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Alternative conceptions in Galilean relativity: distance, time, energy and laws

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This work, a sequel to Panse *et al.* (1994), focuses on how students deal with transformations of time, distance, velocity and energy between frames of reference. Qualitative analysis of a free-response test and of clinical interviews is combined with quantitative analysis of data on a forced-option test. The results indicate that students frequently violate the 'obvious' invariance of time interval between fixed events, and take distance invariance for granted even for non-simultaneous events. They tend to invoke a 'physical drag' picture instead of prescriptive transformation theory to view changes of quantities (especially velocity) from one frame to another. The diffuse meaning of 'laws' shows up variously. Laws are equated to trajectories; and conservation of energy is taken to mean its invariance, for observers, in relative motion.

Introduction

This work is part of a study to investigate students' notions in the domain of Galilean relativity. The first part (Panse *et al.* 1994) dealt with conceptions of 'frames of reference'. Employing the methodology explained therein, this work probes how students handle situations involving transformations of basic kinematic quantities – time, distance, velocity and energy – from one frame to another. Also probed is students' metaconceptual understanding of the word 'laws' and the phrase 'invariance of laws'.

There has been at least one previous study related to this work (Saltiel and Malgrange 1980). In this study a 'natural' model used by students was identified in which velocity becomes the property of a body alone, without reference to a frame, and trajectories are defined in a purely geometrical sense, independent of time and observers. The overlap of the present work with this study is indicated later and may be regarded as replication in a different cultural context. A useful bibliography of the general area of research on alternative conceptions may be found in Pfundt and Duit (1991).

Qualitative phenomenology of alternative conceptions

A free-response test (Appendix A) was designed to investigate students' conceptions qualitatively. A pilot version of the test was tried on a group of ten undergraduate students. After modifications, the test was administered to a larger sample of 39 physics undergraduates from a Bombay college, who were concurrently going through a course on relativity. Four students from this sample were selected for clinical interviews. A holistic interpretation of the students' written scripts and interview responses led to six broad classes of alternative conceptions (ACs). These

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fall into two clusters: one related to transformations of time and distance intervals and the tendency to view velocity addition in terms of 'physical drag'; and the other related to the meaning of laws and their invariance across frames of reference.

AC (I) *Implicit use of absoluteness of time without explicit awareness of invariance of time-intervals* (Δt)

In the usual teaching of physics, the invariance of time-intervals between fixed events is thought to be self-evident, a feature that is contrasted with the highly non-intuitive nature of time-dilation and related effects in special relativity. A surprising result of this study was that many college undergraduates have no qualms violating Δt invariance even in simple (non-relativistic) situations. From the calculations students made for Q.1 and Q.2, it emerges that absoluteness of time is no doubt used *implicitly*; but when the end result of a calculation violates it explicitly, it is rarely perceived as a contradiction.

To calculate the time required for forward and backward walk (of the man on the carriage) relative to the ground observer, the usual procedure followed by students was to obtain the distance covered by the man and divide it by the man's velocity relative to the ground. Most students computed velocity correctly at least for the forward walk ($20 + 2 = 22$ m/s), but revealed a number of barriers in the calculation of distance (see AC (II)). Some equated the distance seen by the ground observer to the length of the carriage; some others equated it to the distance travelled by the train as a whole. In the latter case, they invoked time invariance implicitly (20 m/s $\times$ 50 s $= 1000$ m), and then proceeded to violate it explicitly: Δt (ground) $= 1000$ m$/22$ m/s $= 45{\cdot}4$ s.

A most interesting response was one in which time invariance was used implicitly to prove it explicitly:

> In 50 s, the train covers $50 \times 20 = 1000$ m. For the observer the time taken for the man to reach the front end of the train would be the time taken by the train to cover 1000 m: time = distance/speed = 1000/20 = 50 s. The conclusion is that for such small velocities of motion (i.e. 20 m/s), the time when recorded in the moving body and at rest are nearly the same.

This student is explicitly aware of Δt invariance for non-relativistic speeds and is trying to 'prove' it, unaware that he has already used it in the first step. The interviews also revealed that the allegiance to Δt invariance is a matter of degree, varying with the complexity of the problem situation.

The most telling evidence of the absence of a firm awareness of absoluteness of time is the very fact that most students considered it necessary to 'obtain' the times of forward and backward walks relative to the ground observer by whatever procedures they deemed fit. It seems that physics undergraduates, even when aware of Δt invariance, do not appreciate that it is an axiom of Galilean relativity that is not provable, but is an input to determine how distance and velocities transform from one frame to another.

AC (II) *Invariance of distance intervals between any two events*

The invariance of distance interval between simultaneous events (e.g. length of an object) is a consequence of Galilean transformations. Many students, however, take invariance of distance for granted regardless of whether the events are simultaneous or not (Saltiel and Malgrange 1980). Strong adherence to this conception can lead to violation of time invariance, as noted above. However, even students with a clear knowledge of Δt invariance do not realize the contradiction of Δs invariance with the velocity addition law, as these excerpts show:

T: What will be the time for the forward walk (Q.1)?
S: Time will be 50s only.
T: Why?
S: Time is absolute.

Absence of AC (I)

T: Why 50 s for forward and 60 s for backward walk?
S: Because he chooses to walk slowly on return trip.

Probable absence of AC (III)

T: Distance covered by the man for the train observer?
S: 100 m
T: And for the ground observer?
S: [Takes time to answer] 100 m
T: So like time, distance is also ...
S: No, no. About time, I am sure. Distance ... No, that will be 100 m.
T: Velocity will be 100 m.
S: Velocity for train observer?
T: 2 m/s
T: For ground observer?
S: 20 + 2 equals 22 m/s I think
[Inconsistency brought to notice; immediately realizes.] Distance for ground observer more (hesitates) equals 1000 + 100 equals 1100 m (hesitates)
T: How sure are you about all this?
S: About time, I am sure; about velocities being different, one hundred per cent sure; distances, not sure.

In addition to AC (II), responses to Q.2 contained two additional aspects of students' thinking. One was the unconscious adoption of a 'natural' frame, mostly the ground frame, for kinematic description. The second involved switching unawares from one frame to another. The walking man 'knows' that he is walking on a moving carriage; the ground observer is 'aware' that the man is not actually walking a greater distance. Thus they easily take each other's point of view. This is a kind of psychological version of relativity.

AC (III) Viewing kinematic transformations as arising from 'physical drag'

From responses to Q.1 and Q.2 of the free-response test and also from the interviews, one thing was clear: students transform velocity from one frame to another correctly and confidently, even when they may possess AC (I) and/or AC (II). The velocity addition law is a derived consequence of Galilean transformations of time and distance. What explains the students' correct responses on this count even when they do not transform Δt and Δs correctly?

The probable answer is that students do not use the transformation relations at all, but rather use a dynamical picture – the mechanism of 'physical drag' – to computer velocity. This point, already noted in Saltiel and Malgrange (1980), showed up repeatedly in our study also. Thus when a student computes (correctly) the velocity of the man relative to the ground (Q.1) as $2 + 20 = 22$ m/s, he is probably not using the law of velocity addition; more likely he is viewing the train as carrying the man with it, much like a wind drags a ball along, adding its speed to the ball.

AC(III) is evidenced in the common view that forward motion on a moving carriage is 'easier' than backward motion. The 'physical drag' scheme comes most naturally in connection with upstream and downstream swimming in a river. The problem of a man swimming up and down alongside a drifting barge was posed to two students during the interviews. Both gave the right answers for upstream and downstream velocities confidently, despite the fact that neither could properly handle questions regarding distances and times. It is clear that students effect velocity addition by a different scheme before they start to transform distances and times.

AC(IV) Laws are equations i.e. co-ordinate descriptions of trajectories

One interesting response to Q.5 was that the trajectories of the bird's flight as well as the laws of motion are the same in S_1 and S_3 but are different in S_2. The student, when interviewed, explained that this was so since 'if frames are parallel', 'the equations are the same'. This student was probably equating 'laws' to equations in terms of co-ordinates and using the hunch that with non-parallel axes, the equations will change their form.

A clearer manifestation of AC(IV) appeared in a response which contained the correct answer to Q.5a: the shape of the trajectory of the bird's flight is the same in S_1 and S_2 but different relative to S_3. The response to part (b) was: 'The laws of motion will be the same in S_1 and S_2. Just the co-ordinates will be changed. But with respect to the third frame S_3, the laws will be different.' Here, laws are being equated to shapes of trajectories. The physicist's conception that the same laws could give different shapes of trajectories due to differing initial conditions is evidently missing in the student's thinking.

On the whole, AC(IV) seemed to be more a diffusion and mix-up of standard conceptions than a positive alternative conception.

AC(V) Preference for kinematic/dynamical explanation over 'invariance of laws' based reasoning

AC(V) is a natural corollary of the vagueness in students' thinking regarding invariance of laws. Thus in Q.3, students rarely reason that the boy must jump the same height in both situations, because anything otherwise would violate invariance of laws between two inertial frames. Instead, they go for detailed situation-specific arguments to arrive at their answers, correct or incorrect. It was cross-checked that many of these students had stated the equivalence of laws between frames S_1, S_2 and S_3 in Q.5 correctly. The conclusion is unmistakable. For students the principle of Galilean relativity is a 'cliché' to remember, not a powerful law that provides answers in many situations where the detailed kinematics or dynamics may be messy. As a result, when the principle of Galilean relativity is violated due to errors in kinematic/dynamical arguments in specific situations, the violation is rarely recognized.

AC(VI) Conserving energy across frames

The law of energy conservation is emphasized so much in students' formal instruction that it becomes a 'sacred cow'. This is evidenced by the common thinking that energy is constant from one frame to another. When a situation that is paradoxical for this view is posed before students as in Q.6, the view is not abandoned; rather, it is saved by inventing an explanation. If there is a change in energy, it must be accounted for.

One recurrent view that emerged is that the energy of the surroundings is only apparent. The view regarding real and apparent-ness of motion is not peculiar to the given situation; it is a general alternative conception that has been diagnosed earlier (Panse *et al.* 1994). Another 'explanation' to save AC (VI) is that the energy of the outside objects in the train's frame is equal to the kinetic energy of the train. Here the students are accepting the change in energy, and wanting to account for it in terms of the energy expended in moving the train from rest. Some other spontaneous justifications for AC (VI) are seen in I.8.

Forced option test results

The forced-option test (Appendix B) was administered to a sample to 102 senior physics undergraduates. A 'certainty index' was defined as the percentage of students responding with certainty out of the total number who held a particular conception. The Pearson correlation coefficient between prevalence and certainty of (both correct and alternative) conceptions was nearly as strong ($0{\cdot}65$, $\sigma = 0{\cdot}001$) as in Panse *et al.* (1994).

AC (I): No explicit awareness of invariance of time intervals

In two of the situations, marble-tram and man-carriage, a motion took place in a moving tram/carriage. Statements for the marble-tram situation (I.3) were phrased qualitatively. In the man-carriage situation (I.5 and I.6) however, students were suggested specific values for distance and time, in order to identify the alternative algorithms that they found plausible. The responses are summarized in Tables 1 and 2.

Table 1. Transformation of time and distance: (marble-tram situation).

Item no.	*Conception tested*	*Prevalence* (%)	*Certainty index* (%)
3a	Δt (ground)† > Δt (tram) (no realization of time invariance)	39	53
3b	Δt (ground) = Δt (tram) (correct time invariance)	49	80
3c	Δs (tram)‡ > path-length in tram (perhaps inadvertent change to ground's frame)	18	39
3d	Δs (tram) = path-length in tram (tautologically correct)	88	80
3e	Δs (ground) = Δs (tram) (distance 'invariance' (wrong))	27	64
3f	Δs (ground) > Δs (tram) (possibly correct transformation of distance)	67	71

† Δt (ground) is time taken by marble in the ground's frame.
‡ Δs (tram) is distance covered by marble in tram's frame.

Table 2. Transformation of time and distance: (man-carriage situation).

Item no.	*Conception tested*	*Prevalence* (%)	*Certainty index* (%)
5a	Velocity transformed from carriage to ground (correctly)	85	38
5b or 5c or 5e.	Δt (ground)† calculated using some alternative algorithm (not aware of time invariance)	70	(Av.) 33
5d	Δt (ground) = Δt (carriage) (correct time invariance)	43	45
5e	Implicit use of Δt invariance followed by its explicit violation	40	32
6a	Δs (ground)‡ = Δs (carriage) (wrong distance invariance)	28	52
6b	Δs (carriage) = path-length in carriage (tautologically correct)	88	87
6c	Δs (ground) = distance travelled by carriage in ground's frame	28	55
6d or 6f	Δs (carriage) by switching to ground's frame though the moving frame happens to be more natural	25	18
6e	Δs (ground) = 1100 m (correct transformation of distance)	37	74

† Δs (ground) is time taken by man in the ground's frame.
‡ Δs (ground) is distance covered by man in the ground's frame.

Only 32% of students showed Δt invariance in both situations, a surprisingly small percentage for an idea that is often considered to be intuitively obvious. Further, the certainty index for this response was much higher in the first situation than in the second. It seems that the suggestion of several different alternatives for Δt in I.5 markedly shook the students' faith in Δt invariance.

AC (II) *Invariance of distance intervals between two events*

This AC too was tested in the marble-tram and man-carriage situations (Tables 1 and 2). The results indicate that the majority of students had a qualitative idea about the transformation of distance, although they were not able to calculate exact values. The consistency between the choice of alternatives was low. In particular, about a third of those who chose the correct transformation also chose various alternative algorithms, though many indicated their lower certainty in the alternative responses. In general ACs on distance transformation were less prevalent than those on time transformation.

AC (III) *Viewing kinematic transformations as arising from 'physical drag'*

Students' facility in transforming velocity (a composite variable from the physicist's point of view) was confirmed in the forced-option test (Table 2). This facility probably arose from their use of a 'physical drag' metaphor. The forced option test contained three situations in which the 'drag' style of thinking was tested: boat-river (I.1), ship-pool (I.2) and man-carriage (I.4).

The first two of these situations were conceptually identical, but differed in their

Table 3. Viewing kinematic transformations as arising from physical drag.

Item no.	*Conception tested*	*Prevalence* (%)	*Certainty index* (%)
1b	(For same distance transversed in the river's frame) the swimmer takes more time for the upstream journey than for the downstream journey.	57	74
1c	Swimmer (in river) exerts more on the upstream journey	62	81
2b	(For the distance traversed in the moving ship's frame) the swimmer in the ship's pool takes less time for the 'forward' journey (in the direction of the ship's motion)	33	44
2a	Swimmer (in ship's pool) exerts more on the 'return' journey (against the direction of the ship's motion).	33	59
4a	(Given that the man walking on moving carriage takes longer time on the return journey, this is because:) he has to move against the motion of the carriage.	67	63
4b	(See 4a above) The man takes longer because he happens to walk slower (acceptable answer).	56	47

amenability to the 'drag' way of thinking. The motion in I.1 took place in physical contact with the moving river, so that the swimmer was seen to be carried along by the river. In I.2, on the other hand, the swimmer was perhaps imagined to be more independent of the moving ship.

A physicist would ignore these contextual details, and conclude that since in both situations the distances traversed each way *in the moving frame* were identical, the times would be identical too (since the man swims with constant speed relative to the moving frame). The possibility of more exertion on the upstream journey therefore did not arise here. The 'drag' way of thinking would imply that a swimmer moving against the direction of motion of his 'medium' would have to exert more and thus would take more time. This style of thinking was likely to be better evoked in the river-boat than in the ship-pool situation.

The data bore out these expectations, as Table 3 shows. The consistency between I.1b and I.1c was fairly high ($\chi^2 = 9{\cdot}1$, $\sigma = 0{\cdot}003$), and that between I.2b and I.2a even higher ($\chi^2 = 50{\cdot}2$, $\sigma = 0{\cdot}000$). Within I.1 and I.2 it was possible to carry out consistency checks. Only 3 to 4% of students changed their response from one alternative to the next, showing that the drag AC was a fairly consistent one in these two situations. In I.4 (man-carriage situation), however, the results were not so clear-cut.

AC(IV): Laws are equations, i.e., co-ordinate descriptions of trajectories

This AC appeared to consist of a diffuse set of misunderstandings, not easily translatable into questions involving forced-choice. Therefore, only one item (I.7e) was framed on this idea. Its certainty index was 33%.

AC(V): Preference for kinematic/dynamical explanations over reasoning based on invariance of laws

This AC was tested in I.7 (gun-train). The wrong response to I.7a was probably related to AC(III), namely that the moving bullet would be 'dragged forward' with the train, even in the train's own frame.

The results show that most students cannot exploit the invariance of physical laws in specific situations, even though they may be aware of the principle.

AC(VI): Conserving energy across frames

Item 8 offered various 'justifications' for AC(VI) which were diagnosed earlier through Q.6. The certainty index ranged from 25% for I.8c to 65% for I.8f. A striking fact was that the majority of those with the correct response also selected one of the alternatives incorrectly justifying energy conservation across frames. This highly prevalent AC probably arises more from a misinterpretation of instruction than from intuitive preconceptions.

Conclusion

This study shows that in dealing with any concrete situation, students simply do away with prescriptive transformation theory and instead rely on intuitive kinematic ideas of time and distance, and on dynamical ideas based on physical drag for velocity composition. This approach is successful for velocity transformation, but fails often for time and distance transformation. The intuitive notion of 'fixed space' probably leads them to distance invariance (regardless of simultaneity of events), sometimes at the cost of time invariance. The metaconceptual understanding of 'laws' is inadequate. Laws are taken to be equations that describe trajectories of motion. No wonder the invariance of laws – that powerful principle of Galilean relativity – is rarely employed even when it can effect enormous simplicity. Invariance of laws across frames in relative motion is confused with invariance in time (conservation) in a given frame. This shows up when students confidently conserve energy across frames. It appears that the basic notions of 'event', 'frames of reference', and 'invariance of laws' should receive greater emphasis in students' early training in Newtonian mechanics if their alternative conceptions are to evolve into the standard conceptions of physics.

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Appendix A. Free-response test.

Q.1 An open carriage 100 m long is moving uniformly on a straight track with a speed of 20 m/s. A man walks from the rear end of the carriage to the front end in 50 s according to his watch. He walks back to the starting point in 60 s according to his watch. What will be the times for the forward and backward walk of the man as measured by a ground observer? Explain your answers.

Q.2 In the above situation, comment on the distance travelled by the man during the forward journey and backward journey (*a*) as perceived by the man, and (*b*) as perceived by the ground observer. State in each case if the distance is greater than, equal to, or less than 100 m. Explain your answer.

Q.3 In a lift that is going *up* with uniform speed, a boy can jump to a maximum height of one metre above the floor of the lift. If, instead, the lift were moving *down* with uniform speed, to what maximum height above the floor of the lift could the boy jump? What if the lift were accelerating? Explain.

Q.4 In a race between A and B, A has a head start of 100 m. A runs at a uniform speed of 5·21 m/s and B runs at 7·21 m/s. How long will it take for B to catch up with A? Show the steps leading up to your answer.

Q.5 Consider three inertial frames of reference, S_1, S_2, and S_3. S_2 is stationary w.r.t. S_1, but its origin and direction of axes are different from S_1. The frame S_3 moves with a uniform velocity relative to S_1. For example, S_1 could be a ground frame of reference with its origin on a platform, S_2 another ground frame with its origin on a street outside, and S_3 the frame of reference of a uniformly moving train.

A bird flies between two poles on the platform. The trajectory of the bird's motion is curved relative to S_1.

(*a*) Is the shape of the trajectory the same or different with respect to the frames S_2 and S_3?

(*b*) Are the laws of motion applicable to the bird's flight the same or different for the three frames?

Explain your answer.

Q.6 A train is moving uniformly along a straight track. Relative to the train's frame of reference, objects such as trees, buildings, and even large mountains move in the opposite direction and thus possess enormous kinetic energy. In the ground's frame however, these objects are at rest and therefore do not possess any kinetic energy. How do you account for this huge increase in kinetic energy in the train's frame? Does it not contradict energy conservation?

Appendix B. The forced-option test and results

In the various problem situations below, a series of statements are given. Some of these statements are followed by the options 'a, b, c, d'. Please select one of the four options (a b c d) by circling it, using the following key:

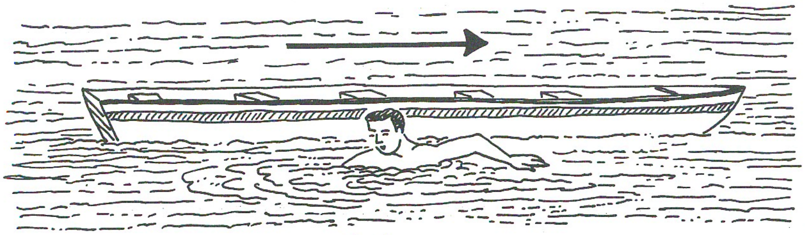
a: The statement is definitely true.
b: Not sure, but the statement might possibly be true.
c: Not sure, but the statement appears to be wrong.
d: The statement is definitely untrue (or) it does not make sense.

Consider the statements only in the given sequence. *Do not go back to any question that you have already read.*

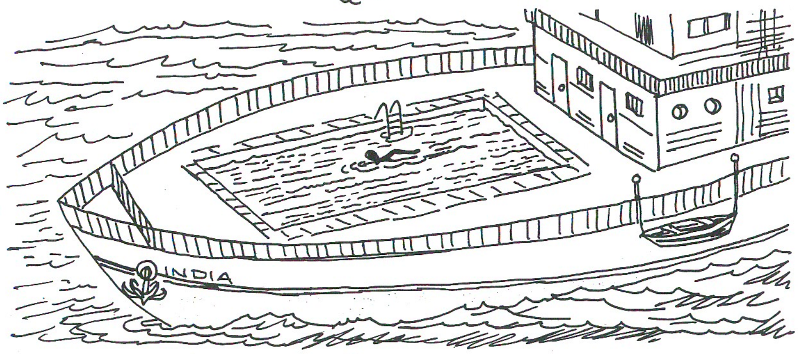
Please *do not* use Einstein's relativity in answering these questions.

(The results are summarized in terms of the percentages of students who agreed with, disagreed with, or gave no response to, the given statement. The correct responses are underlined.)

		Agree (%)	*Disagree* (%)	*No response* (%)
I.1	A river flows uniformly. A long boat drifts down the river (that is, it moves with the same speed as the river). A man swims alongside the boat from one end of the boat to the other end and then returns. Throughout the journey, the man swims with a constant speed relative to the flowing stream (Figure 1).			
1a	The man takes less time for the upstream journey than for the downstream journey.	29	<u>68</u>	3
1b	The man takes more time for the upstream journey than for the downstream journey.	57	<u>40</u>	3
1c	The man has to exert more on the upstream journey than on the downstream journey.	62	<u>33</u>	5
1d	The man spends greater energy on the upstream journey because he has to swim a greater distance than for the downstream journey.	25	<u>70</u>	5
I.2	A ship sails uniformly in the sea. There is a swimming pool on the deck of the ship. A man swims from one end to the other *along the direction of motion of the ship* and returns (Figure 1).			
2a	The man has to exert more on the return journey than on the forward journey.	33	<u>66</u>	1
2b	The man takes less time for the forward journey than for the return journey.	33	<u>66</u>	1

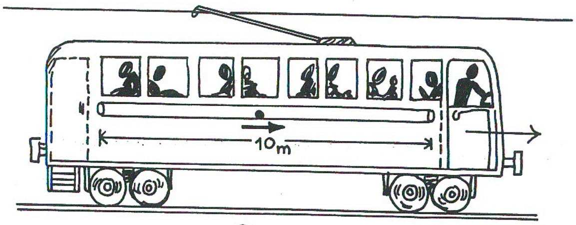


Q-1

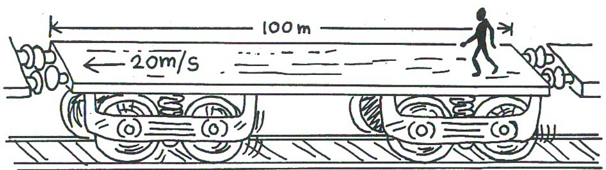


Q. 2

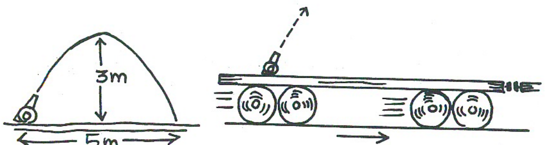
Figure 1.



Q. 3



Q. 4



Q. 7

Figure 2.

		Agree (%)	*Disagree* (%)	*No response* (%)
2c	The man takes more time for the forward journey than for the return journey.	15	83	2
2d	The man spends more energy on the return journey because he has to swim a greater distance than for the forward journey.	10	86	4
I.3	There is a horizontal tube of length 10 m fixed along the length of a tram (Figure 2). The tram is moving uniformly and a marble is rolled down from one end of the tube to the other *in the direction of motion of the tram.* Consider two frames of reference, the ground's frame, and the tram's frame. In the tram's frame, the ball takes 2 s to go from one end of the tube to the other.			
3a	The time taken by the marble to go from one end of the tube to the other, *relative to the ground's frame*, is greater than 2 s.	39	59	2
3b	The time taken by the marble to go from one end of the tube to the other, *relative to the ground's frame*, is equal to 2 s.	49	46	5
3c	The distance covered by the marble *in the tram's frame* is more than 10 m.	18	82	0
3d	The distance covered by the marble *in the tram's frame* is equal to 10 m.	88	11	1
3e	The distance covered by the marble *in the ground's frame* is equal to 10 m.	27	68	5
3f	The distance covered by the marble *in the ground's frame* is more than 10 m.	67	28	5
I.4	An open carriage 100 m long moves uniformly along a straight track with a speed of 20 m/s.			

		Agree (%)	Disagree (%)	No response (%)
	A man walks from the rear end of the carriage to the front end and notes the time for the walk to be 50 s. He walks back to the starting point and notes the time for the backward walk to be 60 s (Figure 2).			
4a	The man takes longer time on the return journey because he has to move against the motion of the carriage.	67	<u>32</u>	1
4b	The man takes longer time on the return journey because he happens to walk slower relative to the carriage in the return journey.	<u>56</u>	41	3
4c	The man takes longer time on the return journey because he has to walk a longer distance in the return journey.	7	<u>91</u>	2
4d	The velocity of the man during the forward journey *in the carriage's frame* is 2 m/s.	<u>73</u>	24	4
I.5	The above journey is being watched by a ground observer.			
5a	The velocity of the man during the forward journey *in the ground's frame* is 22 m/s.	<u>85</u>	14	1
5b	Time taken for the forward journey *in the ground's frame* is $100/22\ s = 4{\cdot}5\ s$ (approx.).	45	<u>50</u>	5
5c	Time taken for the forward journey *in the ground's frame* is $50\ s + 4{\cdot}5\ s = 54{\cdot}5\ s$ (approx.).	33	<u>62</u>	5
5d	Time taken for the forward journey *in the ground's frame* is exactly 50 s.	<u>43</u>	50	7
5e	Since the train travels a distance of $50 \times 20 = 1000\ m$, the time taken for the forward journey *in the ground's frame* is $1000/22\ s = 45\ s$ (approx.).	40	<u>51</u>	9
I.6	In the above situation,			
6a	The distance travelled by the man *in the ground's frame* is 100 m.	28	<u>67</u>	5

	Agree (%)	*Disagree* (%)	*No response* (%)
6b The distance travelled by the man *in the carriage's frame* is 100 m.	<u>88</u>	9	3
6c The distance travelled by the man *in the ground's frame* is 1000 m.	28	<u>66</u>	6
6d The distance travelled by the man *in the carriage's frame* is 1000 m.	15	<u>81</u>	4
6e The distance travelled by the man *in the ground's frame* is 1100 m.	<u>37</u>	54	9
6f The distance travelled by the man *in the carriage's frame* is 1100 m.	12	<u>82</u>	6
I.7 Two identical toy guns are mounted at the same inclination, one on the ground, and the other in a train in uniform motion. The range and maximum height of a bullet shot from the gun *on the ground* are 5 m and 3 m respectively, and its trajectory is a parabola (Figure 2). Consider the range and maximum height of the bullet shot on the train *relative to the train's frame*:			
7a The range is greater than 5 m due to the horizontal motion of the train, but the maximum height is still 3 m.	46	<u>49</u>	5
7b Both the range and the maximum height would be different from those for the bullet shot on the ground, since the train's frame is a moving frame.	39	<u>58</u>	3
7c The range and the maximum height are the same as those for the bullet shot on the ground, since the laws of motion are identical in the two frames.	<u>50</u>	42	8
7d The trajectory of the bullet shot on the train, *relative to the train's frame*, is a parabola.	<u>77</u>	19	5
7e The trajectory of the bullet shot on the train, *relative to the ground's frame*, is identical to the trajectory relative to the train's frame, since the laws of motion are identical in the two frames.	39	<u>56</u>	5

		Agree (%)	Disagree (%)	No response (%)
1.8	A train is moving uniformly along a straight track. Relative to the train's frame of reference, objects such as trees, buildings and even large mountains move in the opposite direction and thus possess enormous kinetic energy. In the ground's frame, however, these objects are at rest and therefore do not possess any kinetic energy. The huge difference in kinetic energy between the two cases does not contradict the law of energy conservation because,			
8a	The energy required to move the train appears as the kinetic energy of the outside objects relative to the train.	67	<u>29</u>	4
8b	The energy of the outside objects is equal and opposite to the train's energy. The two cancel, and thus energy is conserved.	41	<u>56</u>	3
8c	Distant objects move with smaller relative velocities, and hence have less energy, so energy is conserved.	16	<u>78</u>	7
8d	Increase in kinetic energy of outside objects is compensated by decrease in potential energy.	32	<u>63</u>	5
8e	Energy may change from one frame to another, and hence there is no question of energy conservation.	<u>38</u>	57	5
8f	Energy of objects in the moving train's frame is only apparent. Actually all these objects are at rest.	76	<u>22</u>	3