

A Teacher's Guide to Hidden Motion Misconceptions

Why marks can hide shaky understanding — and what class-level misconception heatmaps reveal across kinematics

For physics teachers and department leads

A field guide to persistent misconceptions in kinematics — from the meaning of velocity and average speed through to acceleration, turning points, and motion diagrams — 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 either or both of the two motion diagnostics, Motion Foundations and Motion Change.

FundaFirst HS • A ConceptArc Education initiative

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Why Marks Can Hide Shaky Understanding

A student scores 75% on a kinematics test. They can plug numbers into equations, match graph shapes to descriptions, and produce correct answers on familiar problem types. Their mark says they understand motion.

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 “20 metres per second” actually means as a physical process. Ask them to find the average speed on a round trip where the two legs take different amounts of time. Ask them whether a vertical line on a position–time graph represents real motion. Ask them about the acceleration of a ball thrown straight up at its highest point, where its velocity is momentarily zero.

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’ detailed studies of introductory physics showed that students who could manipulate equations often could not explain the operational meaning of the quantities in those equations. Trowbridge and McDermott demonstrated that position–velocity confusion persisted even after targeted instruction, and that students routinely answer that two objects with the same final speed must have the same acceleration. Beichner’s work on graph interpretation showed that students could reproduce graph shapes without understanding what the graphs represented physically. Knight’s motion-diagram research showed that students consistently locate acceleration along the velocity vector rather than along the change in velocity. 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.

What this calls for 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. **Motion Foundations** targets the foundational layer (position, displacement, average and instantaneous velocity, x - t graph reading); **Motion Change** targets the second layer (acceleration, signed components, turning points, motion diagrams, and the position–velocity–acceleration graph chain). Either can be run on its own; together they cover the core conceptual kinematics surface commonly taught at upper-secondary level and in introductory university mechanics.

Five Motion Misconceptions Worth Tracking

These are five persistent and instructionally important conceptual errors in kinematics, documented across decades of published research. Each one survives conventional teaching and produces correct answers often enough to stay hidden. The first two are surfaced primarily by Motion Foundations; the last three by Motion Change.

Trap 1: The Hill Illusion Foundations

Students look at a position–time graph where the curve is high but flat and conclude the object is moving fast. They are reading the graph as a picture of the path — higher means faster — instead of recognising that a flat section (zero slope) means the object is at rest. This confusion between position and velocity on graphs is one of the most robustly replicated findings in physics education research.

Trap 2: The Arithmetic Mean Trap Foundations

A student drives from A to B at 40 km/h and returns at 60 km/h. Asked for the average speed, most students answer 50 km/h — the arithmetic mean of the two speeds. The correct answer is 48 km/h, because average speed is total distance divided by total time, and the slower leg takes longer. This error is remarkably stubborn and reveals that students treat “average” as a property of the speeds themselves rather than a derived ratio.

Trap 3: The Stopped-Momentarily Trap Change

Throw a ball straight up. At the highest point of its vertical flight, its velocity is momentarily zero. Ask students for the acceleration at that instant and many will answer zero — reasoning that if the ball is not moving, nothing is happening. But gravity has not switched off; the acceleration is g , downward, throughout the flight. This is one of the most heavily documented misconceptions in kinematics: students fuse $v = 0$ with $a = 0$, treating “at rest momentarily” as if it meant “at rest in the Newtonian sense”.

Trap 4: The Wall-Bounce Trap Change

A ball moves at 5 m/s east, hits a wall, and rebounds at 5 m/s west. Ask students for the change in velocity during the impact. Many answer zero — the speed is unchanged, after all. But velocity is a vector; the change in velocity is 10 m/s westward, not zero. They are computing the change in speed ($\Delta|v| = 0$) and reporting it as the magnitude of the velocity change ($|\Delta v| = 10$ m/s). The two are different quantities, and the difference is exactly what acceleration measures.

Trap 5: The Trowbridge–McDermott Comparison Change

Two cars start from rest and reach the same final speed after travelling along the same straight road. Car A takes 10 seconds; Car B takes 5 seconds. Many students conclude the two cars had the same acceleration, because the final speeds match. The correct answer is that Car B's acceleration was twice as large, because the same change in velocity occurred in half the time. This comparison error — documented by Trowbridge and McDermott in their canonical 1980–81 studies — persists even after targeted instruction on $a = \Delta v / \Delta t$.

Example Heatmap Using Simulated Data

Illustrative data (n = 24)

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: 16/30 (53%) Median: 16/30 Range: 5–29

This heatmap shows results from the **Motion Change** diagnostic (30 questions across 10 misconception bands M1–M10 plus a Newton-bridge item T1). The Motion Foundations heatmap follows the same format, with 24 questions across 8 bands E1–E8.

Q#	Concept Tested	Overall	A (25–30)	B (19–24)	C (13–18)	D (0–12)	Band
Q01	Speed vs signed component (bounce)	54%	100%	71%	50%	20%	M1
Q02	Direction needs time-ordering	50%	100%	71%	38%	20%	M1
Q08	Bare-letter v ambiguity	46%	100%	57%	38%	20%	M1
Q03	Wall bounce: $\Delta v $ vs $ \Delta v $	42%	75%	57%	38%	0%	M2
Q07	Negative a_x but speeding up	46%	100%	71%	25%	20%	M2
Q10	Acceleration direction from Δv	38%	75%	57%	25%	0%	M2
Q04	Horizontal turning point: $v_x=0$, a_x not zero	33%	75%	43%	25%	0%	M3
Q05	Vertical-throw apex: a downward	29%	50%	43%	25%	0%	M3
Q21	Sign of a at $v=0$	38%	100%	43%	25%	0%	M3
Q06	Speeding up in the $-x$ direction	50%	100%	71%	38%	20%	M4
Q22	Sign triple to scenario	46%	75%	57%	50%	0%	M4
Q09	Same final speed, shorter time	38%	75%	57%	25%	0%	M5
Q20	x - t curvature comparison	42%	100%	43%	38%	20%	M5
Q11	Linear-deceleration motion diagram	58%	100%	86%	50%	20%	M6
Q12	Reversed-arrow error	50%	100%	71%	38%	20%	M6
Q13	Projectile apex: a still down	54%	100%	71%	50%	20%	M6
Q14	S-curve at constant speed	58%	100%	86%	38%	40%	M6
Q15	Crossing x - t graphs	50%	100%	57%	50%	20%	M7
Q16	x - t parabola $\rightarrow$ v - t line	54%	100%	71%	50%	20%	M7
Q17	a - t to v - t / x - t chain	50%	75%	71%	50%	0%	M7
Q18	a - t to v - t with $v(0)$ not zero	46%	75%	71%	38%	0%	M7
Q19	v - t line $\rightarrow$ x - t parabola	54%	100%	71%	50%	20%	M7
Q27	Variable a : const- a formula invalid	42%	75%	57%	38%	0%	M8
Q28	Free-fall sign discipline	38%	75%	57%	25%	0%	M8
Q23	Projectile component independence	50%	100%	71%	38%	20%	M9
Q24	Δv in circular constant-speed motion	46%	75%	71%	38%	0%	M9
Q26	Perpendicular a (east + south fan)	54%	100%	71%	50%	20%	M9
Q29	a - t graph $\rightarrow$ physical scenario	67%	100%	86%	63%	40%	M10
Q30	"Final speed" problem boundary	71%	100%	86%	75%	40%	M10
Q25	Trampoline at maximum sag	38%	75%	43%	38%	0%	T1 Bridge

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

- Q04, Q05, Q21 – Band M3.** The stopped-momentarily misconception is the deepest weakness in this cohort: 25–43% in Bands B and C, 0% in Band D. Even Band A misses Q05. Students fuse $v = 0$ with $a = 0$ across the whole class.
- Q03, Q10 – Band M2.** Band D scores 0% on both M2 items. The $\Delta|v|$ vs $|\Delta v|$ distinction (Q03) and the Δv -direction reasoning (Q10) are absent in the lowest-scoring quartile and fragile in Band C.
- Q09, Q20 – Band M5.** The acceleration-comparison error cuts across all bands. Even Band B is at 43–57%; Band C is below 40%. "Same final speed = same acceleration" (Q09) and the curvature-comparison miss on x - t graphs (Q20) are broadly distributed.

Red cells mark the highest-leverage targets. Compare the Overall column against Band C/D to find misconceptions hiding behind class averages. The T1 row (separated above) is a Newton-bridge item that surfaces at-rest-instant reasoning carrying over from kinematics into force diagrams; it is scored individually but never independently flagged in the band-level cohort summary. For classroom pilots, FundaFirst HS generates a class heatmap from your students' responses and delivers it within 48 hours of completion.

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 diagnostic you run — Motion Foundations, Motion Change, or both — produces 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 cluster. Colour-coding helps show more clearly where understanding breaks down across the class. Items are grouped by misconception band so cluster patterns become visible at a glance.

One-page cohort summary

Which misconception clusters hit hardest, what they mean, how your class distributes across performance bands, and what the overall profile tells you about where your students are. Designed for a head of department or course leader to act on without needing to re-derive anything from the heatmap.

Band-level profiles

What each performance band means for your students — from “ready to extend” to “needs foundational rebuilding” — with specific guidance on what each group needs next. The four bands are deliberately coarse so the next instructional step is unambiguous for each group.

Targeted remediation toolkit

Not generic revision advice. A four-document set — a Mistake Museum, a Words That Hurt language guide, a Remediation Worksheet, and a Teacher Answer Key — mapped to the specific misconceptions 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.

How to Run a Pilot

Step 1. Request a pilot.

Visit fundafirsths.com or email admin@fundafirsths.com. Tell us which diagnostic matches your current unit — Motion Foundations, Motion Change, or both. If you are partway through a kinematics block and want to find out where understanding has actually settled, 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. Motion Foundations takes about 25 minutes (24 questions); Motion Change takes about 30–35 minutes (30 questions). Either can be completed in class or as a short take-home task.

Step 4. You receive the full analysis.

We generate your class heatmap, cohort summary, band profiles, 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 two motion diagnostics together cover core kinematics content taught in IB DP Physics (A.1 Kinematics), AP Physics 1 (Unit 1 Kinematics), A-Level & AS Physics (Mechanics), and GCSE / IGCSE Physics. **Motion Foundations** covers position, displacement, distance, average and instantaneous velocity, and x–t graph reading (8 misconception bands, 24 questions). **Motion Change** covers acceleration, signed components, turning points, motion diagrams, the position–velocity–acceleration graph chain, kinematic equations, and limited 2D motion (10 misconception bands plus 1 Newton-bridge item, 30 questions).

A six-module Newton's Laws diagnostic is also available, covering forces, free-body diagrams, weight and gravity, and Newton's third law.

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