Learning from Explanation: The Timing and Source of Explanations For Learning Early Algebra

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National Science Foundation
WHERE DISCOVERIES BEGIN
AERA 2014

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Should children be taught new concepts directly…

or discover these ideas for themselves?

2

Direct Instruction

Should children be taught new concepts directly…

Exploratory Learning

or discover these ideas for themselves?

3

Direct Instruction

Exploratory Learning

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Direct Instruction

Lessens burden on cognitive resources

(Kirschner et al., 1996)

Exploratory Learning

Increases motivation and depth of understanding

(Wise & O'Neill, 2009)

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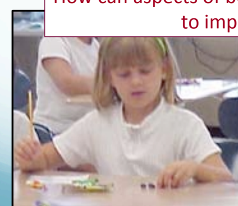
Direct Instruction

Lessens burden on cognitive resources

(Kirschner et al., 1996)

How can aspects of both approaches be combined to improve learning?



Exploratory Learning

Increases motivation and depth of understanding

(Wise & O'Neill, 2009)

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Theoretical Perspective

- Integrate exploration and instructional guidance
  - Capitalize on strengths of both
    - (Lorch, et al, 2010; Mayer, 2004; Schwartz & Bransford, 1998)

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Sequencing Exploration and Instruction

- Instruction followed by problem exploration (*Instruct-Explore*): Predominant approach in U.S.
- Problem exploration, followed by instruction (*Explore-Instruct*): Alternative approach with promise

(Kapur, 2011, 2012; Schwartz & Bransford, 1998; Schwartz, Chase, Chin & Oppezzo, 2011; Schwartz & Martin, 2004)

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Instruction and Exploration: Source of Explanations

Direct Instruction

- **Instructional-explanations**: explanations provided by experts meant to elucidate underlying reasons and patterns
- **Self-explanations**: explanations *constructed* by learners in attempt to make sense of new information (Chi, 2009)

Exploratory Learning

- Both types of explanations can improve learning but also have limitations (e.g., Renkl, 2002; Rittle-Johnson, 2006; Wittwer & Renkl, 2010).

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Objective

- Synthesize three of our recent studies on exploration and explanation
- All children explored unfamiliar mathematics problems and received instructional explanations.
  - Manipulated the order of exploration and instruction.
  - Studies varied in whether and how children were prompted to self-explain during the explore phase.

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Learning Content: Math Equivalence

Two sides of the equation represent the same quantity

3 + 4 = 3 + 4

Children often treat the equal sign operationally

3 + 4 = [7] + 4

- "It means add the numbers" or "get the answer"

Need to get to a relational view

- Look at relations across both sides of the equal sign
  - (e.g., Baroody & Ginsburg, 1983; McNeil & Alibali, 2005)

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Important but Unfamiliar

- Important: Mathematical equivalence is an early developing & foundational concept in algebra
  - Provides the foundation for key algebra proficiencies (e.g., Carpenter et al., 2003; Kieran, 1992; Knuth, Stephens, McNeil, & Alibali, 2006; MacGregor & Stacey, 1997)
- Unfamiliar: Elementary school children rarely exposed to equations with operations on both sides (i.e., math equivalence problems)
  - E.g., Of all instances of the equal sign in 2nd-4th grade math textbook, operations were present on both sides of the equal sign only 1 to 6% of the time (Rittle-Johnson, Matthews, Taylor, & McEldoon, 2011).

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Study 1: Impact of order and self-explanation prompts in one-on-one tutoring


Journal of Experimental Child Psychology 113 (2012) 552–568

Contents lists available at SciVerse ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

ELSEVIER

Exploring mathematics problems prepares children to learn from instruction

Marci S. DeCaro[a,*], Bethany Rittle-Johnson[b]

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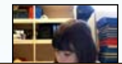
Tutoring Session



Instructional Explanation Phase

3 + 4 = 3 + 4

There are two sides to this problem...

What the **equal sign** *means is that the things on both sides of the equal sign* are **equal** *or* **the same**...

Instruct – Explore

Problem Exploration Phase

3 + 4 + 8 = ☐ + 8

7 is the right answer.

Explore – Instruct

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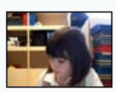
Materials based on Matthews & Rittle-Johnson, 2009

Tutoring Session



Prompted to Self-Explain

3 + 4 + 8 = 7 + 8

Ashley got 7, which is the right answer.

3 + 4 + 8 = 15 + 8

Madison got 15, which is a wrong answer.

Or to Solve Additional Problem (e.g., 6 + 4 + 5 = ☐ + 5)

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Hypotheses

1. Explore-Instruct order should…
   - Help children better gauge their understanding of the underlying concept (or lack thereof)
   - Challenge them to try to new ways to solve problems, helping them notice important problem features

   … prepare children to learn from instruction at a deeper level
   - (Bjork, 1994; Carpenter et al., 2003; Duffy, 2009; Mayer, 2004; Schwartz & Martin, 2004; Schwartz, Sears, & Chang, 2007)

2. Self-explanation prompts should promote knowledge activation and integration and lead to greater learning
   - (Chi et al, 1984; Siegler, 1995; Renkl, 1997, Rittle-Johnson, 2006)

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Method

Participants:

- 159 2nd-4th graders

Design:

- Pretest-Intervention-Posttest
  - Immediate Posttest and 2-week retention test

Intervention Context:

- One-on-one tutoring session
- Randomly assigned to one of four conditions:
  - Explore-Instruct OR Instruct-Explore
  - Self-Explain OR Solve Additional Problems during explore phase

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Math Equivalence Assessment

Used at Pretest, Posttest & Retention Test

Procedural Knowledge

- Use correct strategy to solve problems
  - Learning (Familiar): 7 + 6 + 4 = 7 + _
  - Transfer (Novel features): 6 + _ = 6 + 5 + 3

Conceptual Knowledge

- Understand concept of equivalence
  - Equal Sign (explicit): What does the equal sign mean?
  - Structure of equations: 4 + 8 = 8 + 4 True or False?

(Matthews, Rittle-Johnson, McEldoon, & Taylor, 2012; Rittle-Johnson, Matthews, Taylor, & McEldoon, 2011)

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Results

- Self-explanation prompts did not impact performance relative to solving additional problems
- Focus on order: Instruct-Explore vs. Explore-Instruct
  - Intervention
  - Posttest and retention test

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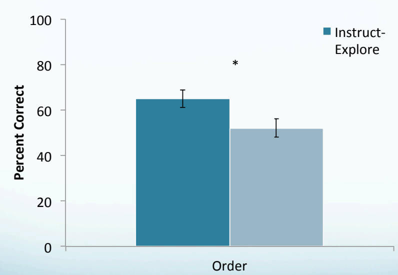
Intervention Problem Solving Accuracy



*Explore-Instruct group had lower accuracy at intervention

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Intervention Results: Strategy Variability

Number of Different Strategies Used

	Instruct-Explore	Explore-Instruct	Standard Error
Correct Strategies (3 possible)	1.17	1.34	.08
Incorrect Strategies (2 possible)	**.47**	**.74***	.07

*Explore-Instruct group used a wider variety of strategies

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Encoding of Problem Structure at Intervention

2 problems shown for 5s each (e.g., 5 + 2 = ☐ + 3)

- Write down from memory
- Often make systematic errors in line with misconceptions (e.g., 5 + 2 = ☐) (McNeil & Alibali, 2004)

	Instruct-Explore	Explore-Instruct
Problems encoded correctly	44%	54%*

*Explore-Instruct group more accurate at encoding problem features

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Intervention Explanation Quality

- Concept-based explanations such as: "They both have to equal the same."
- For conditions that were prompted to explain, no differences in explanation quality based on order of activities, $F < 2$, ns.

	Instruct-Explore	Explore-Instruct
Frequency of concept-based explanations	35%	26%

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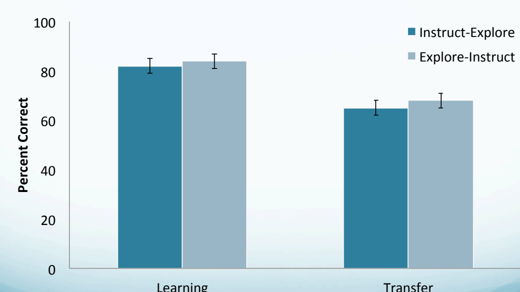
Study 2: Procedural Knowledge Across Posttest and Retention Test



No effect of order. Also no effect of self-explanation prompts.

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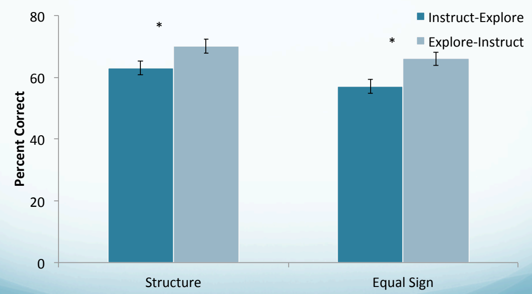
Conceptual Knowledge



*Explore-Instruction condition had greater conceptual knowledge
No effect of self-explanation prompt

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Summary of Study 1

Exploring problems prior to instruction boosted subsequent conceptual knowledge

- Exploratory experiences challenged students to
  - Try a wider variety of problem-solving strategies
  - Attend more to problem structure

Instructional explanations can reduce exploration and learning (Bonowitz et al., 2011)

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Summary of Study 1

- Self-explanation prompts did not improve learning
- Timing of instructional explanations did not impact explanation quality

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Improving Connection between Instructional Explanations and Self-Explanation Prompts

- Different self-explanation prompts can trigger different cognitive processes and lead to different learning outcomes
  - (Nokes, Hausmann, VanLehn & Gershman, 2011)
- Thus, in Study 2, we used conceptual self-explanation prompts to facilitate knowledge integration.
  - Fyfe, E. R., DeCaro, M. S. & Rittle-Johnson, B. (in press). An alternative time for telling: When conceptual instruction prior to exploration improves mathematical knowledge. *British Journal of Educational Psychology.*

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Potential Benefits to Instruct-Explore Approach

- Effective self-explanation prompts during problem-solving can help learners integrate recent instruction with ongoing problem-solving task (e.g., Berthold & Renkl, 2010; Wittwer & Renkl, 2008)

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Study 2 Method

Participants:
- 122 2nd & 3rd graders

Design:
- Pretest-Intervention-Posttest
  - Immediate and 2-week retention test

Intervention Context
- One-on-one tutoring session
- Two conditions: Explore-Instruct vs. Instruct-Explore
  - Conceptual self-explanation prompts given to all students
    - E.g., "Why does 7 make this a true number sentence?"
  - Included familiar problem types in line with common misconception to activate and engage misconception
    - (Vosniadou & Vamvakoussi, 2006)

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Intervention Self-Explanation Content

- Instruct-Explore condition provides more concept-based explanations, such as "They both have to equal the same."

	Instruct-Explore	Explore-Instruct
Frequency of concept-based explanations	46%*	26%

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Study 2 Intervention Strategy Variability

Number of Different Strategies Used

	Instruct-Explore	Explore-Instruct	Standard Error
Correct Strategies (3 possible)	2.2*	0.8	.3
Incorrect Strategies (5 possible)	**1.6***	**3.0**	.3

*Explore-Instruct used fewer correct strategies as well as more incorrect strategies

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Study 2:
Encoding of Problem Structure at Intervention

2 problems shown for 5s each (e.g., 5 + 2 = ☐ + 3)

- Write down from memory

	Instruct-Explore	Explore-Instruct
Problems encoded correctly	52%*	37%

*Instruct-Explore group more accurate at encoding problem features

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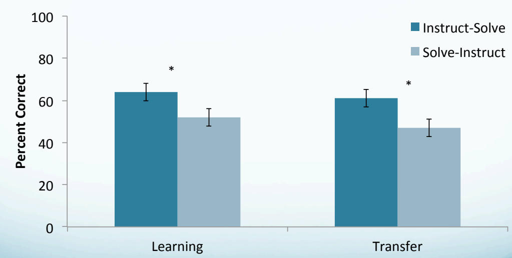
Study 2: Procedural Knowledge Across Posttest and Retention Test



*Instruct-Explore led to greater procedural knowledge on both learning and transfer items

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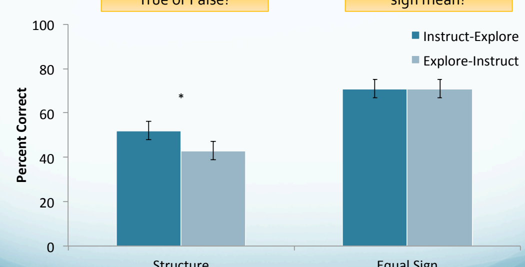
Conceptual Knowledge

4 + 8 = 8 + 4
True or False?

What does the equal sign mean?



* Instruct-Explore had higher knowledge of structure and similar explicit knowledge of equal sign

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Mediators

- Both self-explanation quality and problem-solving accuracy during the intervention mediated the impact of condition on learning outcomes

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Study 2 Summary

- Contrary to Study 1, instruct-explore ordering improved the quality of self-explanations and invention of correct strategies, which in turn supported greater learning outcomes

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Study 3: Impact of Order in Classroom Context

- Effective exploration seemed easier to achieve than effective self-explanation in a classroom setting.
- Thus, focus on order of activities without self-explanation prompts. Predicted Explore-Instruct condition would support greater learning

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Study 3 Method

Participants:
- 47 2nd graders

Intervention Conditions:
- Explore-Instruct vs. Instruct-Explore
- Implemented in small groups of 3-6 students during one math class by research assistants
- Posttest was following day, rather than immediately after intervention

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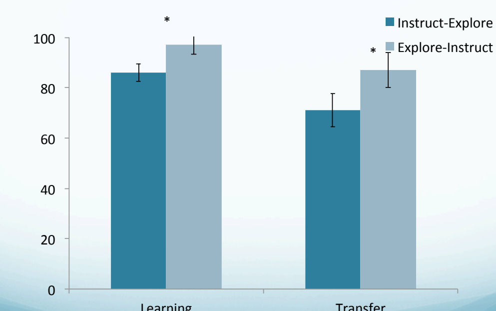
Study 3: Procedural Knowledge at Posttest



***Explore-Instruct condition solved more problems correctly**

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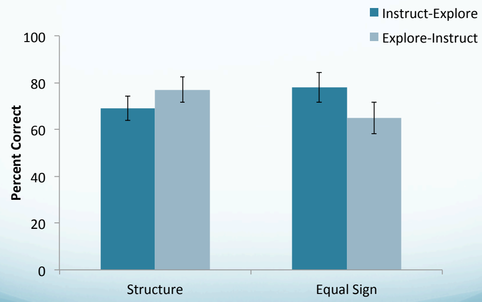
Conceptual Knowledge



*No Effect of Order

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Study 3 Summary

- Exploring problems prior to instructional explanations boosted subsequent knowledge in a classroom setting

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Summary Across Studies

- Exploring unfamiliar math equivalence problems prior to instructional explanations leads to greater knowledge than solving the problems after instructional explanations
  - If students are *not* supported in generating self-explanations that draw on instructional-explanations during problem solving
  - If prior misconceptions are not activated (tentative)

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Exploration **Before** Instruction

- There is a *time for telling* – often *after* students explore (Schwartz & Bransford, 1998)
- Exploration prior to instruction:
  - Activates prior knowledge
  - Helps students notice important features of problems
  - Helps students recognize that they don't understand
  - Preparing them to learn from the instruction
    - (Bjork, 1994; Carpenter et al., 2003; Duffy, 2009; Mayer, 2004; Kapur, 2011, 2012; Schwartz & Martin, 2004; Schwartz, Sears, & Chang, 2007)

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Boundary Conditions

- There is a time for providing instruction before exploration.
- Instructional explanations prior to promoting concept-based self-explanations during exploration is one promising time.

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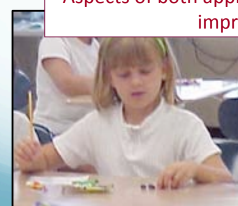
Direct Instruction

Should children be taught new concepts directly…

Aspects of both approaches can be combined to improve learning



Exploratory Learning

or discover these ideas for themselves?

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Want to Hear More?

- Today 12:25 to 1:55pm, Marriot, Fourth Level, 413
- 59.033: Research on Mathematical Explanations and Discourse
  - Learning from Explanation: Does it matter who provides them?
    - Abbey Loehr and colleagues
  - Enhancing the quality of children's explanations to promote patterning knowledge
    - Emily Fyfe and colleagues

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Acknowledgements

Children's Learning Lab

Marci DeCaro

Emily Fyfe

Abbey Loehr

Katie McEldoon

Student RAs (Maryphyllis Crean, Polly Colgan, Rachel Ross, Maddie Black, Laura McLean and Ellen O'Neal)

Funding Sources

NSF CAREER grant to Rittle-Johnson

NSF Graduate Research Fellowship to Fyfe

IES Pre- and Post-Doc Training Grants

Slides, Paper and Materials available at:

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vanderbi.lt/childrenslearninglab

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