeper and more lasting!



Part 3

STRATEGIES IN PRACTICE

Turning Ideas into Everyday Teaching



Practical strategies for real classrooms.



SPACED PRACTICE: FROM THEORY TO PRACTICE

Building lasting Physics knowledge over time

Revisit
Apply
Connect
Remember

1 WHAT IS SPACED PRACTICE?

Spaced practice means revisiting previously learned material after increasing periods of time, rather than practising everything at once.



Learn → Wait → Revisit → Wait → Revisit → Wait → Apply

2 SEE IT IN ACTION: FORCES

The same knowledge, revisited over time, in different ways!

PREVIOUS LEARNING (Already taught)

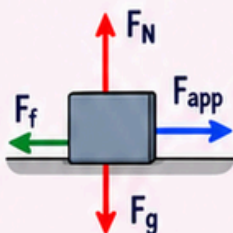
- ✓ Types of forces
- ✓ Free-body diagrams
- ✓ $F_{\text{net}} = ma$
- ✓ Solving force problems



DAY 1 REVISIT

Focus on one aspect.

Draw a free-body diagram for a box being pushed across a horizontal surface.



Recall and practise.

DAY 3 APPLY

Use what you know.

A 5 kg box accelerates at 2 m/s^2 . Calculate the net force acting on the box.

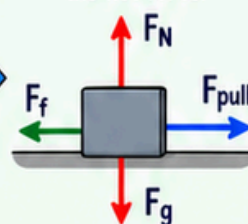


Apply to solve a problem.

DAY 7 REVISIT & CONNECT

Combine ideas.

A box is pulled to the right. Friction acts to the left. Draw the free-body diagram and determine the net force.

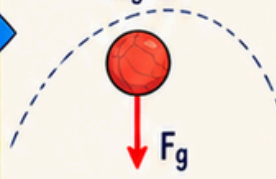


Connect and use together.

DAY 14 USE IN A NEW CONTEXT

Transfer your learning.

A ball is thrown through the air. What force acts on the ball after it leaves the thrower's hand? Draw the free-body diagram.



Apply in a different context.

3 TEACHER TIPS

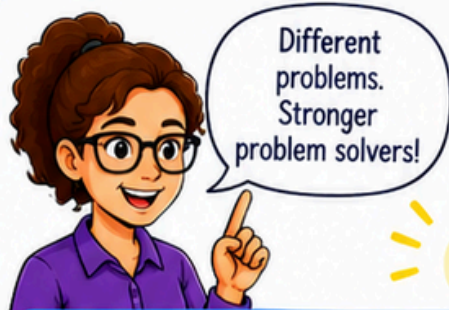
✓ Revisit learning before students forget it completely.

✓ Increase the time between successful reviews.

✓ Revisit ideas in different contexts, not just with the same question.

Same ideas
+ more time =
stronger learning!





INTERLEAVING: FROM THEORY TO PRACTICE

Learning to choose the right Physics approach

Different concepts.
Same context.
Deeper understanding!

1 WHAT IS INTERLEAVING?

Interleaving means mixing different types of problems or related concepts during practice, rather than practising one type repeatedly before moving to another.

Blocked practice (one topic at a time)

Forces Forces Forces Forces

- ❌ Feels easier in the short term
- ❌ Students often use the same method without thinking

Interleaved practice (mixed and meaningful)

Forces Vectors Circular motion Momentum

- ✅ Students must identify what Physics applies
- ✅ Improves long-term learning and transfer
- ✅ Builds flexible problem-solving skills

2 SEE IT IN ACTION: A CAR JOURNEY

One context. Different Physics ideas.
Students decide what knowledge to use.

A. CHANGING DIRECTION



The car travels around a sharp bend at a constant speed of 12 m s^{-1} .

What is the direction of the acceleration at this point?

B. CALCULATIONS & CAUSE

The radius of the bend is 25 m and the car travels at 12 m s^{-1} .

Calculate the size of the acceleration.

Explain what causes this acceleration.

Physics ideas:
centripetal acceleration,
net force, circular motion

C. EXTERNAL FACTORS

State TWO external factors that could change the motion of the car as it travels around the corner, and explain how these factors would affect the motion.



Physics ideas:
friction, road conditions,
speed, radius, centripetal force

D. COLLISION & SAFETY

The car has a crumple zone. A collision increases the time of impact from 0.2 s to 0.8 s. The mass of the car and occupants is 1600 kg.

Use Physics principles and calculation(s) to explain how a crumple zone can make the car safer for the occupants during a collision.

Physics ideas:
impulse, momentum,
force, impact time, safety

3 TEACHER TIPS

- ✅ Choose meaningful contexts that connect the concepts.

This helps students see how ideas link together.

- ✅ Consider students' prior knowledge.

If understanding is still developing, too much variety can overload working memory.

- ✅ Ask students to identify the Physics before solving.

Focus on when and how to use each idea, not just the calculation.

Interleaving helps students learn not only **HOW** to solve a problem, but **WHEN** to use each strategy.



RELATED IDEAS + PURPOSEFUL MIXING = FLEXIBLE LEARNING

Better Physics Learners!



Why?
How?
So what?

ELABORATION: FROM THEORY TO PRACTICE

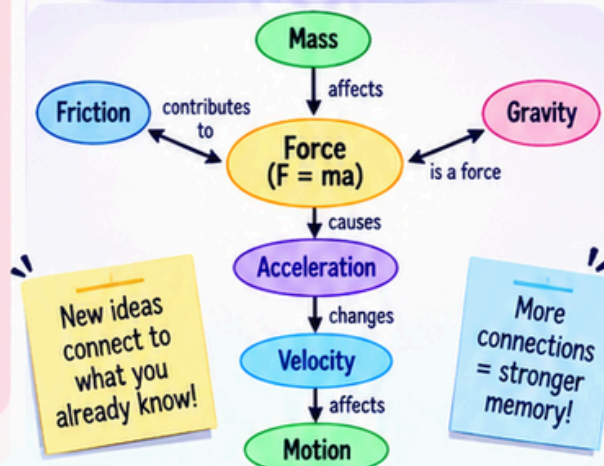
Making meaningful connections to deepen
Physics understanding

Explain.
Connect.
Justify.
Remember
more!

1 WHAT IS ELABORATION?

Elaboration is the process of asking students to **explain** their reasoning, make meaningful **connections** between new and prior knowledge, and **justify** why ideas or solutions work, in order to deepen understanding and strengthen long-term learning.

Elaboration builds a network of ideas



It's more than a longer answer!



Not just more detail

- Listing facts without explaining
- Repeating information
- Describing surface features (e.g., what something looks like)



Meaningful elaboration

- Explaining how and why
- Connecting ideas
- Using prior knowledge
- Justifying your reasoning
- Thinking more deeply about the concept

2 ELABORATION IN ACTION: FOUR PRACTICAL APPROACHES

A. EXPLAIN YOUR THINKING

Explain how and why.

Why did you use $F = ma$ here? Explain your reasoning.



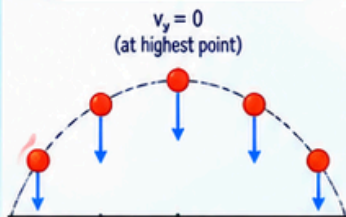
The forces are unbalanced, so there is a net force. A net force causes acceleration, so I can use $F = ma$.

Encourage students to explain each step, not just give the answer.

B. ASK WHY & HOW

Use questions that require deeper thinking.

Why does a projectile accelerate even at its highest point?

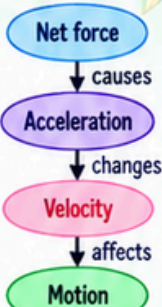


Follow up: What force is acting? Which direction is the acceleration? What happens to the velocity? How does this affect the motion?

C. MAKE CONNECTIONS

Link new ideas to what you already know.

How are these ideas connected?



You can also use a concept map to make and explain these connections.

Connect to prior knowledge, other Physics ideas, or real-world experiences.

D. COMPARE & CONTRAST

Identify similarities and differences, and explain why they matter.

How are velocity and acceleration similar and different?

Velocity

- Tells us how fast and in what direction
- Has units m s^{-1}
- Describes motion

Acceleration

- Tells us how velocity changes
- Has units m s^{-2}
- Caused by a net force

Comparing ideas helps you see what is the same, what is different, and how the concepts relate.

3 TEACHER TIPS



Give students time to think and explain.

Even brief activities (like a one-minute "Think-Pair-Share") can spark elaboration.



Match the strategy to the learner.

Use scaffolded explanations for learners with less prior knowledge, and more open-ended questions for those with stronger understanding.



Check for accuracy.

Students can elaborate incorrectly, especially when their prior knowledge is limited. Provide feedback.



Make it part of everyday teaching.

Brief "why" or "how" questions, analogies, and real-world connections can be woven into almost any activity.

Deeper thinking today. Stronger understanding tomorrow!



MEANINGFUL CONNECTIONS = DEEPER UNDERSTANDING = BETTER PHYSICS LEARNERS!

Think deeper. Go further!



RETRIEVAL PRACTICE: FROM THEORY TO PRACTICE

Bringing Physics knowledge back from memory

Use it
Recall it
Build it
for the future!

1 WHAT IS RETRIEVAL PRACTICE?

Retrieval practice is the **active recall** of previously learned information from memory without first looking at notes or worked examples. Retrieving knowledge strengthens access to it, making it easier to recall and use again.



The more you
retrieve,
the stronger
it gets!

2 SEE IT IN ACTION: FOUR PRACTICAL APPROACHES

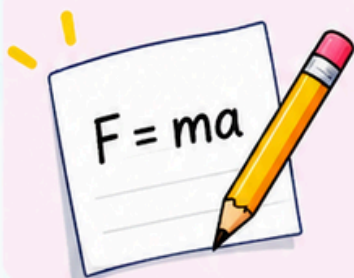
Retrieval can take many forms. Here are some examples:

RECALL & ANSWER

Bring facts, concepts, relationships or formulas back from memory.

Example:

- What is Newton's Second Law?
- What forces act on a projectile?

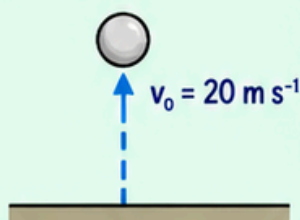


SOLVE & APPLY

Retrieve knowledge and use it to solve a problem or apply it to a new context.

Example:

A ball is launched vertically upwards with an initial velocity of 20 m s^{-1} . Calculate the maximum height.

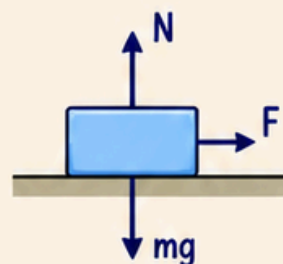


DRAW & REPRESENT

Retrieve knowledge by creating a diagram, graph or other representation from memory.

Example:

Draw a free-body diagram for a box on a horizontal surface.



EXPLAIN FROM MEMORY

Retrieve an idea and explain it in your own words without checking your notes.

Example:

Explain why a projectile accelerates even at its maximum height.



3 TEACHER TIPS

✓ Keep it low-stakes.

The goal is learning, not grading.



✓ Give time to think.

Allow students time to retrieve before revealing or discussing the answer.



✓ Retrieve before looking.

Encourage students to attempt the task without notes or worked examples first.



✓ Provide feedback.

Students need to identify and correct errors after retrieval.



✓ Adjust the challenge.

Use prompts or cues when knowledge is still developing, then gradually remove support as understanding grows.



More retrieval. Stronger learning. Brighter futures.



See it
and say it!
It helps
you remember!

DUAL CODING: FROM THEORY TO PRACTICE

Combining words and visuals to support understanding

Same
information.
Two ways.
Stronger
learning!

1 WHAT IS DUAL CODING?

Dual coding is the practice of **combining words with meaningful visuals** to represent the same idea. Using verbal and visual representations together can help students understand, organise, and remember information more effectively.

WORDS

Say it
Explain it
Read it



VISUALS

See it
Diagram it
Show it

Two ways to remember
A stronger understanding

2 SEE IT IN ACTION: FOUR PRACTICAL APPROACHES

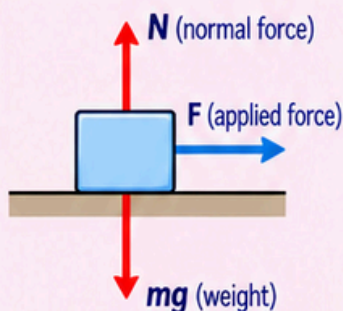
Here are some ways to use dual coding in Physics:

WORDS + DIAGRAMS

Connect an explanation to a visual representation.

Example:

Explain the forces acting on a box while showing a free-body diagram.

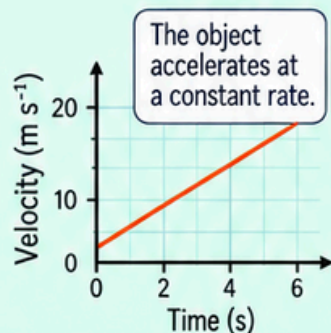


WORDS + GRAPHS

Connect what is happening physically with what the graph represents.

Example:

Describe an object's motion while interpreting a velocity-time graph.

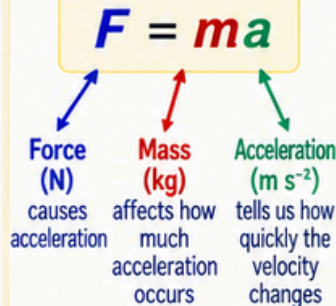


WORDS + EQUATIONS

Connect mathematical symbols with their physical meaning.

Example:

Explain Newton's second law and what each variable represents.

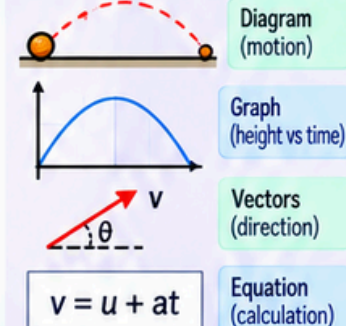


MULTIPLE REPRESENTATIONS

Show the same idea in different but connected forms.

Example:

Represent projectile motion using a diagram, graph, vector and equation.



3 TEACHER TIPS



Make visuals meaningful.

Every diagram should help explain the concept.



Connect words and visuals.

Explicitly show students how the two representations relate.



Keep it simple.

Remove unnecessary details that may distract attention.



Build representations gradually.

Draw or reveal diagrams as you explain rather than presenting everything at once.



Teach students to interpret visuals.

Don't assume they automatically know how to read a graph, diagram or model.



Don't just show it. Help students connect what they SEE with what it MEANS.



I can see it in real life!

CONCRETE EXAMPLES: FROM THEORY TO PRACTICE

Making abstract Physics ideas easier to understand

Real situations.
Real meaning.
Stronger learning!

1 WHAT ARE CONCRETE EXAMPLES?

Concrete examples use **specific, familiar situations** to help students understand an abstract concept. By connecting an idea to something students can see, experience, or imagine, the concept becomes easier to understand and remember.



A car suddenly stops



The passenger moves forward

Physics concept:

Inertia
(Newton's First Law)

Concrete experience → Physics concept → Abstract understanding

2 SEE IT IN ACTION: FOUR PRACTICAL APPROACHES

REAL-LIFE SITUATIONS

Connect Physics to familiar experiences.

Example:

Why do passengers move forward when a car suddenly brakes?



Inertia
(Newton's First Law)

DEMONSTRATIONS

Let students observe the concept happening.

Example:

Drop a ball and observe how its velocity changes as it falls.



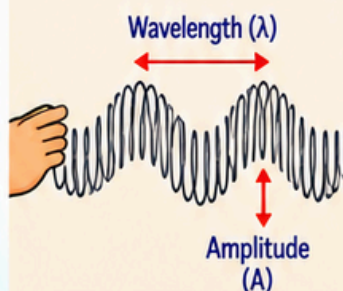
Falling objects accelerate downwards at 9.8 m s^{-2} (gravitational acceleration).

PHYSICAL MODELS

Use simple objects to make an abstract relationship visible.

Example:

Use a rope or slinky to demonstrate wavelength, amplitude and wave behaviour.



CONTEXTUAL PROBLEMS

Put equations and calculations into meaningful situations.

Example:

A cyclist increases speed from 4 m s^{-1} to 10 m s^{-1} in 3 s. Calculate the acceleration.



$$a = \frac{v - u}{t}$$

3 TEACHER TIPS



Start with something students can understand.

Connect new ideas to familiar situations or experiences.



Make the Physics explicit.

Don't assume students will automatically see the scientific principle in the example.



Connect concrete to abstract.

Move deliberately from the situation to the concept, then to the diagram or equation.



$$F = ma$$



Use more than one example.

One example can cause students to associate a concept too narrowly with a particular situation.



Vary the context.

Help students recognise the same Physics principle in different situations.



Start with what students can see. Connect it to what Physics helps them understand.