Seeing the Forest from the Trees: A Comparison of Two Instructional Models Using Contrasting Cases

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Abstract

6th grade students learned about horizontal projectile motion through Compare and Contrast (CC) instruction or Invention (INV) activities using identical contrasting cases generated by a Physics Education Technology (PhET) computer simulation. Results showed that the INV treatment led to superior learning outcomes over the CC condition. Worksheet analyses revealed that CC students mainly focused on single factor features, whereas the inventing directive led students to focus on finding an overall explanation. As a result, the INV students were more likely to give deeper structure accounts of the features that could explain all the contrasting cases; they found the forest from the trees.

OBJECTIVE

With the rapid growth of computer simulations, student experimentation can become a mainstay of regular instruction without prohibitive cost or risk. By their nature, experiments with multiple conditions produce 'contrasting cases' of results. Our research investigates what models of instruction can best help students learn from these contrasting cases. Our objectives are two-fold: 1) Develop evidence on the psychology and effectiveness of an instructional approach called 'Inventing with Contrasting Cases' (ICC), and 2) develop guidelines for the design of computer simulations intended to support learning. Here, we focus on the former objective by describing the results of a study comparing two approaches to using contrasting cases derived from computer simulations, namely, ICC vs. Compare and Contrast.

BACKGROUND

There is a substantial literature that indicates juxtaposing multiple cases or problem instances can positively influence learning and transfer. This includes work on analogy (Gentner et al., 2003), near misses (Gick et al., 1992), perceptual learning (Biederman et al., 1987), memory (Bransford et al., 1989), procedural learning (Rittle-Johnson et al., 2009), and category induction (Williams et al., 2010). In our work, we juxtapose contrasting cases that vary from one another along a set of dimensions, much like an experiment varies the levels of a factor (we provide examples below). So, rather than working on the problem of how to help students design experiments, e.g. with control of variable strategy or the hypothetico-deductive process, we are working on the problem of helping students in the inductive process of finding patterns.

Our approach is to have students try "inventing" a general explanation that can handle all contrasting cases, much like a good theory can explain the results of multiple experimental conditions. For example, in one series of studies, we provided students with sets of contrasting cases designed to help them induce the structure of density (**, in press). When students were asked to invent a single procedure for generating a "crowdedness index" for the cases, they learned the ratio structure of density and spontaneously transferred to new problems. They outperformed control students, who were told about density at the outset and then applied the formula to the exact same contrasting cases.

One question from this work is whether the key ingredient of the inventing activity was that it implicitly asked students to compare and contrast the cases. Our hypothesis is that comparing and contrasting across cases is necessary for induction, but it is not sufficient for the types of results found in the preceding study. Our hypothesis is that asking students to simply find the similarities and differences across cases leads them to notice discrete, surface features of the cases. To get strong learning effects, students still need to be encouraged to produce a *comprehensive* explanation of the similarities and differences; that is, they must be tasked with finding an underlying structural similarity that explains all contrasting cases. To test this hypothesis, the current study compares the effects of (a) instructions to compare and contrast versus (b) instructions to invent a general solution. Both groups were given identical contrasting cases. We examine both learning outcomes and students' worksheet answers that lead to different learning outcomes.

METHODS

Participants and Design:

Two 6th-grade classes from two high-SES schools with the same math teacher participated. Due to logistical constraints, intact classes were randomly assigned to the two treatments, Invent (INV, n = 19) or Compare & Contrast (CC, n = 21). In both conditions, students variously worked individually or in groups, consistent with regular classroom practice. All tests were taken individually.

Materials and Procedures:

The lessons were organized around the PhET "Projectile Motion" simulation (http://phet.colorado.edu/en/simulation/projectile-motion). Learners can fire objects out of a cannon by manipulating different variables, including angle, initial speed, mass, and air resistance (Figure 1).

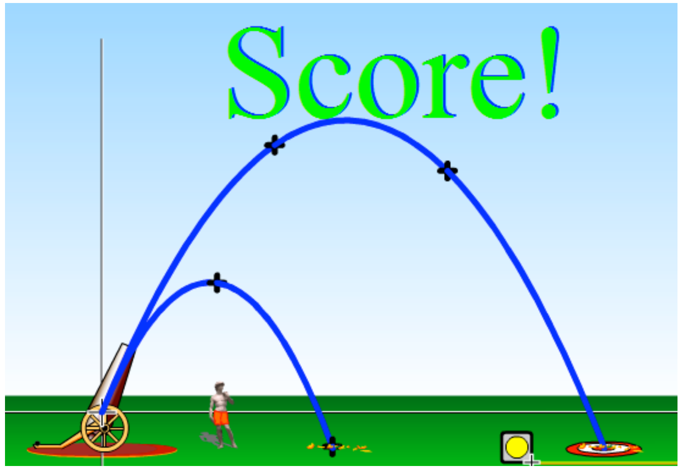


Figure 1. Phet Projectile Motion Simulation

Projectile motion problems depend on decomposing the x- and y-components of the motion, where changes on the y-component are governed by gravitational acceleration. For 6th-graders, we simplified the domain to focus on the horizontal x-component of shots and removed air resistance such that the horizontal distance (d_x) is given by the horizontal velocity (v_x) multiplied by time aloft: d_x=v_x*t.

The study occurred on four consecutive Friday classes (50 min each). Figure 2 shows the overall timeline of the study, with eight assessments throughout. The first two weeks were identical for both conditions, serving to introduce students to projectile motion, the simulation, the simulation's use of '+' signs to mark the position of a shot at each second, etc.

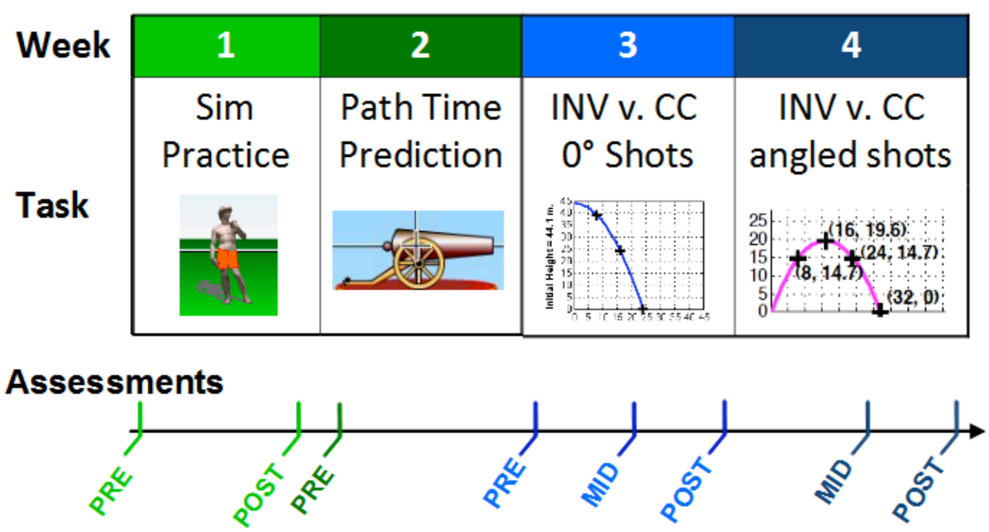


Figure 2: Study Timeline

In week 3, all students answered a pretest item and then were elected into pairs by seat-assignments. All were given a “cover story” of working for an amusement park that shot visitors out of cannons (Figure 3) plus a set of contrasting cases (Figure 4). All pairs were told to figure out the right place for the water tank such that each visitor has a good landing. Each set of cases represented a different company’s “cannon rides” in which visitors were shot straight out at 0° angle, but at different speeds and from different heights. Each case included all the relevant information (e.g., height, speed, etc.).

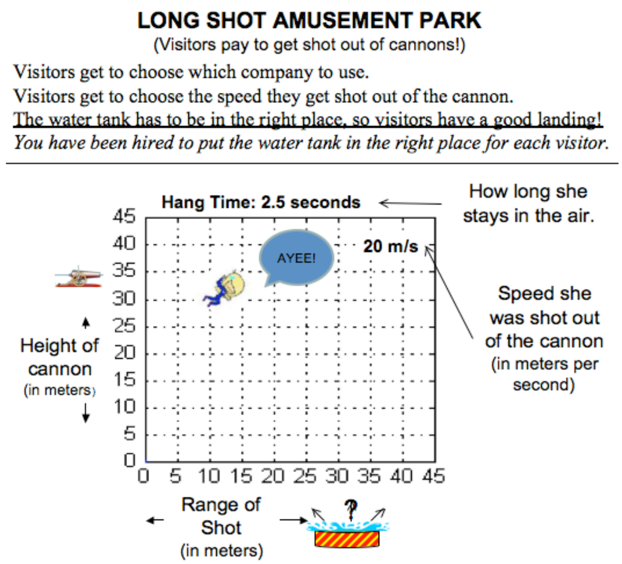


Figure 3. Coversheet For Contrasting Cases, Week 3.

The treatment difference occurred in the instructions that students received. CC pairs were prompted to “Compare and contrast the examples and companies. Explain the similarities and differences.” INV pairs were told to “Invent a single method to figure out where to put the pool no matter which company and speed a visitor chooses.” This phase lasted 15 minutes. Students answered a brief test item, used the simulation to test their ideas, and then took the posttest.

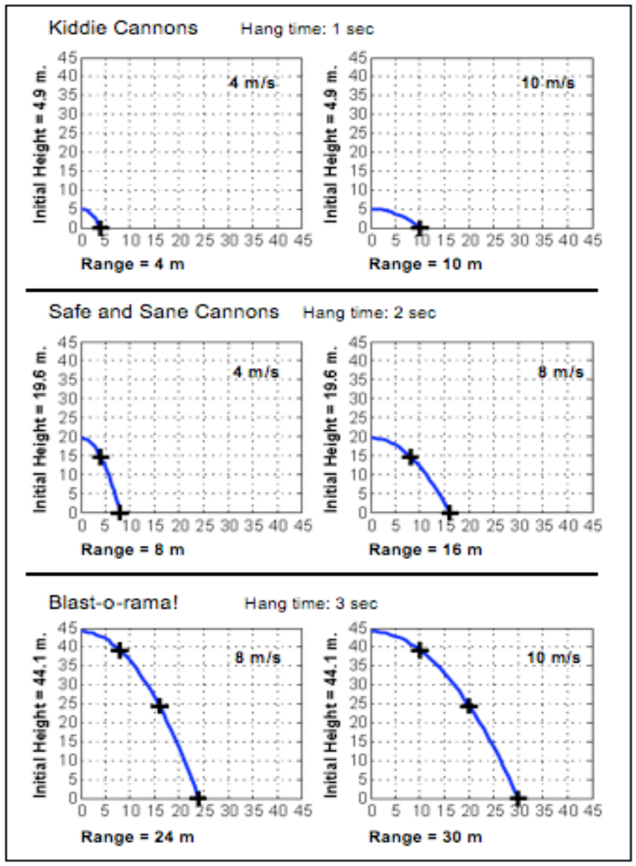


Figure 4. Contrasting Cases For Cannon Companies With 0° Angle Shots, Week 3.

Week 4 implemented the treatment difference in a similar way, except that now students worked with parabolic shots. Using the same cover story, pairs of students received worksheets with cases of cannon rides from two companies (Figure 5). All pairs were told that a camera had to take pictures of the visitors; their task was to decide which track to use for the camera (x- or y-axis), and "how it should move on the track to get a picture each second." The INV group was told to come up with a general solution, and the CC group was told to find the similarities and differences across the cases. Afterwards, students answered a midtest item, were given a 5-minute lecture covering both vertical and horizontal components of projectile motion, and finally completed a more extensive posttest.

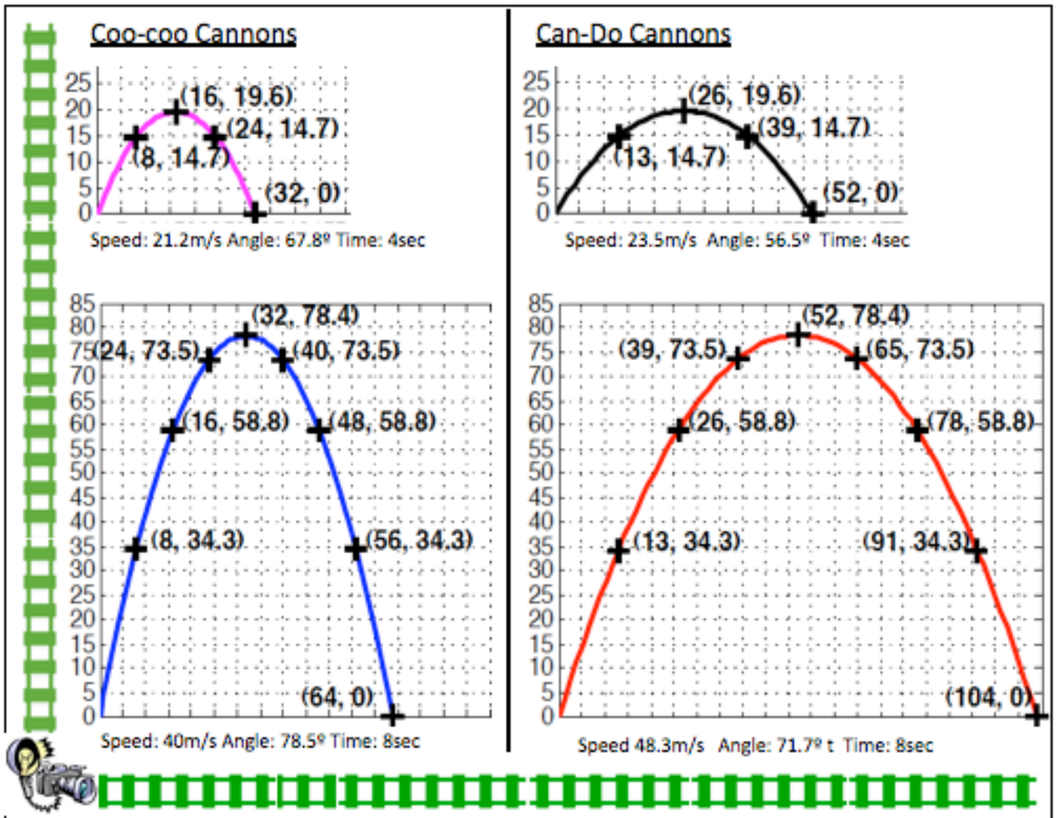
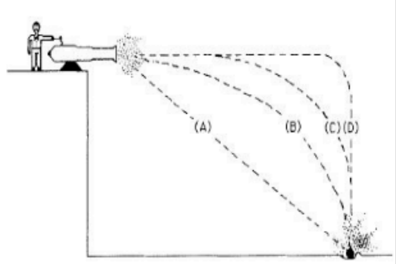


Figure 5. Contrasting Cases for Cannon Companies with Angled Shots, week 4.

Measures:

Some examples of test items in the study appear in Figure 6a and Figure 6b. For learning outcomes, some answer items required coding; two independent coders evaluated such items, with inter-coder reliability above 0.9 for all. Additionally, we coded students' worksheets in weeks 3 and 4 (described below).

A. Which of the shot paths in the diagram below best represents the path of the cannon ball?



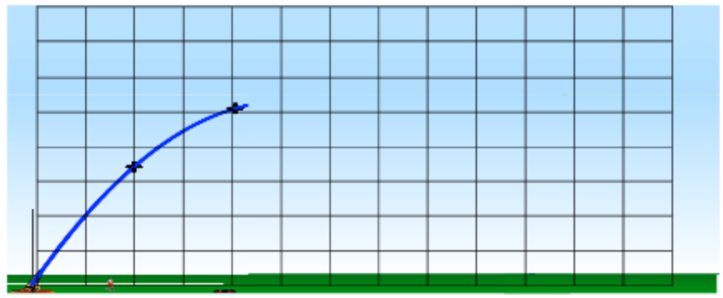
B. A bowling ball is shot out of a cannon straight out at a speed of 18 m/s. The cannon is at a height of 11 m. The ball has a mass = 9 kg and diameter = 0.3m. The ball lands in 1.5 seconds. There is no air resistance.

i) How far does the ball go before landing (what is its range)? _______________

ii) How do you know?

Figure 6a. Samples test items in Week 3. Item A is an FCI question given at pre- and posttest. Item B or its isomorph was given at mid- and posttest.

C. A cannon ball is shot at an upward angle. The ball will stay in the air for 5 seconds before it lands. The picture below shows the first two seconds of its flight.



i) Draw on the picture where you think the shot will land.

ii) How did you decide where it will land?

Figure 6b. Samples test items. Item C was given as a posttest item for week 4.

RESULTS

The two groups were comparable at the outset of Week 3 when the treatment differences began: there were no significant differences between treatment groups on two tests given by the teacher before the study, or any of our assessments before or at pretest on week 3.

Test Scores:

On the midtest of week 3, just after the two treatments had completed their first CC or INV activities, they began to separate (Figure 7). For item B in Figure 6, the INV group outperformed the CC group: 87.5% versus 30% respectively, $\chi^2(1, N=36) = 11.90$, $p = 0.001$ (a solution was worth 1 if it was completely correct or 0 if not). For an isomorphic item B in the posttest, the advantage remained; 87.5% (INV) versus 40% (CC), $\chi^2(1, N=36) = 8.44$, $p = 0.004$. It seems that working with the simulation after the treatment provided some modest help for the CC condition.

Item A in Figure 6, however, did not show any differences between treatments, either in pretest or posttest. Figure 7 shows that students were near ceiling at both points. This is interesting, because the item is drawn from the Force Concept Inventory (Hestenes et al., 1992) and is notoriously problematic for adults. One possible explanation is that the simulation, which the students had been using for the first two weeks, provided the help needed for students to correctly identify the proper trajectory.

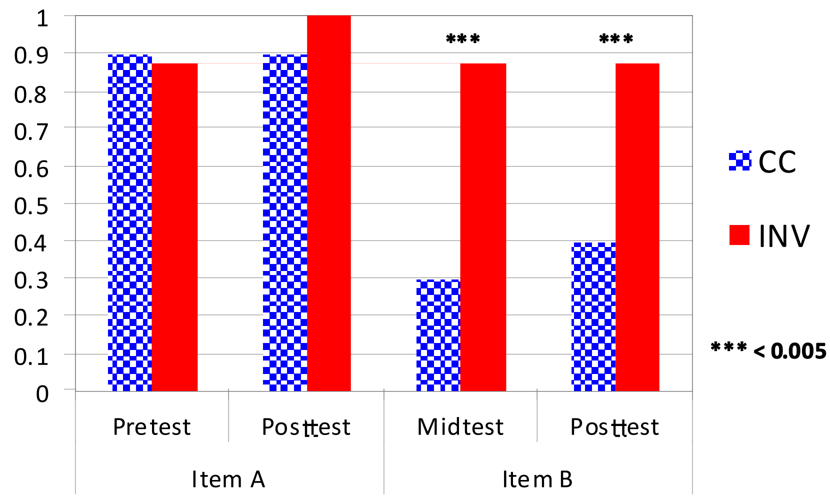


Figure 7. Week 3 results. Item A was replicated exactly across pre- and posttest. Item B had two isomorphs which were counterbalanced across the midtest and posttest.

In Week 4, the groups only showed differences on posttest item C in Figure 6. No significant difference was found on either the midtest item (floor effect) or three other posttest items. For item C, we coded 1) whether students correctly predicted the landing location and 2) whether they drew the correct trajectory. For the former, the INV group was significantly more likely to find the correct landing spot than the CC group; 47.4% versus 15% respectively, $\chi^2(1, N=39) = 4.79$, $p = 0.029$. For the trajectory, INV also outperformed their CC peers: 57.9% versus 25% respectively, $\chi^2(1, N=39) = 4.36$, $p = 0.037$.

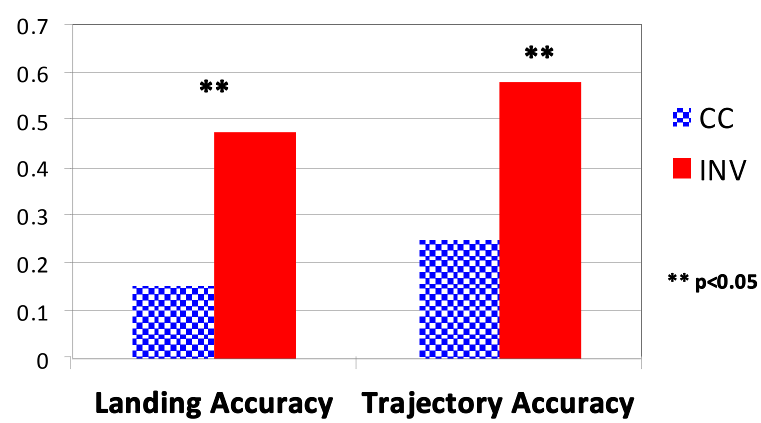


Figure 8. Week 4 results on Item C. Student answers were coded for accuracy of both the landing location and the trajectory path.

Worksheets Analysis:

The assessments of learning provide one indication of the treatment effects. A more direct measure compares what students produced on the worksheets. These differences help explain the source of the learning effects. Our leading hypothesis was that the CC treatment would lead students to pay attention to single factor features, whereas the INV treatment would lead them to find structural relations among features. We thus coded worksheets for the number of single, double, and triple physics factor statements, where a double factor tried to relate two physics features, etc. Figure 9 shows examples and coding of factor statements from two pairs of students from week 3, separated by condition. Certain statements, such as "They are different company," were classified as non-physics factors and not included in the analysis.

Compare and Contrast (CC):	Invent (INV):
Difference: -They start at different height. *[Single]* -They go different speeds *[Single]* -They are different company **Similar:** -more speed = further Distance *[Double]* -more height = further *[Double]* -They are all cannons	d=rt(distance=rate X time) To find where the person will land, you multiple the hang time by how many meters per second. *[Triple]*

Figure 9. Example of transcribed worksheet answers from two pairs of students (one CC pair and one INV pair), week 3. Coding of statements is indicated in *[italics]*.

For Week 3 worksheets (Fig. 4), CC pairs produced an average of 3.0 single-factor statements (SD_{CC} = 1.05) and 0.09 double-factor ones (SD = 1.28). In contrast, INV pairs produced no single- or double-factor statements. Instead, 100% of INV pairs produced a triple-factor statement compared to 10% for the CC group, $\chi^2(1, N=18) = 14.40$, $p < 0.001$. Similar patterns appear on the Week 4 worksheets. The CC students produced 3.11 single-factor statements (SD = 1.26) whereas the INV produced none. There were very few double-factor statements in either condition. Finally, 77.8% of INV pairs produced triple-factor statements compared to 33.3% of CC pairs; $\chi^2(1, N=18) = 3.6$, $p = 0.058$.

CONCLUSION

The INV treatment led to superior learning outcomes over the CC condition in week 3 and on one item in week 4. The directive to compare and contrast led students to focus on the level of single features, whereas the inventing directive led students to focus on finding an overall explanation. As a result, the INV students were more likely to give deeper structure accounts of the features. They generated, or were on their way to generating, the correct relationship among the three factors v_x, d_x, and t. By relating multiple features, INV students found a fundamental structural similarity that explained all the contrasting cases; they found the forest among the trees.

We believe that driving towards an overall explanation is a fundamental characteristic of science, and therefore, it is worthwhile to have students do the same. The current results indicate that this activity can be integrated into regular instruction with computer simulations to help students learn hard science concepts.

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