Ranney, M. (1987b). *Restructuring conceptions of motion in physics-naive students*. (Report No. SE-053-227). Pittsburgh, PA: University of Pittsburgh, Learning Research and Development Center. (Also ERIC Document Reproduction Service No. ED 357 965; pp. 1-15) [This is an expanded version of a paper that was peer-reviewed and subsequently presented at the 1987 meeting of the American Educational Research Association.]

Restructuring Conceptions of Motion in Physics-Naive Students[1]

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[1]Presented at the annual meeting of the American Educational Research Association, Washington, D.C., April, 1987. This research is supported by Grant NR667-534 from the Office of Naval Research.

ABSTRACT

Students lacking formal training in physics have great difficulty predicting the paths of various projectiles. With respect to pendulum-bobs that are released from various points in a swing, a previous experiment found that empirical feedback (i.e., resultant trajectories) produced transfer-of-training to other pendular-based tasks. However, such feedback did *not* facilitate transfer to some isomorphic dropping & throwing situations. In the present experiment, subjects were additionally provided with a subtle analogical hint, in that they had to judge which of the pendular-release situations are fundamentally similar to the dropping & throwing items.

The results show that the similarity judgments successfully catalyzed transfer from the pendular-release feedback to the dropping & throwing tasks. The data further show that the subjects restructured their understanding of the *relationships* between various kinds of projectiles and improved the *integration* of their beliefs about motion. After two weeks, these conceptual changes remained stable.

But such learning was limited by the nonconceptual nature of the feedback. Even after eventually receiving feedback for the similarity-judgment tasks (i.e., the correct choices), the students could not transfer their new conceptions of motion to tasks involving zero-gravity. Indeed, these new ideas rarely included the denial of previously held beliefs about impetus. While a few subjects came to deny prior internal-force and curvilinear impetus beliefs, none of them fully denied the notion of dissipation, in which an object's initial speed "peters out."

PERSPECTIVE

Departing from much of the current cognitive research on problem solving, this line of research seeks to experimentally induce instances of *productive thinking* -- the Gestalt term for significant acts of conceptual reorganization. Such reasoning stands in contrast to *business-as-usual thinking*, in which the basic concepts and operations for a given problem are relatively well-formed (as in the solution of a textbook physics problem). In general, this work explores three central issues in the acquisition and utilization of knowledge in complex domains: (1) How do people recognize the presence of inconsistent configurations of knowledge? (2) How do they accommodate such self-contradictory representations? (3) In which ways can empirical feedback facilitate and extend an individual's conceptual reorganizations?

Two crucial characteristics make naive physics an interesting domain for the study of conceptual restructuring: (a) Subjects readily exhibit conceptual inconsistencies and (b) they often "reason above their heads" about diverse and complicated constructs (e.g., force, inertia, vectors, etc.). Some research indicates that the fragmentary and unintegrated nature of one's knowledge of motion (diSessa, 1983) may be due to the non-ideal and often illusory nature of actual kinematic events (McCloskey et al., 1983). The result is a set of well-documented misconceptions (e.g., Halloun & Hestenes, 1985), including several impetus notions: *internal force*, in which objects released in a gravitational field maintain their prior rectilinear motion, *curvilinear impetus*, in which an object maintains the curved motion that preceded its release, and *dissipation impetus*, in which the initial speed of an object somehow "dissipates."

As mentioned above, a prior experiment showed that providing feedback for predictions of objects released from moving pendulums does *not* produce transfer to isomorphic dropping & throwing situations. The present experiment facilitated such transfer by providing items that hint at the utility of considering the tasks analogically -- and later giving feedback for these hints.

METHOD

SUBJECTS

This experiment included 42 college students 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 medley 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 conceptual changes 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.

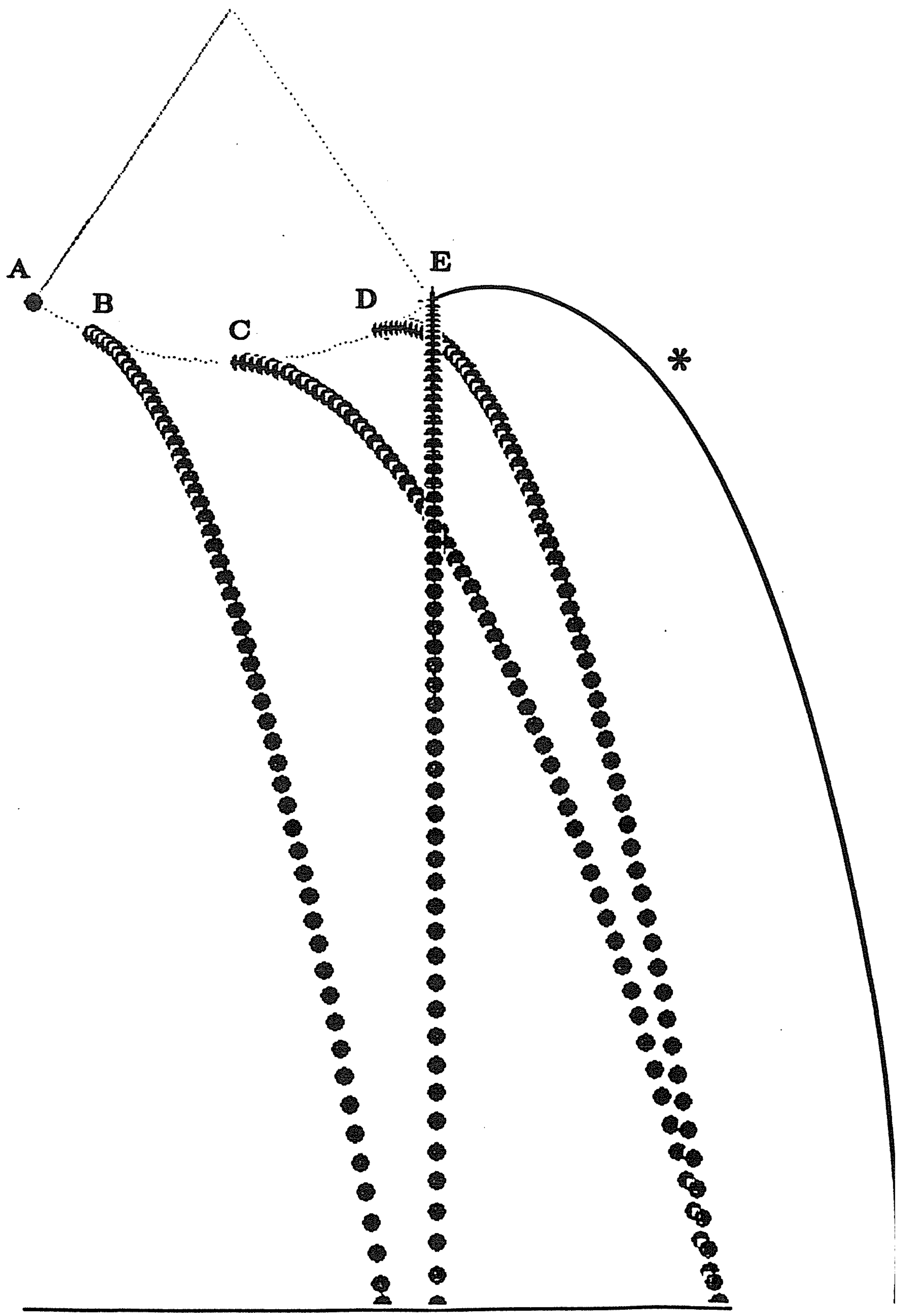


FIGURE 1. Some pendular-release positions, with their resultant (feedback) trajectories. A common prediction (*) is also shown.

Each subject was individually tested and their verbal protocols were audio-taped. The students were asked to describe and explain every prediction and trajectory drawing. In order to facilitate conceptual change, 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

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

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. Nonconceptual 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 aspects. Subjects combined these aspects in a great variety of ways, yet inter-rater reliabilities were quite high (95%).

Accuracy Data

Between Phases 2 and 6, the dropping & throwing performance significantly increased from 44% to 66%. So, when combined with the analogical hint embodied by the similarity-judgment tasks, subjects *did* used the pendular-release feedback to catalyze transfer.

Figure 2 exhibits the students' accuracies for each of this experiment's five types of tasks -- as a function of testing-time (pre-, post-, and delayed post-test; note that the pre-test value for the zero-gravity tasks comes via the control group). The data generally indicate that subjects acquired a better understanding of the various tasks' *inter-relationships*: Each of the four types of tasks that involve normal gravity exhibited improved performance from the pre-test to either of the post-tests. 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 experiment yielded temporally stable learning, as the transfer was maintained after a two-week delay. Across the zero-gravity tasks, however, the experimental subjects (who got feedback) were *not* significantly more accurate than those in the control group.

Conceptual Changes

The corpus of data was also coded with respect to impetus conceptions. *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 exactly rectilinear aspects (horizontal or diagonal line segments) among the subjects' drawings. Finally, *curvilinear impetus* was evidenced by either concave trajectory-aspects (for normal-gravity predictions) or a curved prediction for the zero-gravity task that was preceded by a curved motion.

Figure 3 exhibits the experimental subjects' reliance on the three types of impetus, as a function of testing time. In general, the observed decrease in impetus beliefs was quite small, so the experimental manipulations were not very successful with respect to negating such fundamental fallacies: (1) *All* of the subjects initially held a belief in *dissipation*, and none of them ever fully denied it. (Still, some students developed an "incomplete dissipation" belief, in which the initial speed is never completely exhausted.) (2) Although initially as dominant as dissipation, 25% of the subjects came to fully deny the notion of *internal force*. (3) Finally, while fewer subjects ascribed to *curvilinear impetus*, it was also difficult to reject; following

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

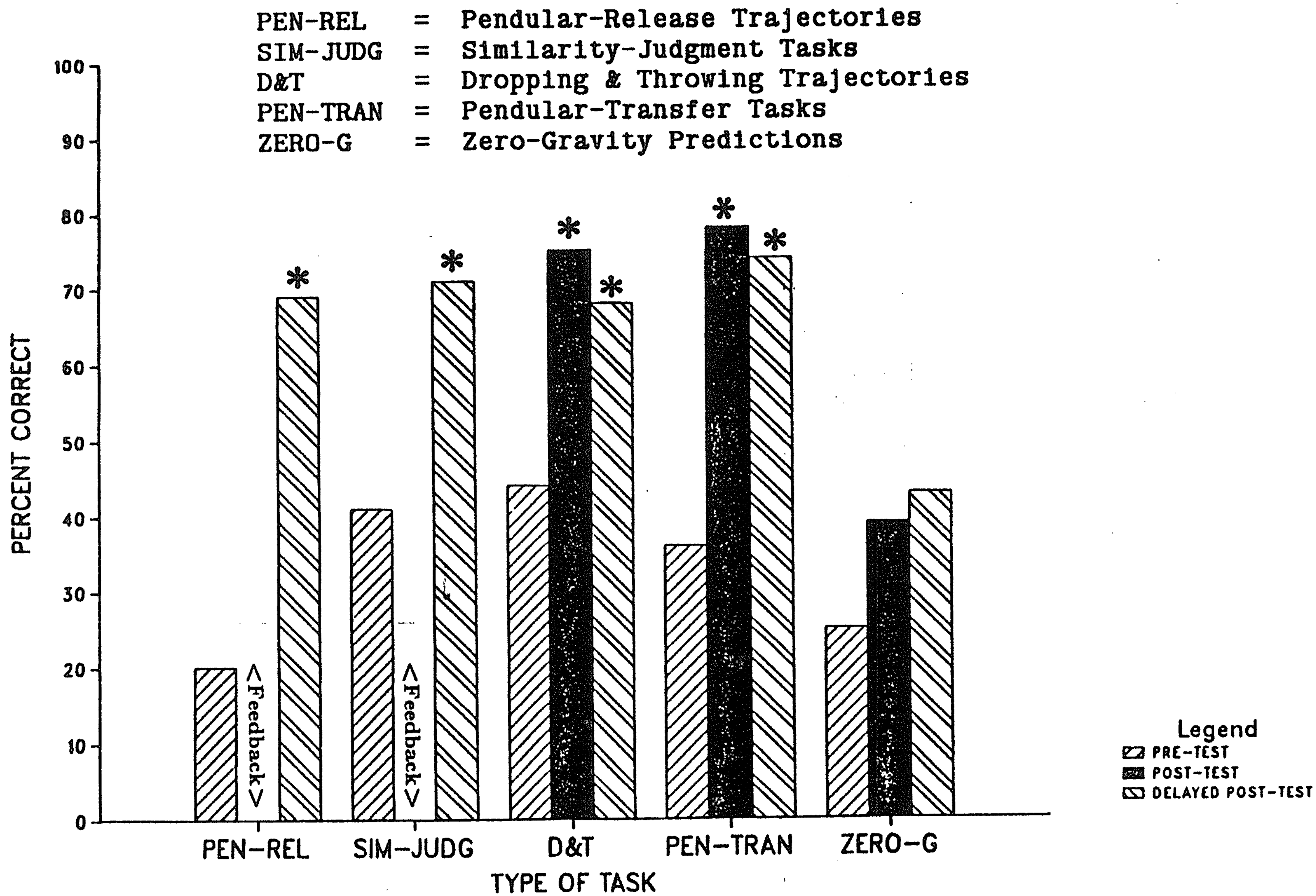
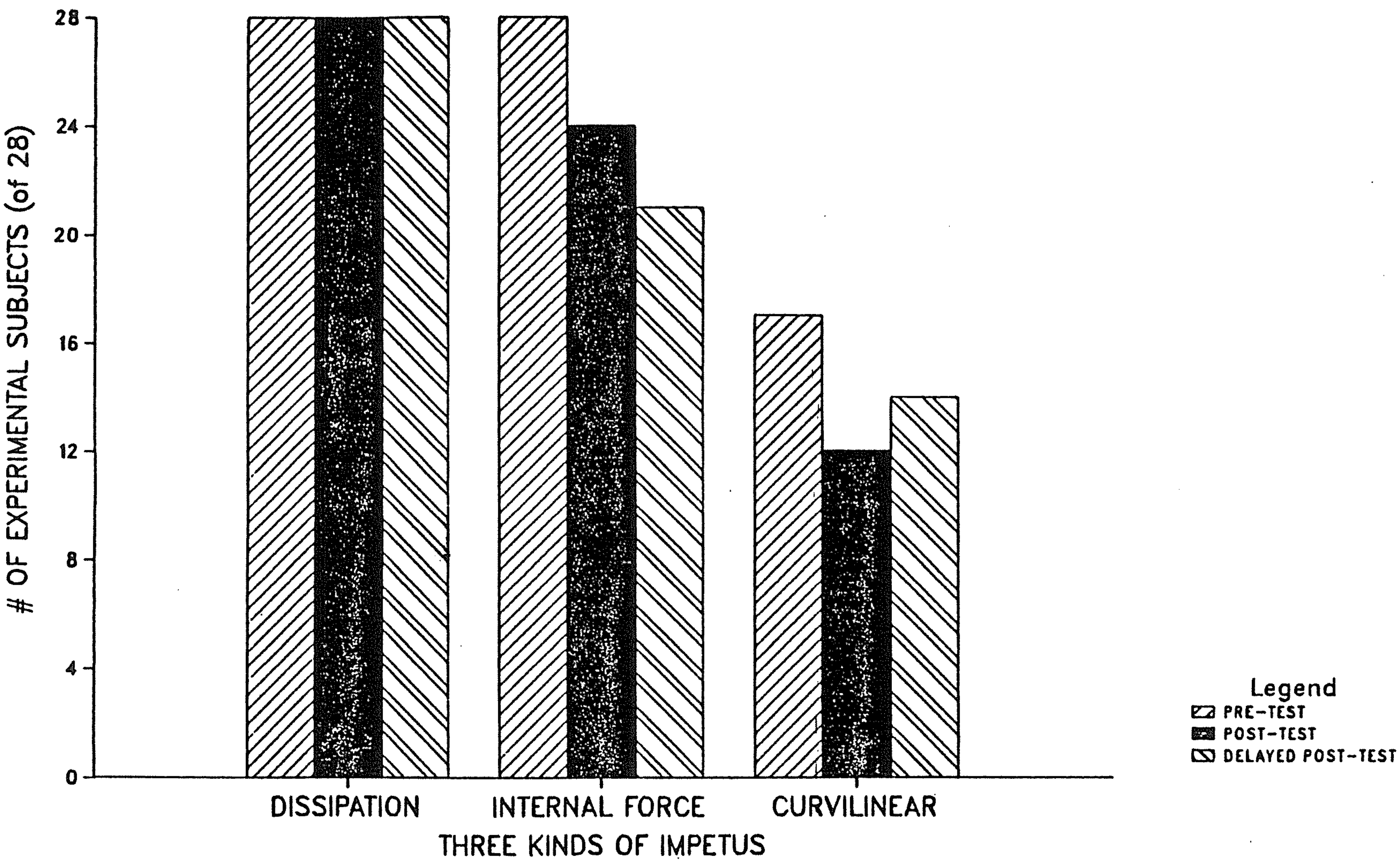


FIGURE 3. The number of subjects ascribing to dissipation, internal-force, and curvilinear conceptions of impetus -- at three testing times.



pendular feedback, virtually all of the subjects eventually vanquished concave trajectory aspects from their predictions, but curvilinear impetus was still evidenced in many responses to the zero-gravity curved-release task.

Beyond impetus beliefs, the students *were* engaging in conceptual change. Protocol analyses suggest that virtually all of the students improved the *integration* of some previously isolated sources of knowledge. An example: More than half of the 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 trajectory.) After being surprised by the straight-down feedback, all of these subjects appropriately integrated their beliefs about pendular-motion and release velocities. Here is one subject's protocol:

> Wow! That's interesting! I guess, because [that's] the endpoint, and it . . . It doesn't actually, stop there, but it's like an endpoint. It *sort of* stops . . . It slows down so that it can begin to go the other direction. So I guess, for a *split second*, it would stop. And if it were to break there, it would make a fall straight down . . . Oh, wow!

CONCLUSIONS

One can argue that productive thinking and its associated conceptual restructurings, rather than the mere accretion of information, represent the ultimate goals of a student's education. If this is true, it is essential to gain a better understanding of how we can improve an individual's ability to recognize and eliminate conceptual conflicts and inconsistencies. The present findings indicate that subjects can identify and accommodate several contradictory beliefs about motion, based solely upon empirical and nonconceptual feedback. The products of these representational changes include the ability to generate more accurate trajectory predictions and a better-integrated understanding of projectiles moving in a gravitational field.

However, purely empirical feedback clearly has its limitations, since such feedback is only loosely interpretable. In the experiment reported here, subjects generally retained (or only slightly modifed) their impetus beliefs; none of the nonconceptual feedback included a logical mandate to reject the fallacies of impetus and infer the principle of inertia. These empirical findings entail several implications for the field of science education. Science instruction should include the sort of "predict, observe, re-predict" cycle employed here; but the use of such empirical feedback should be followed by the conceptual feedback that is needed to place the *next* cycle on a higher level of sophistication.

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