

# A Teacher's Guide to Hidden Momentum Misconceptions

Why marks can hide shaky understanding — and what class-level misconception heatmaps reveal across impulse, conservation, and collisions

For physics teachers and department leads

*A field guide to persistent misconceptions in momentum — from what an impulse actually delivers, through conservation conditions, recoil, and signed vector momentum, to elastic and inelastic collisions and the bounce-versus-stick comparison — that survive conventional teaching and hide behind good test scores. Includes example diagnostic output and details on how to run a free classroom pilot using the Momentum (Linear) diagnostic.*

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**FundaFirst HS · A ConceptArc Education initiative**

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## Why Marks Can Hide Shaky Understanding

A student scores 75% on a momentum test. They can compute  $p = mv$ , balance a conservation equation, and produce correct answers on familiar problem types. Their mark says they understand momentum.

But ask them a different kind of question — one that tests the concept behind the formula rather than the formula itself — and the picture changes. Ask them what a 4 N s impulse does to a cart that already carries 6 kg m/s. Ask them how fast a rifle recoils when its bullet is 200 times lighter. Ask them where the momentum goes when two equal clay lumps collide head-on and stop dead. Ask them whether a cart that couples to an identical cart at rest keeps its incoming speed.

What emerges is not a knowledge gap. It is something more persistent: a stable but incorrect mental model that produces right answers on routine problems and wrong answers on conceptual ones. The student does not know they hold it. The teacher cannot see it in a percentage score. And unless it is specifically surfaced, it survives instruction, revision, and even strong exam results.

Physics education researchers have documented this pattern extensively. Arons' treatment of introductory mechanics showed that students who could manipulate the impulse-momentum theorem often could not say what an impulse actually changes, and prescribed the controlled comparisons — same force, same time, different masses — that separate impulse from velocity change. Lawson and McDermott's 1987 study of the impulse-momentum theorem found students predicting that equal pushes produce equal speeds regardless of mass — compensating one quantity with another instead of keeping them apart. Knight's instructor-side work documents the same families of error around collisions: momentum read as speed, conservation read as "nothing changes", sticking read as momentum destroyed. Chabay and Sherwood's systems-first treatment shows how often these errors trace back to a system boundary that was never chosen. Across decades of research, the finding is consistent: students can pass tests while holding the same misconceptions they entered with.

The pattern is consistent: conventional assessment rewards procedural fluency but is largely blind to conceptual coherence. A class can look competent on paper while carrying systematic misconceptions that will resurface under unfamiliar conditions — in later topics, in university courses, or on exam questions that probe understanding rather than recall.

The diagnostic layer most physics departments are missing is not a harder test. It is a different kind of test — one designed to surface the specific misconception a student holds, not just whether their answer is right or wrong. The **Momentum (Linear)** diagnostic targets this layer: 24 questions across 9 misconception bands — impulse-as-change, conservation and the system boundary, conditions for conservation, reciprocity, signed vector momentum, two-dimensional conservation, and the collision cluster (what is conserved; what momentum alone can determine; bounce versus stick) — plus a cross-cutting compensation lens. It is designed for upper-secondary physics and introductory university mechanics.

# Five Momentum Misconceptions Worth Tracking

*These are five persistent and instructionally important conceptual errors in momentum, documented across decades of published research. Each survives conventional teaching and produces correct answers often enough to stay hidden. The tag on each trap is the misconception band that tracks it; the fifth is the instrument's cross-cutting compensation lens.*

## Trap 1: The Push Becomes the Momentum I1

A cart already carries 6 kg m/s of momentum and receives a 4 N s impulse along its motion. Asked for the momentum afterward, many students answer 4 kg m/s – the impulse has become the new momentum, and the starting 6 has been dropped. But an impulse delivers a *change* in momentum: the cart ends at  $6 + 4 = 10$  kg m/s. Reading impulse as a state rather than a transfer is the foundational momentum misconception – it sits upstream of everything that follows.

Ref: Arons, 1997; Knight, 2002

## Trap 2: Always Conserved – and Its Mirror Image CS2

A car brakes to a stop. Many students, taking the car alone as the system, say its momentum is conserved – “momentum is always conserved” – missing the large external impulse from road friction. Show the same students two baseballs colliding in mid-air and the error flips: “gravity acts on them, so momentum cannot be conserved” – missing that gravity's impulse over the brief contact is negligible. Both errors skip the actual condition: for a chosen system over a stated interval, total momentum is conserved when the net external impulse is negligible.

Ref: Arons, 1997; Chabay & Sherwood, *Matter & Interactions*

## Trap 3: The Wall-Bounce Trap, Round Two V1

A 0.15 kg ball hits a wall at 20 m/s and rebounds at 20 m/s. Asked for the magnitude of its momentum change, many students answer zero – the speed is unchanged, so nothing changed. But momentum is a signed vector: from +3 kg m/s to -3 kg m/s is a change of magnitude 6 kg m/s – about 2 m v. If your class met this trap in kinematics as a velocity change, it returns here as a momentum change – still missed.

Ref: Knight, 2002; Arons, 1997

## Trap 4: Conserved Momentum, Unchanged Speed COL1

A 1 kg cart at 6 m/s couples to an identical cart at rest. Many students keep the speed at 6 m/s – “because momentum is conserved.” But conserving the momentum, 6 kg m/s, now spread over 2 kg, gives 3 m/s; keeping the speed would *double* the momentum. This is the headline confusion of the collision cluster: momentum read as speed. Its companions – “sticking destroys momentum” and “kinetic energy is always conserved” – round out the cluster.

Ref: Knight, 2002; Moore, *Six Ideas That Shaped Physics, Unit C*

## Trap 5: Same Push, So Same Speed L-COMP

The same constant force acts for the same time on a cart of mass  $m$  and a cart of mass  $2m$ , both starting from rest. Equal force for equal time means equal impulse and equal momentum change. What differs is the velocity change:  $\Delta v = \Delta p / m$ , so the lighter cart ends twice as fast. Lawson and McDermott documented students collapsing these three quantities into one – expecting the bigger mass to take a bigger impulse, or equal pushes to produce equal speeds. The diagnostic tracks this as a cross-cutting lens that fires only when both faces of the error are selected together.

Ref: Lawson & McDermott, 1987

# Example Heatmap Using Simulated Data

## Illustrative data (n = 25)

Simulated dataset shown to illustrate the heatmap output format and the kinds of misconception patterns a diagnostic can reveal. Informed by documented misconception patterns in physics education research. Not drawn from a classroom or pilot cohort.

Mean: 14.2/24 (59%) Median: 14/24 Range: 6–23

This heatmap shows results from the **Momentum (Linear)** diagnostic (24 questions across 9 misconception bands, administered in band-grouped order, plus the cross-cutting L-COMP compensation lens). Columns group students by total score.

Q#	Concept Tested	Overall	A (20–24)	B (16–19)	C (11–15)	D (0–10)	Band
Q01	Impulse changes momentum, not sets it	96%	100%	100%	100%	83%	I1
Q02	Same force, same time: equal Delta-p, unequal speed	56%	67%	75%	38%	50%	I1
Q03	Forces on a ball in free flight (impetus probe)	68%	100%	100%	50%	33%	I1
Q04	Impulse as the area under a force-time graph	52%	100%	62%	62%	0%	I1
Q05	Bounce: momentum transferred, not destroyed	72%	100%	88%	25%	100%	CS1
Q06	Recoil from rest	76%	100%	88%	75%	50%	CS1
Q07	Internal spring cannot move the centre of mass	56%	100%	62%	25%	67%	CS1
Q08	Same-speed reversal: a change of about 2 m v	56%	100%	88%	25%	33%	V1
Q09	Momentum is a signed vector	76%	100%	100%	75%	33%	V1
Q10	Sign of Delta-p versus sign of Delta-KE	60%	67%	50%	88%	33%	V1
Q11	What is conserved in a perfectly inelastic collision	48%	67%	75%	38%	17%	COL1
Q12	Sticking does not destroy momentum	64%	100%	75%	88%	0%	COL1
Q13	Conserved momentum is not conserved speed	44%	100%	62%	12%	33%	COL1
Q14	Inelastic: momentum yes, kinetic energy no	56%	100%	88%	50%	0%	COL1
Q15	Cannon: equal and opposite forces, unequal speed	48%	100%	62%	25%	33%	N3
Q16	Internal forces cannot self-propel a system	80%	100%	100%	75%	50%	N3
Q17	Car braking: a non-isolated system	60%	100%	62%	62%	33%	CS2
Q18	Mid-air collision: force versus impulse	44%	100%	38%	62%	0%	CS2
Q19	Two-dimensional collision: conserve components	60%	100%	50%	75%	33%	V2
Q20	The 90-degree equal-mass elastic result	52%	67%	50%	62%	33%	V2
Q21	Momentum alone does not determine a collision	64%	100%	75%	62%	33%	COL2
Q22	What more is needed: elastic vs partly inelastic	32%	33%	50%	25%	17%	COL2
Q23	Clay versus rubber: which delivers more impulse	52%	67%	75%	25%	50%	COL3
Q24	Stop versus bounce: about m v versus about 2 m v	52%	100%	75%	50%	0%	COL3

% Correct: 0–20% 20–50% 50–70% 70–90% 90–100%

- Q11–Q14 – Band COL1, the collision-cluster keystone.** COL1 reads MAJOR: 13 of 25 submissions (52%) confirm it, with 7 more provisional. The headline item Q13 – the coupling cart whose speed is kept instead of halved – sits at 44% overall and collapses to 12% in Band C. Until momentum and speed are separated, no other collision result can settle.
- Q02 + Q15 – the L-COMP compensation lens.** 3 of 25 submissions (12%) selected both faces of the compensation error together – “the bigger mass takes a bigger momentum change” with “equal forces mean equal speeds” – firing the cross-family lens. The parent bands I1 and N3 each read WATCHLIST: confirmed in only 2 and 1 submissions, but provisional in 11 and 12 – the wide, single-hit spread the status is designed to catch before it consolidates.
- Q19–Q24 – the lower-confidence trio.** V2, COL2, and COL3 all read MAJOR, mostly through the combined confirmed-plus-provisional route (COL2: 1 confirmed but 17 provisional), and each carries the two-item lower-confidence caveat. Read them as directional – which probe fails carries more information than the band score.

Red cells mark the highest-leverage targets. The governing readout is not the raw percentages but the per-submission statuses aggregated to the cohort: every band reads MAJOR, WATCHLIST, MODERATE, or CLEAR, and the two-item bands (V2, COL2, COL3) carry a lower-confidence caveat. The L-COMP lens and the two folded threads – the impetus probe on Q03 (selected by 20% of this cohort) and the turning-angle distractor on Q10 (16%) – are reported as annotations, never as band flags. For classroom pilots, FundaFirst HS generates a class heatmap from your students’ responses and delivers it within 48 hours of completion.

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# What Teachers Receive from a Classroom Pilot

Within 48 hours of your class completing the diagnostic, we deliver a complete misconception analysis to your inbox. Each class that runs the Momentum diagnostic receives its own self-contained set of materials:

## Class-level misconception heatmap

Performance by question and by student performance band (A–D), with each item tagged to its misconception band. Colour-coding shows where understanding breaks down across the class; items are administered and displayed in band-grouped order, so cluster patterns are visible at a glance, and the folded threads (the impetus probe and the turning-angle distractor) appear as annotations.

## Cohort summary

Each band's status — MAJOR, WATCHLIST, MODERATE, or CLEAR — with the L-COMP compensation readout, what the flagged bands mean, and the priority order for remediation. Designed for a head of department or course leader to act on without re-deriving anything from the heatmap.

## Per-band status verdicts

What each status means for your class — from a consolidated misconception that needs structured repair to a wide-but-shallow WATCHLIST pattern worth a single targeted lesson — with the two-item bands explicitly caveated as lower-confidence, directional signals.

## Targeted remediation toolkit

Not generic revision advice. A four-document set — a Mistake Museum of 20 named traps, a Words That Hurt language guide of 17 entries, a 22-item Remediation Worksheet in 10 assignable sections, and a Teacher Answer Key — mapped to the specific misconception bands your class triggered. Diagnosis and remediation in one package, so you do not need to build anything yourself.

*Everything is teacher-readable, designed for immediate classroom use, and delivered as part of the free pilot. Six PDFs per diagnostic: heatmap, cohort summary, Mistake Museum, Words That Hurt, Worksheet, Teacher Answer Key. Nothing else is required from you between completion and delivery.*

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# How to Run a Pilot

## Step 1. Request a pilot.

Visit [fundafirsths.com](https://fundafirsths.com) or email [admin@fundafirsths.com](mailto:admin@fundafirsths.com). If your class is partway through — or just past — a momentum unit and you want to find out where understanding has actually settled, this diagnostic is the right instrument; if you are earlier in the mechanics sequence, we will recommend the right starting point.

## Step 2. We send the diagnostic link.

You receive a diagnostic link and a short setup message you can paste directly to your students. No student accounts, no logins, no software installs needed. Student names are optional; schools may use anonymized student IDs instead.

## Step 3. Students complete the diagnostic.

Share the link with your class. The Momentum diagnostic takes about 26–30 minutes (24 questions) and can be completed in class or as a short take-home task. No calculator is required.

## Step 4. You receive the full analysis.

We generate your class heatmap, cohort summary, status verdicts, and remediation toolkit, and email everything to you — typically within 48 hours of class completion.

There is no charge for the classroom pilot. No payment information is collected. No subscription is created. No ongoing commitment.

The Momentum (Linear) diagnostic covers the momentum content taught in IB DP Physics (A.2 Forces and momentum), AP Physics 1 and AP Physics C (impulse, momentum conservation, collisions), A-Level & AS Physics (Mechanics — momentum and impulse), and IGCSE Physics extension. **24 questions across 9 misconception bands** — impulse I1; conservation CS1 and CS2; reciprocity N3; vector and two-dimensional momentum V1 and V2; collisions COL1, COL2, and COL3 — plus the cross-cutting L-COMP compensation lens and two folded threads tracked as heatmap annotations.

*Motion (two diagnostics), Newton's Laws (six modules), and Energy diagnostics are also available — together with Momentum they cover the kinematics–forces–momentum–energy arc.*

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## Request a classroom pilot

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