Examples and Mathematics: How to design physics materials for learning and transfer

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Introduction

- Equations are an important in math and science
  - CCSS: Create equations in two or more variables
    Look for and make use of structure
  - NGSS: Model scientific phenomena with math
- However, students do not always think to use them when solving problems

How can instruction help students learn to use precise, general explanations, such as equations, to explain scientific phenomena?

Inventing with Contrasting Cases
- Showing a series of instances and asking students to invent a general explanation is more effective than telling the solution (Schwartz, Chase, Oppezzo, & Chin, 2011)
- Contrasting cases are rooted in ideas from perceptual learning: contrasts help people to notice relevant features (Gibson & Gibson, 1955)

Prompting the Use of Mathematics
- Prompting students to use math instead of words in explanations may help them create more adult-like problem solutions (Schwartz, Martin, & Pfaffman, 2004)

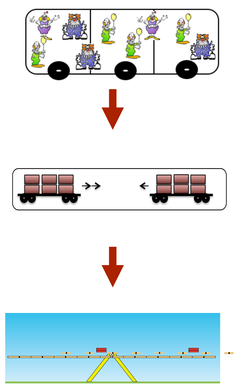
Methods

Participants
- 108 community college students
- Students who already knew momentum or torque formulas were excluded from the sample

Setting
- 1-hour laboratory study
- Participants worked individually on pencil & paper

Study Procedure

Warm-Up Activities → Learning Activity: Collisions Contrasting Cases & Posttest → Transfer Activity: Balance Scale Contrasting Cases & Posttest



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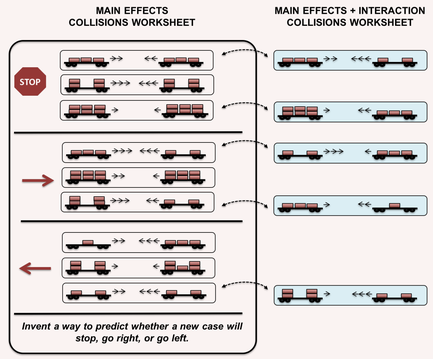
Content: Two-Factor Physics Problems

- Problems where two factors are multiplicatively combined to predict a result
  - Inelastic collisions — Momentum = mass x speed
  - Balance scale — Torque = mass x distance
- Two types of cases
  - **Main Effects (ME)** — At least one factor is held constant or both predict the same result
  - **Interactions (I)** — Two factors trade off, independently predicting opposite results

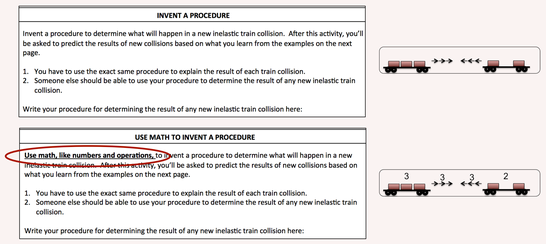
Designing Contrasting Cases

- All experimental manipulations applied to the inelastic collisions learning activity
- Between-subjects 2 x 2 factorial: Choice of Examples x Instructions

Manipulation 1: Choice of Examples
- Some participants only received main effects
- Others saw main effect & interaction cases
- Same total number of cases

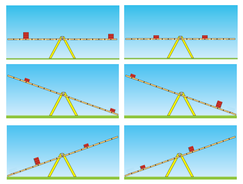


Manipulation 2: Instructions to Use Math
- Instructions to use math in solutions
- Labeled numerical values for mass and speed
- Orthogonal to choice of examples

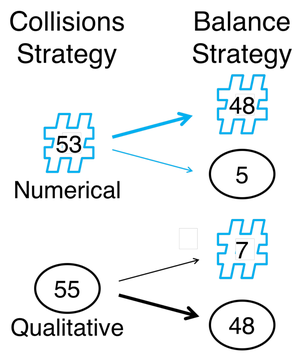


Transfer Task

- Preparation for Future Learning assessment (Bransford & Schwartz, 1999) investigating whether experiences on the collisions task affected learning about the balance scale, a new two-factor physics problem
- All participants received main effects and interaction cases
- No instructions to use math or labeled numbers
- Materials should be sufficient to find a multiplicative solution

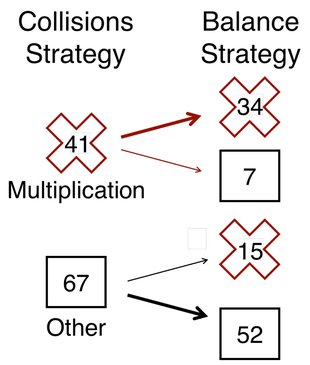


Strategy Choice Results



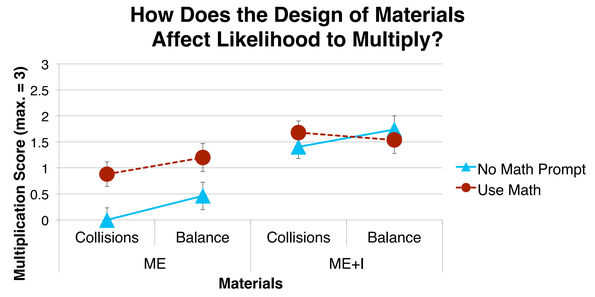
- Strategies on each task were coded as multiplicative, additive, or using no math operations

Strategy use on the learning task was a very strong predictor of strategy use on the transfer task
- Participant using mathematical strategies on collisions were likely to continue using math on balance
- A participant who multiplied on collisions was also likely to multiply on balance



Learning and Transfer Results

A composite Multiplication Score was computed for each participant on each task, with three possible points:
1. Multiplication strategy written on worksheet
2. Perfect score on posttest items requiring multiplication
3. Self-report of multiplication strategy on open-ended posttest question asking to explain an answer



- Seeing interactions on collisions increases likelihood of multiplying on collisions and balance, $p < .01$
- The prompt to Use Math marginally improves multiplication scores, $p = .06$
- Marginal materials * prompt interaction, $p = 0.09$

Conclusions

- Choosing the right examples is important
  - **Oversimplifying materials** can have negative consequences for learning; students are less likely to create mathematical equations
  - Oversimplification hinders learning on future problems, suggesting negative transfer of qualitative solutions
- **Prompting** students to use mathematics may help
  - Especially true in conjunction with incomplete materials: prompt may compensate for missing information
  - However, prompting is not as effective as selecting a comprehensive set of contrasting cases
- Direct implications for the selection of examples and design of prompts for learning materials
- Future work should investigate ways to help students with insufficient, correct-at-the-time understanding learn from more complex information on subsequent tasks

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