Desirable Difficulties in Science Learning in a Web-Based Inquiry Science Environment (WISE)

Marcia C. Linn, Robert A. Bjork, Lindsey E. Richland, Britte H. Cheng, Nate Kornell, Matthew J. Hays, Jason R. Finley, Dan S. Fink

IDDEAS Goals and Research Reflections

Introducing Desirable Difficulties for Educational Applications in Science (IDDEAS) seeks to take advantage of powerful findings from laboratory research to improve science learning.

Desirable difficulties are instructional activities that slow the rate of learning—even increasing errors—but lead to better performance on subsequent assessments.

- Generation/Testing
- Interleaving
- Spacing

We focus on testing desirable difficulties with more complex materials and longer retention intervals than are typical of laboratory studies, and on carrying out parallel classroom studies.

Web-based Inquiry Science Environment (WISE, http://wise.berkeley.edu) as a research tool:

- Delivers scientific educational content in multiple formats
- Offers a number of customizable ready-made modules
- Authoring tools enable experimental manipulation
- Gathers embedded assessments of student progress
- Already in use in many classrooms

Reflections

- In both laboratory and classroom contexts, some desirable difficulties were found to benefit learning, some were not, and some were found to interact with other factors.
- Our findings both extend previous psychology and education research and raise new questions.
- Translating desirable difficulties to classroom education is less than straightforward, and requires addressing previously unconsidered issues.
- Generalizing laboratory results requires new research designs and new assessment practices
- Classroom studies raised issues about how to take advantage of the social context of the classroom.

Participants

Marcia Linn
Principal Investigator
University of California, Berkeley

Robert Bjork
Principal Investigator
University of California, Los Angeles

Lindsey Richland
Post-doctoral scholar
University of California, Irvine

Britte Cheng
Graduate Student
University of California, Berkeley

Nate Kornell
Post-doctoral scholar
University of California, Los Angeles

Matthew Hays
Graduate Student
University of California, Los Angeles

Jason Finley
Researcher
University of California, Los Angeles

Dan Fink
Researcher
University of California, Los Angeles

Michele Spitulnik, Postdoctoral scholar & TELS Affiliate; **Erika Tate,** Graduate Student & TELS fellow; **Turadg Aleahmad,** TELS technology leader; **Corrie Garner,** Middle school science teacher

Participating school districts: Mt Diablo Unified School District, Berkeley Unified School District

UCLA Undergraduate Research Assistants: Alexandra Hessenius, Amy Moore, Asako Kameya, Blaize Wallace, Carlyn Crisostomo, Catherine Hong Vo, Elizabeth Goss, Erin Glass, Fernando Cervantes, Francis Yau, Greg Cragg, Jeffrey Beyers, Jenny Yevginya Bukshpun, Jerry Lin, Jesse Venticinque, Karthik Gunnia, Katherine Huang, Katy Cohanshohet, Kerry Young, Lindsay Petersen, Liza Saglamer, Makah Leal, Matt Vincent, Melissa Lox, Richard Lee, Ross Otto, Shannon Liu, Sharon Jung, Tabasom Dadvand, Taylor Hanan, Thao Lee, Timothy Wong, Yasi Shamtoub

Generation - Laboratory

Generation has robust effects on laboratory learning

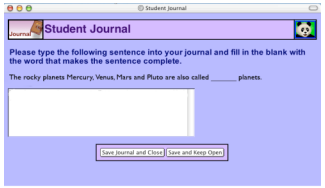
In a series of 4 experiments we examined the effects of generation on learning of complex science material.

Complex Science Learning

- Astronomy activities were taught using the Web-Based Inquiry Science Environment (WISE)

Embedded Assessments

- Prompt students to retrieve previously learned information from memory
- Serve as assessments and learning events

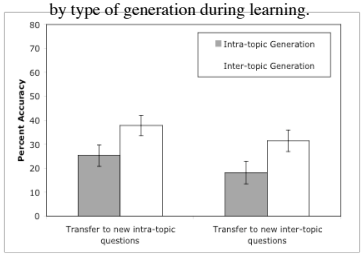


Intra-topic Embedded assessment

Types of Generation

- Generation within a topic (intra-topic generation) promotes fact learning.
- Generation across topics (inter-topic generation) promotes knowledge integration.

Performance on Post-test (48 hour delay) by type of generation during learning.



Inter-topic generation had a robust positive effect on learning

- This result is especially interesting considering that performance during study was higher on the intra-topic generation.

Generation - Classroom

Examining Instruction and Reflection Prompts

In 3 classroom studies, we studied the effects of generation (in the form of various types of reflection prompts) on learning of astronomy material delivered via WISE

Research Settings:

Study One

- San Francisco Bay Area urban public school
- ~140 8th grade students
- Large range of reading ability, socio-economic status
- Teacher had over 10 years experience (new to WISE)

Studies Two & Three

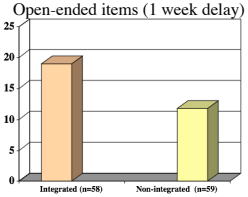
- San Francisco Bay Area suburban public school
- ~185 8th grade students
- Some range of reading ability, SES
- Teacher's second/third year teaching (and using WISE)

In studies 1 & 2, reflection prompts during instruction were fill-in-the-blank and were either integrated (across multiple concepts, e.g., mass & distance) or non-integrated (within one concept).

In study 3, prompts were open-ended and varied in their scope (narrow or broad), and complexity (simple or complex).

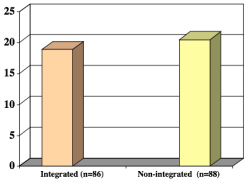
In studies 1 & 2, reflection opportunities that prompted students to integrate concepts were more beneficial than those that did not.

Study 1 Results: Post-test, Open-ended items (1 week delay)



Reflection Prompt:
$F(1,115) = 18.769$, $p = .000$

Study 2 Results: Post-test (1 week delay)



Reflection Prompt:
$F(1,172) = 3.946$, $p = .049$

Interleaving - Laboratory

Advantages

- In laboratory settings, interleaving naturally introduces the positive effects of spacing.
- Interleaving increases difficulty during learning, which can improve learning.
- Interleaving may promote knowledge integration across related concepts.

Effects of learning conditions

- Interleaving is beneficial under educationally realistic conditions for learning discrete concepts such as geometry formulas (Taylor, Rohrer & Pashler, 2006).
- **In a series of 5 experiments** we examined the effects of interleaving on learning of complex science material:
  - Astronomy:
    - planet mass vs. planet distance from sun
    - star formation vs. planet formation
  - Malaria vs. Genetically Modified Foods
- We found no straightforward advantages of interleaving, but have identified key issues and found significant interactions.

Complications

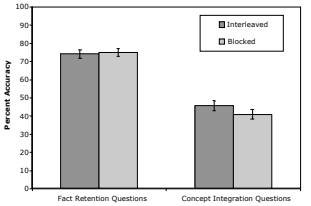
- Cumulative and narrative information requires effortful, deep processing even in the absence of interleaving.
- In the absence of repetition, information does not benefit from multiple spaced repetitions.

Interleaving and Spacing

- Spacing and interleaving may be effective to the extent that they require generating/reloading previously learned information
- Spacing and interleaving are hard to separate because interleaving necessitates spacing
- **In a series of 4 experiments** using foreign language vocabulary we have not found a consistent advantage of interleaving above and beyond the benefits of spacing.

Other Interactions

- We have found the effects of interleaving of educational material interact with:
  - time of testing (learning vs. post-test)
  - recall prompts during learning
  - type of post-test question (example below)



Interaction of Presentation Order with Type of Post-test Question, 48 hour delay (sig. $p < .05$) [using Astronomy materials: mass vs. distance]

Interleaving - Classroom

Examining Instruction and Presentation Order

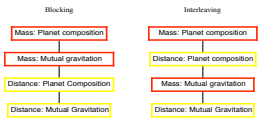
- Will blocked or interleaved sequence of instruction better support student learning?

In a classroom study, instruction was delivered via WISE. Students were introduced to basic physics principles in the context of the search for life on planets outside our solar system.

Using WISE, it was possible to carefully control:

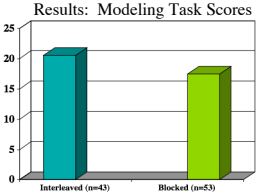
- Instructional delivery (sequence and wording)
- Reflection prompts
- Visual stimuli

Stimuli: Blocking vs. Interleaving



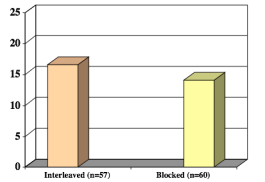
Interleaving was beneficial for student learning as measured by a solar system modeling task, but not by open-ended post-test questions.

Results: Modeling Task Scores



Order of Instruction:
$F(1,94) = 6.010$, $p = .016$

Results: Open-ended items (Post-test)



Order of Instruction:
$F(1,115) = 1.989$, $p = .16$

References: Taylor, K. M., Rohrer, D., & Pashler, H. (2006, May). *The Benefits of Mixed Practice on the Long-Term Retention of Mathematical Skills.* Poster presented at the 18th annual convention of the Association for Psychological Science, New York, NY.