Contradictions and Reorganizations Among Naive Conceptions of Ballistics[1]

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Abstract

While offering predictions and explanations for various projectile situations, laypeople occasionally yield contradictory entailments and conceptual incoherence. Using protocol analyses and subjects' graphic trajectory depictions, a series of experiments assessed the prospect of reducing these inconsistencies by providing the individuals with "nonconceptual" (empirical and analogical) feedback. The results indicate that such feedback induced the development of more coherent configurations of kinematic knowledge. However, reconceptualizations regarding the dynamics of physical motion were rather rare.

[1]Presented at the annual meeting of the Psychonomic Society, Chicago, November, 1988. This research was supported by a grant from the James S. McDonnell Foundation to Princeton University and by grant N-00014-85-K0337 from the Office of Naval Research, awarded to Lauren B. Resnick and Stellan Ohlsson of the Learning Research and Development Center of the University of Pittsburgh.

INTRODUCTION

Current research in the domain of informal physical reasoning indicates that people often engage in context-specific thinking when performing tasks that require predictions about future motion (e.g., diSessa, 1987; Kaiser, Jonides, & Alexander, 1986). While these predictions are generally temporally consistent (Hojnacki, 1988), the knowledge sources that result in their context-specificity occasionally produce contradictory entailments and conceptual incoherence (Ranney, 1987a). Using a constraint-satisfying, connectionist, model of explanatory coherence, Ranney and Thagard (1988) recently modeled two episodes in which subjects resolved such conflicts while explaining a surprising ballistic observation.

The present experiment was designed to determine the extent to which empirical and analogical feedback can produce coherence-enhancing reorganizations among naive beliefs about kinematics and dynamics. From this perspective, there are two ways in which "informal physicists" can improve the coherence of their beliefs: (1) by inducing more general principles of motion (i.e., by questioning the notion of impetus and approximating the notions of inertia and Newtonian dynamics), and (2) by refining their understanding of the relationships among various projectile motions (e.g., thrown, dropped, and rolling objects). Prior analyses (Ranney, 1987b) seem to have underestimated the potential for the present paradigm to effect both of these sorts of reorganizations.

METHOD

Subjects

This experiment included 42 undergraduates from an introductory psychology course; 28 experimental subjects were to receive feedback, while 14 control subjects received no feedback. The subjects had *never* taken a course in physics.

Tasks

This study employed five sets of predictions. Two sets involved situations that are fundamentally similar, yet superficially dissimilar. These items were used in an attempt to force subjects to notice and eliminate their inconsistencies regarding motion:

Pendular-Release Tasks. The first set of eight tasks (adapted from Caramazza, McCloskey & Green, 1981) requires subjects to predict (draw) the trajectories of pendulum-bobs that have been released at various points during in a swing. Figure 1 displays these positions, as well as some actual (feedback) paths. The swinging pendulum was animated on a computer, in real time.

Dropping & Throwing Tasks. The second set of tasks required that subjects draw the trajectories of heavy objects in a variety of dropping & throwing situations. As shown in Table 1, a subset of these tasks are essentially isomorphic to the pendular-release problems (e.g., a horizontally thrown object and a pendulum-bob released at the nadir of a swing are physically analogous situations).

The remaining tasks include one set that represents an analogical hint with respect to the preceding sets, and two sets designed to tap different levels of transfer:

The Similarity-Judgment Tasks. For these items, subjects were asked to match each pendular-release situation to one or more of its "fundamentally similar" dropping & throwing counterparts.

Pendular-Transfer Tasks. These two tasks, involving a trapeze and a wrecking-ball, represented near-transfer targets for belief revisions spawned by the pendular-release items.

Zero-Gravity Tasks. This set of six far-transfer tasks involved subjects' trajectory predictions for projectiles released in the *absence* of gravity. These included releases that followed no motion, rectilinear motion, and curvilinear motion.

Design and Procedure

Table 2 shows the basic sequence of tasks received by the experimental subjects. After a *pre-test*, subjects received pendular feedback, followed by re-predictions for the dropping & throwing tasks. Simple feedback (the correct choices) for their similarity-judgments was then provided, followed by a *post-test*. Two weeks later, the subjects received session 2, an unexpected *delayed post-test*. The control group only received Phases 1-4 and 8-10, experiencing neither feedback nor the delayed post-test.

Each subject was individually tested and their verbal protocols were audio-taped. They were asked to describe and explain every prediction and trajectory drawing. In order to facilitate belief revisions, they could change any prior prediction or explanation at any time -- even across phase boundaries and during the feedback phases. Furthermore, the subjects could review any feedback item until the end of session 1.

Table 1. Fundamental similarities between the pendular-release and dropping & throwing tasks.

Pendular-Release Tasks		**Dropping & Throwing Tasks**
Extreme (endpoint) position	<---->	Object dropped from a standstill
Intermediate-downward position	<---->	Object thrown obliquely downward
Intermediate-upward position	<---->	Object thrown obliquely upward
Nadir position	<---->	Object thrown horizontally Object dropped by walking person Object dropped from a train
	Foils:	Object thrown straight downward Object thrown straight upward

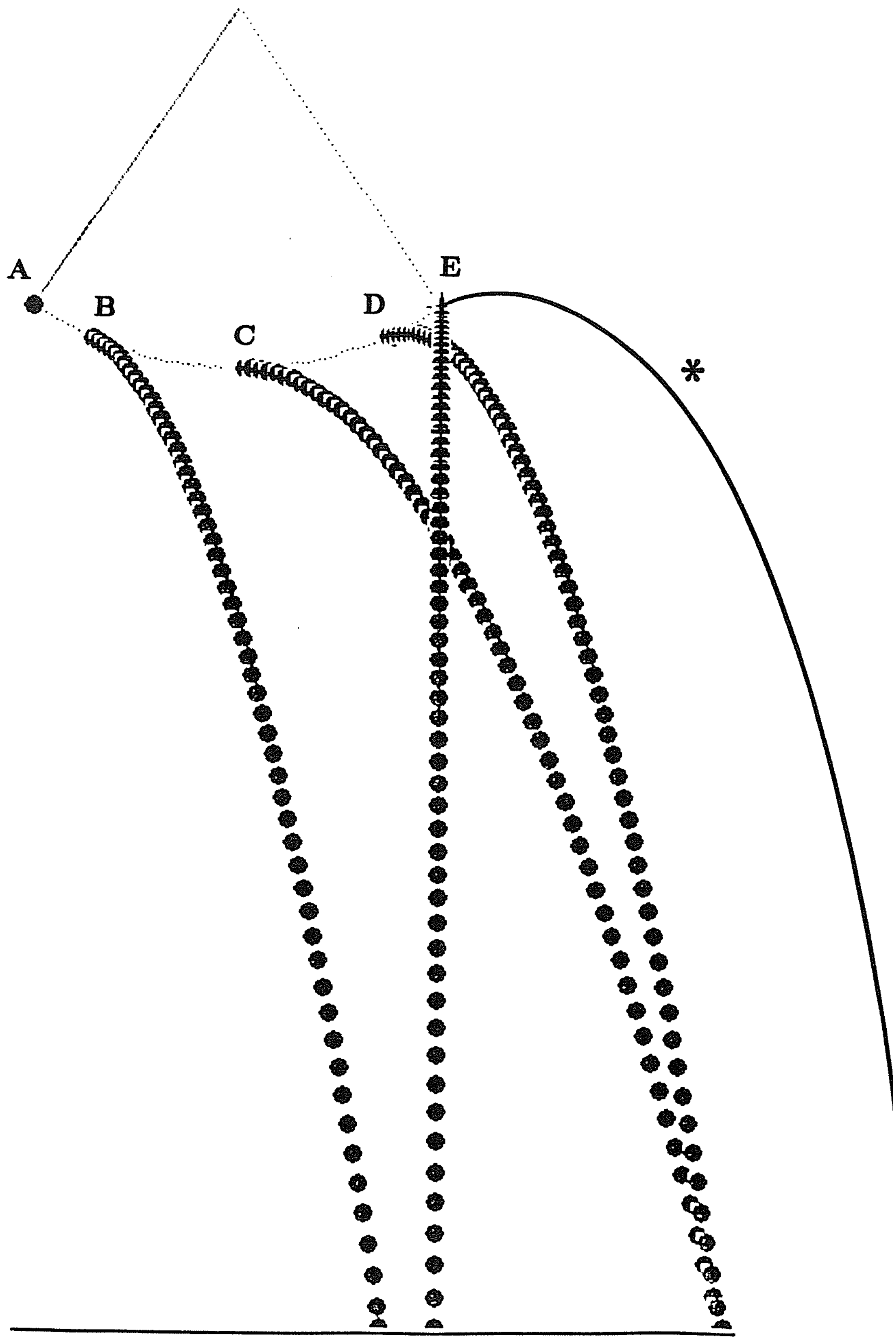

FIGURE 1. Some pendular-release positions, with their resultant (feedback) trajectories. A common prediction (*) is also shown.

Table 2. The basic presentation sequence for the various types of tasks employed.

Session 1

Pre-Test Phases

1. Pendular-Transfer Predictions
2. Dropping & Throwing Trajectory Predictions
3. Pendular-Release Trajectory Predictions
4. Similarity-Judgments about the tasks of Phases 2 and 3

Intervening Phases

5. Empirical *Feedback* for the Pendular-Release
6. Dropping & Throwing Re-Predictions
7. Nontheoretical *Feedback* for the Similarity-Judgments

Post-Test Phases

8. Dropping & Throwing Trajectory Re-Re-Predictions
9. Pendular-Transfer Re-Predictions
10. Zero-Gravity Abstract-Motion Predictions

Session 2: Two Weeks Later

Delayed Post-Test Phases

11. Pendular-Transfer Predictions
12. Pendular-Release Trajectory Predictions
13. Dropping & Throwing Trajectory Predictions
14. Similarity-Judgments about the tasks of Phases 2 and 3
15. Zero-Gravity Abstract-Motion Predictions

RESULTS

Each individual's drawn trajectories were decomposed and coded with respect to ten possible kinds of rectilinear and curvilinear features. Subjects combined these features in a great variety of ways, yet inter-rater reliability across the codings was 95%.

Improvements in Accuracy

Figure 2 exhibits the subjects' accuracies for each of this experiment's five types of tasks, as a function of testing-time (pre-, post-, and delayed post-test; the pre-test value for the zero-gravity tasks was garnered from the control group). The data generally indicate that subjects acquired a better understanding of the *phenomenal relationships* among the various tasks: Each of the four types of tasks that involve normal gravity exhibited improved performance from the pre-test to the both the post-test *and* the delayed post-test. The increases in accuracy for the pendular-release and similarity-judgment tasks show that the subjects incorporated the two types of feedback rather well. The dropping & throwing and pendular-transfer data show that the

<u>FIGURE 2.</u> Accuracy values for the five kinds of projectile tasks (* = a significant increase from the pre-test).

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PEN-REL    =  Pendular-Release Trajectories
SIM-JUDG   =  Similarity-Judgment Tasks
D&T        =  Dropping & Throwing Trajectories
PEN-TRAN   =  Pendular-Transfer Tasks
ZERO-G     =  Zero-Gravity Predictions
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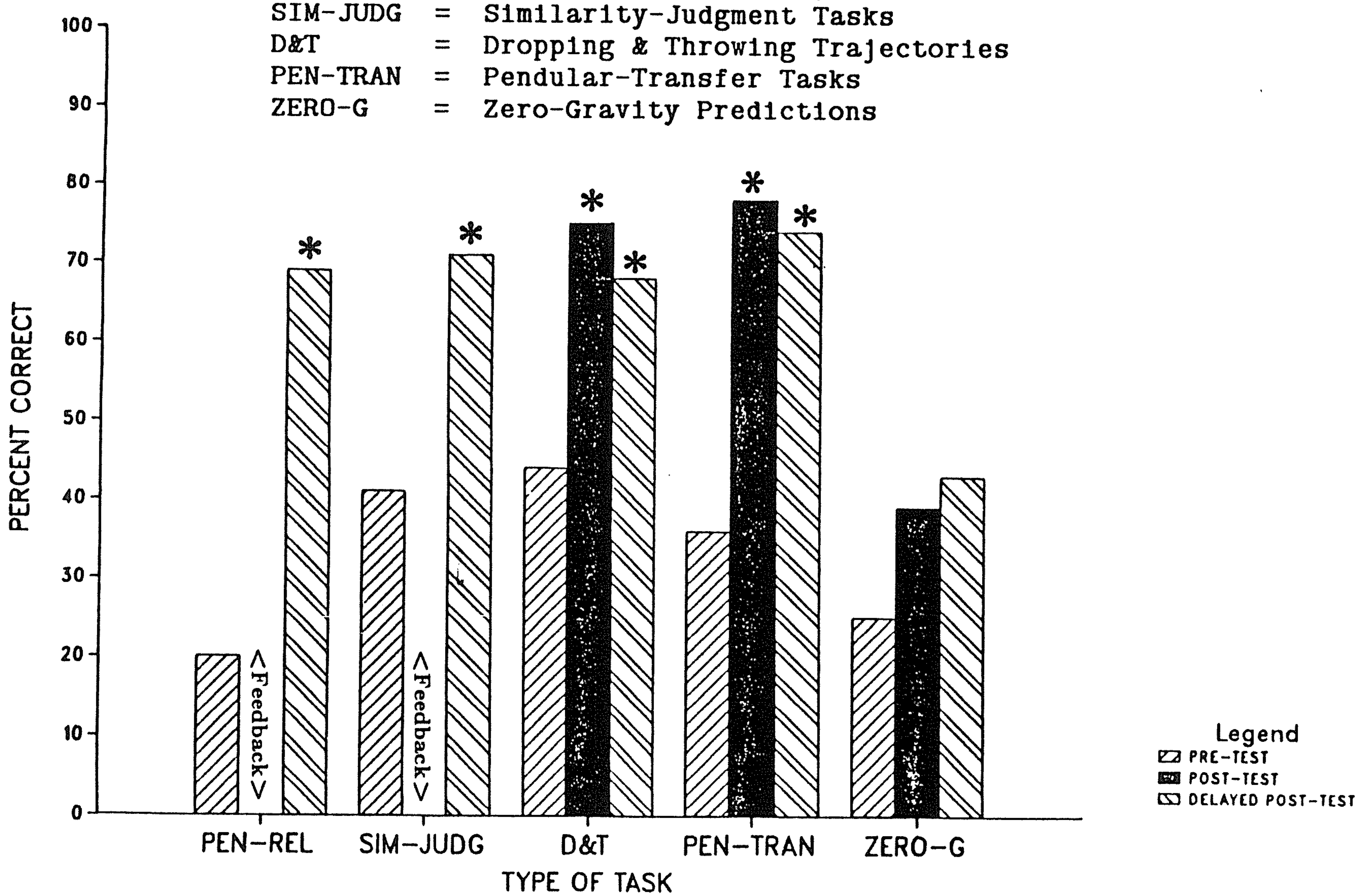

experiment yielded temporally stable learning, as the transfer was maintained after the two-week delay. Across the zero-gravity (far-transfer) tasks, however, the experimental subjects did *not* exhibit a significant improvement, compared to baseline performance.

A Reduced Reliance on Impetus Beliefs

The corpus of data was also coded with respect to three impetus beliefs (cf. Halloun & Hestenes, 1985), of which two are discussed here: *Dissipation* is the belief that a moving object's initial speed somehow "runs out," while *internal force* is the belief that objects released in a gravitational field maintain their prior rectilinear motion. Dissipation beliefs were evidenced by (a) laterally-moving objects that gravity eventually pulled exactly straight-down, (b) zero-gravity projectiles that lost their initial speed, and (c) explicit statements of dissipation. Internal force beliefs were evidenced by rectilinear features (horizontal or diagonal line segments) among the subjects' drawings.

Figure 3 shows the number of experimental subjects that *ever* responded in accordance with these two types of impetus, as a function of testing time. Although these results indicate that few individuals ever fully denied their initial impetus beliefs, the data suggest movement in that direction. For instance, some subjects developed an "incomplete dissipation" belief, in which the initial speed is only asymptotically exhausted. Furthermore, Figure 4 shows significant reductions in the *frequency* with which these fallacious dynamic beliefs were employed.

Reorganizations in the Relationships among Ballistic Situations

Evidence of Initial Contradictions and Incoherence. The following sampling of results is offered as converging evidence that laypeople occasionally yield inconsistent predictions and explanations:

- More than half of the experimental subjects initially predicted that a pendular-release from an endpoint would result in a trajectory with some lateral movement -- even though they also maintained that these were positions of zero (instantaneous) velocity. Figure 1 shows such a prediction. (After being surprised by the straight-down feedback, all of these subjects appropriately integrated their beliefs about pendular-motion and release velocities; see Ranney & Thagard, 1988.)
- When subjects' predictions for the "trapeze" pendular-transfer task were compared to isomorphic situations from the pendular-release tasks, 81% of these trajectory-pairs were inconsistent (i.e., comparable pairs of drawings did not contain the same features).
- 75% of the subjects who drew vertical (straight-down) trajectories from the nadir of the pendulum (position C) chose the same position as the optimal point for a wrecking ball to hit a building -- because it represents "the point of maximum velocity."

Evidence of Improved Consistency and Coherence. There are several lines of evidence indicating that the experimental subjects improved their conceptual organizations of the normal-gravity phenomena used in this study:

- During the pre-test, subjects yielded asymmetrical responding during the pendular-release tasks 26% of the time. For instance, an individual might have predicted an angled ("rectilinear") trajectory from position C during a leftward swing, but a curvilinear trajectory from position C during a rightward swing. Two weeks after receiving feedback, such

The Number of Subjects Employing Either of Two Types of Impetus During Any Task in Any Set of Tasks

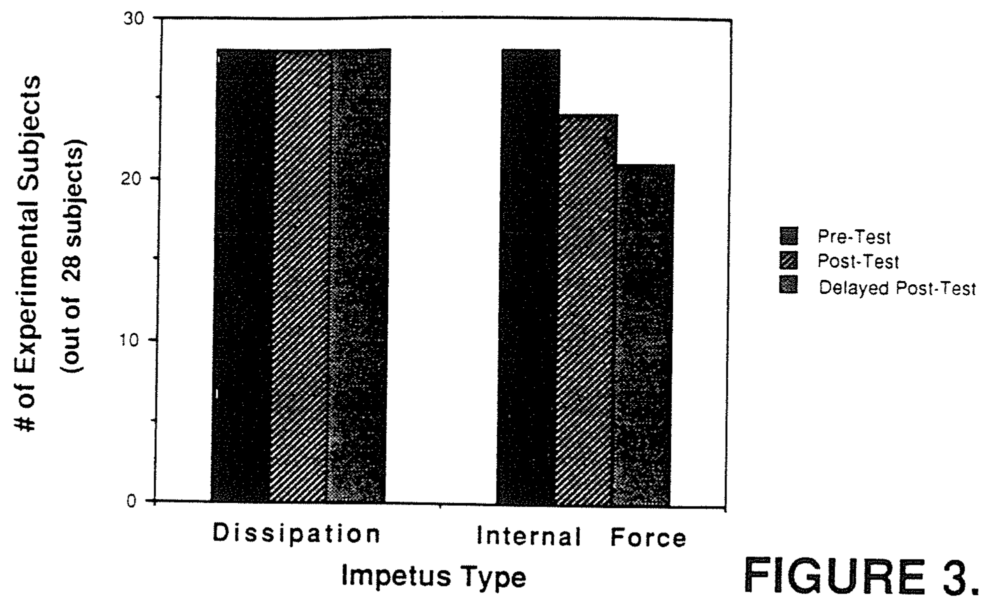

FIGURE 3.

Subjects' Reliance Upon Two Types of Impetus for the Dropping & Throwing Tasks, Over Time

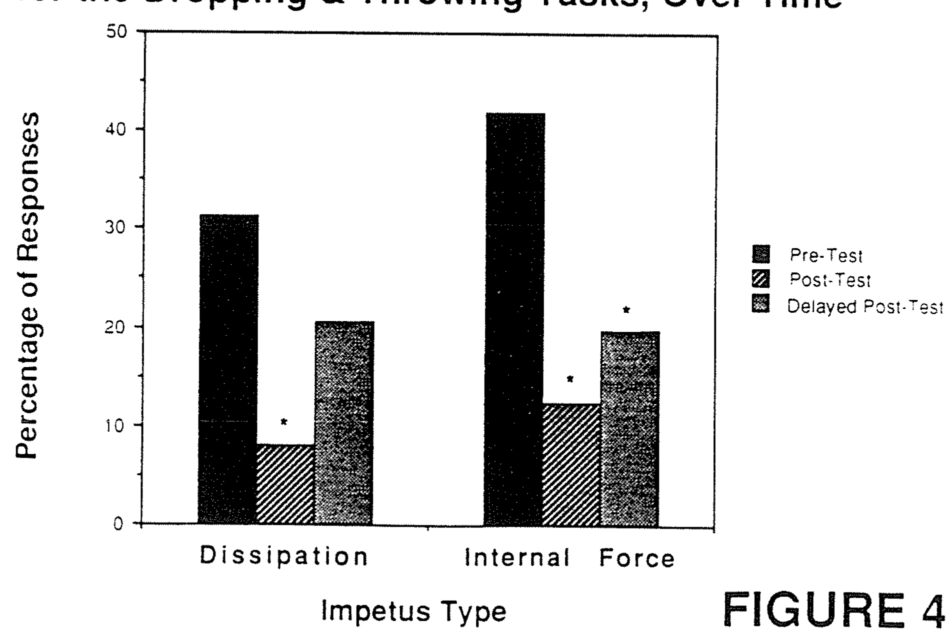

FIGURE 4.

(* = a significant decrease from the pre-test) asymmetrical instances were significantly lower (10%).

- Inconsistencies between (a) elicited descriptions of variations in pendular speed and (b) predictions regarding the pendular-transfer tasks significantly dropped from 29% during the pre-test to 14% during the post-test -- even though feedback was never directly provided for any of these tasks.
- During the pre-test, only 20% of subjects' predictions for the pendular-release tasks matched their predictions on isomorphic dropping & throwing tasks. By the time of the delayed post-test, however, 52% of the subjects drew the same trajectories for isomorphic tasks.
- Initially, only 31% of the time did subjects draw the same type of trajectory for the pendular-release and dropping & throwing tasks that *they* claimed were fundamentally similar. By the time of the delayed post-test, this "behavioral agreement" value rose to 71%. The improvement in consistency was even significant for non-Newtonian assessments of similarity (e.g., for subjects who thought a pendular-release from position C was fundamentally similar to an object thrown straight downward).
- Correlations among the accuracies of the four sets of normal-gravity tasks improved, further suggesting that the relationships among various situations were becoming more coherent. During the pre-test, only 2 of the 6 correlations ($r = .37$ and $.42$) were at least marginally significant, whereas two weeks after receiving the empirical and analogical feedback, 5 of the 6 correlations reached these levels ($r = .28$ to $.60$).
- Finally, multidimensional scalings of the similarity-judgment choices demonstrate that subjects' representations of the dropping & throwing problems, for which feedback was never directly received, were becoming more coherent. Figure 5 shows that during the pre-test phases, these situations were generally viewed as isolated entities, with only a few surface similarities over largely uninterpretable dimensions. In contrast, Figure 6 shows a tighter clustering for the delayed post-test data, as well as more interpretable dimensions (i.e., "path rectilinearity" and perhaps "horizontal speed").

CONCLUSIONS

At no point in this experiment did subjects receive any conceptual feedback or theoretical explanations (i.e., information involving the notions of force, velocity, acceleration, mass). Yet two weeks after receiving the small amount of empirical and analogical feedback, these individuals retained both the feedback and the moderate amount of transfer that was observed in the immediate post-test.

The *non*theoretical feedback provided was sufficient to significantly improve the subjects' understanding of the *relationships* among various kinematic concepts and phenomena. The evidence for this assertion comes from (a) the stable improvements in accuracy, (b) greater response consistency over a variety of ballistic situations, (c) improved intertask correlations, (d) illuminating protocol statements, and (e) changes in the similarity space among tasks for which no feedback was directly provided.

Both before and after this feedback, however, "deep" conceptual changes (i.e., from impetus to inertia) were rare. Perhaps this is because the informal physicist's knowledge of motion appears to be neither well-structured nor highly consistent: How does one restructure what is not initially structured? Even so, the data indicate that the sort of "predict, observe, re-predict" cycle used in this study was sufficient to reduce subjects' reliance upon fallacious

Multidimensional Scaling of the Pre-Test Data for the Dropping & Throwing Tasks

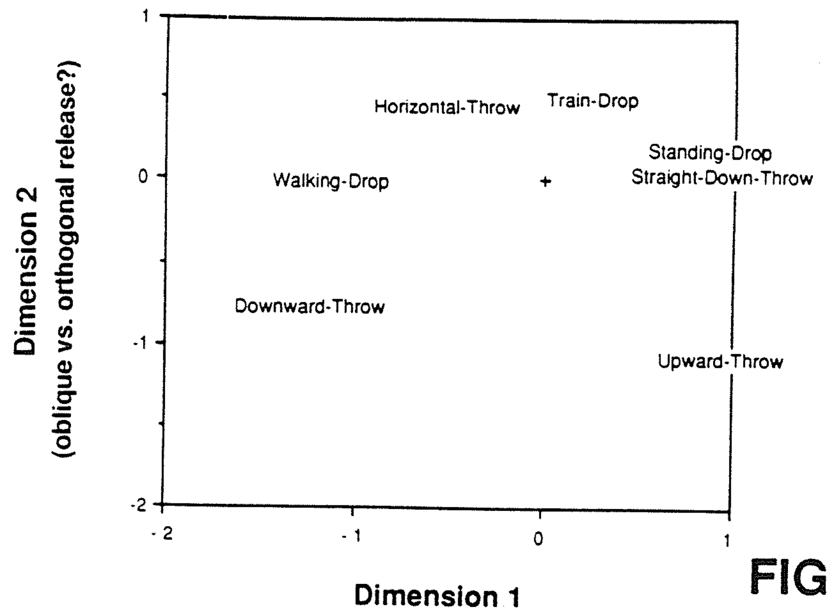

FIGURE 5.

Multidimensional Scaling of the Delayed Post-Test Data for the Dropping & Throwing Tasks

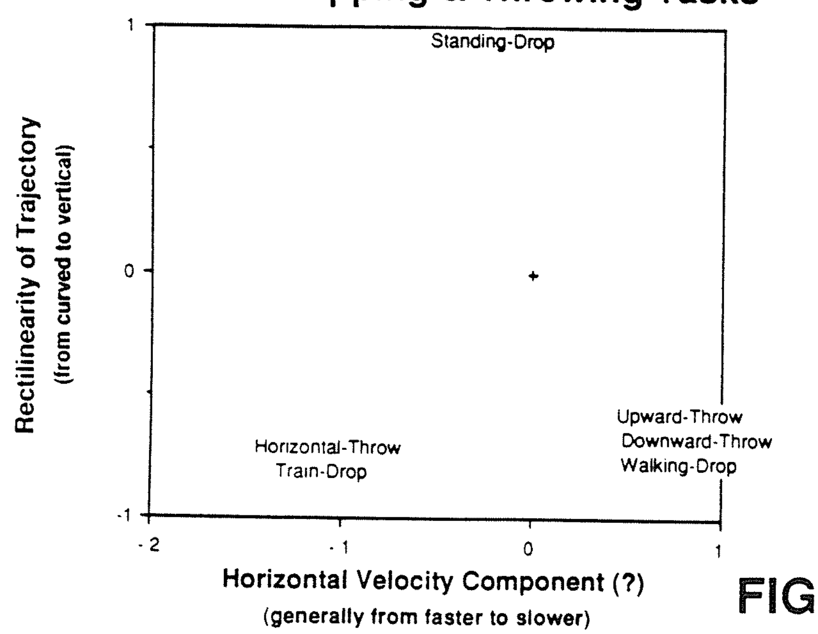

FIGURE 6.

impetus beliefs. It remains to be seen whether this paradigm will yield similar findings for lay-people in other domains of reasoning.

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