Productive Failure

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Outline

- The case for failure
- Designing for productive failure
- Empirical evidence
- Discussion & implications
- Q&A

The case for failure...

Past research:

- *Cognitive Strain and Disfluency*
- *Theory of Constructive Failure* (Clifford, 1978, 1984)
- *Desirable Difficulties* (Schmidt & Bjork, 1992)
- *Impasse-driven Learning* (VanLehn et al., 2003)
- *Assistance Dilemma* (Koedinger et al., 2008)
- *Preparation for Future Learning; Inventing to Prepare for Learning* (Schwartz & Bransford, 1999; Schwartz & Martin, 2004)

What is Productive Failure?

Understand what students know about a novel concept that they have not been taught yet

Afford opportunities to activate and differentiate prior and intuitive knowledge….to generate, explore, critique, and refine representations and solution methods (RSMs) for solving complex problems

Invariably, such a process leads to failure (in relation to a desired goal)…

But, this may precisely be the locus of deep learning… provided some form of structure follows subsequently

Designing for Productive Failure

(Kapur & Bielaczyc, 2012)

GENERATION & EXPLORATION

PHASE I

- Complex problems
- Collaboration
- Affective support for persistence

CONSOLIDATION & KNOWLEDGE ASSEMBLY

PHASE II

- Consolidation
- Well-structured Problem solving OR Instruction OR Feedback OR Explanation, etc.

DELAY OF STRUCTURE

Productive Failure (Kapur, 2008)

Target Concept: Newtonian Kinematics
N = 309, 11th-grade physics students in India

Well-structured Problems (WSP)	Well-structured Problems (WSP)	Ill-structured Problems (ISP)
Ill-structured Problems (ISP)	Well-structured Problems (WSP)	Ill-structured Problems (ISP)

Compared with WSP groups, ISP groups:

1. Generated multiple representations and methods
2. Engaged in complex interaction patterns of explanation, critique, elaboration
3. Low convergence in their discussions
4. Poor group performance
5. **BUT**, better individual performance on both well- and ill-structured problems

Discussion

1. Can variation in individual or group prior knowledge explain productive failure?

2. Can variation in group performance explain productive failure?

3. Effect of prior knowledge—individual and group—as well as group performance not significant

4. Therefore, efficacy seemed to be embedded in the complex, divergent, interactional dynamics in the ill-structured groups (Kapur & Kinzer, 2009)

5. In progress: When Productive Failure fails...

The Problem
(Grade 8/9 students)

Who's the most consistent striker?

Year	Mike Arwen	Dave Backhand	Ivan Right
1988	14	13	13
1989	9	9	18
1990	14	16	15
1991	10	14	10
1992	15	10	16
1993	11	11	10
1994	15	13	17
1995	11	14	10
1996	16	15	12
1997	12	19	14
1998	16	14	19
1999	12	12	14
2000	17	15	18
2001	13	14	9
2002	17	17	10

Mike Arwen : Mean = $\frac{280}{20}$

= 14 goals /year

Mode = 14

Dave Backhand : Mean = $\frac{280}{20}$

= 14 goals / year

Mode = 14

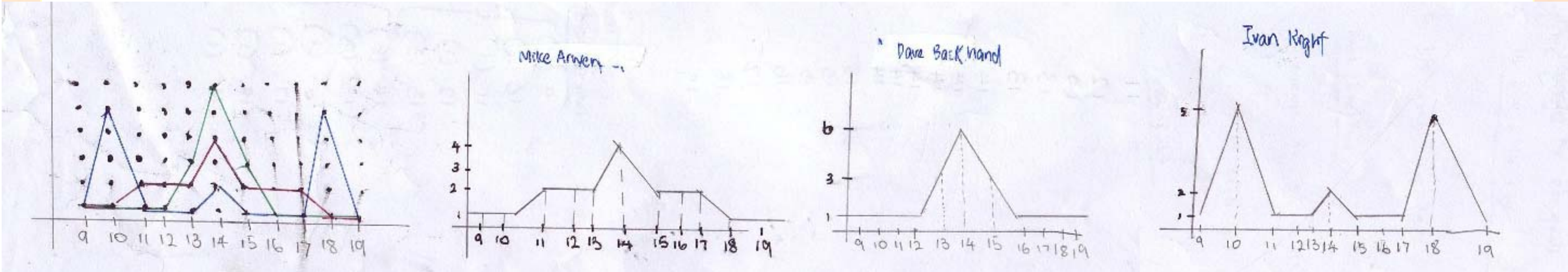
Ivan Right : Mean = $\frac{280}{20}$

= 14 goals / year

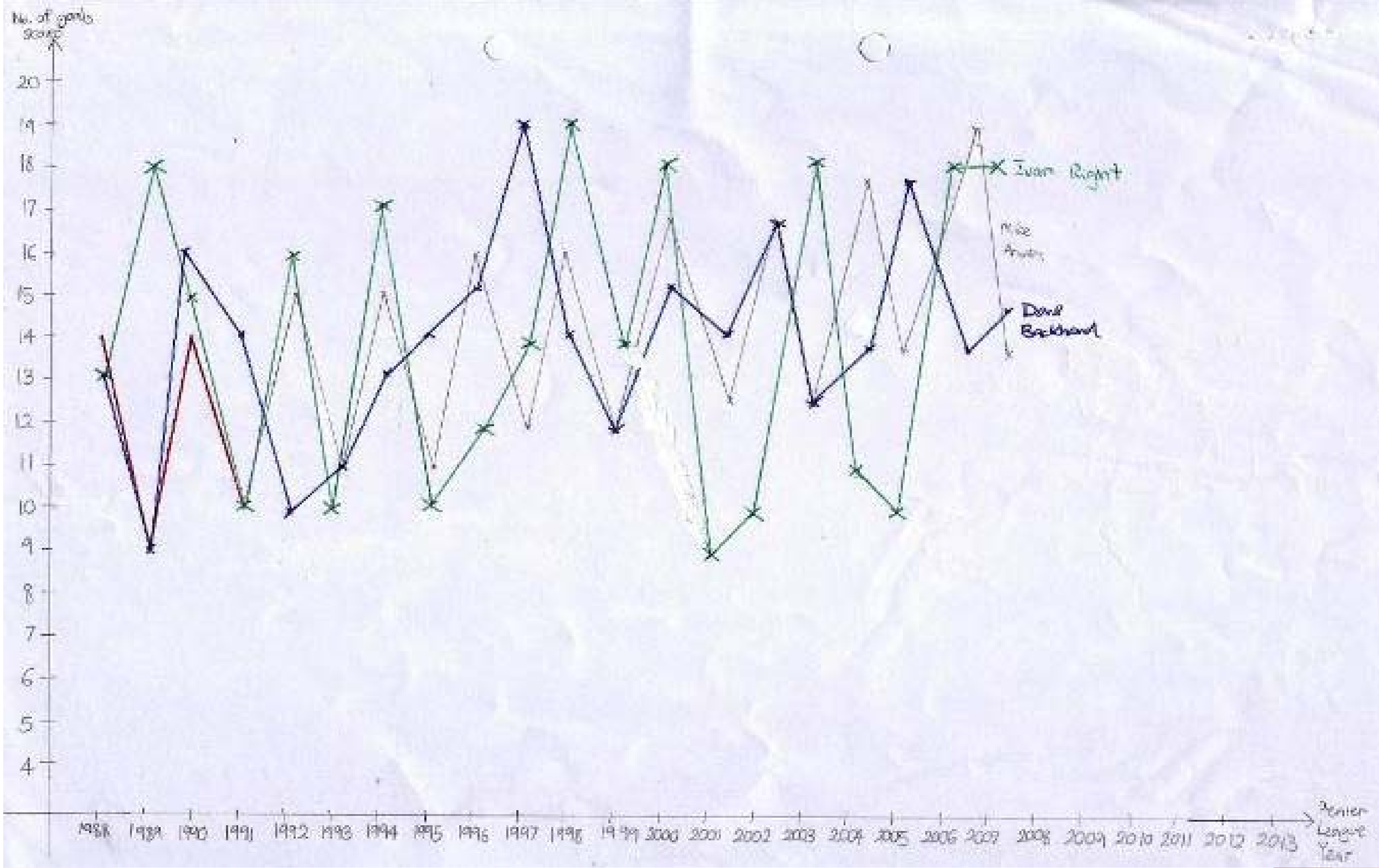
Mode = 18 and 10

comparing regularity

Player	9	10	11	12	13	14	15	16	17	18	19
Mike Arwen	1	1	2	2	2	4	2	2	2	1	1
Dave Backhand	1	1	1	1	3	6	3	1	1	1	1
Ivan Right	1	5	1	1	1	2	1	1	1	5	1



9 10 11 11 12 12 13 13 14 14 14 14 15 15 16 16 17 17 18 19


No. of goals scored
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
Ivan Right
Mike Arven
Dave Backhand
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Premier League Year

From Question paper: Average = $\frac{280}{20}$

Mike has 8 years < average

4 years = average

8 years > average

Dave has 7 years < average

6 years = average

7 years > average

Ivan has 9 years < average

2 years = average

9 years > average

Frequency of years above, below, and at average

Consistency = years at the mean / years away from the mean

Sum of year-on-year deviation

Mike:

9 − 14 = −5
14 − 9 = 5
10 − 14 = −4
15 − 10 = 5
−4
4
−4
5
−4
4
−4
5
−4
4
−4
5
−4
5
−4

Total: 0 ✓ mike

Dave:

−4
7
−2
−4
1
2
1
1
4
−5
−2
3
−1
3
−4
1
4
−4
1

Total: −2

Ivan:

5
−3
−5
1
−6
7
−7
2
2
5
−5
4
−9
1
8
−7
−1
8
0

Total: −5

Range amount for:

Mike Arwen: 9 − 19 = 10
Dave Buckland: 9 − 19 = 10
Ivan Right: 9 − 19 = 10

x

Average of year-on-year absolute deviation

MIKE = (5+5+4+5+4+4+4+5+4+4+4+5+4+4+4+5+4+5+4) / (20 − 1)

= 84/19 = 4.26

DAVE = (4+7+2+4+1+2+1+1+4+5+2+3+1+3+4+1+4+4+1) / 19

= 54/19 = 2.84   DAVE is most consistent

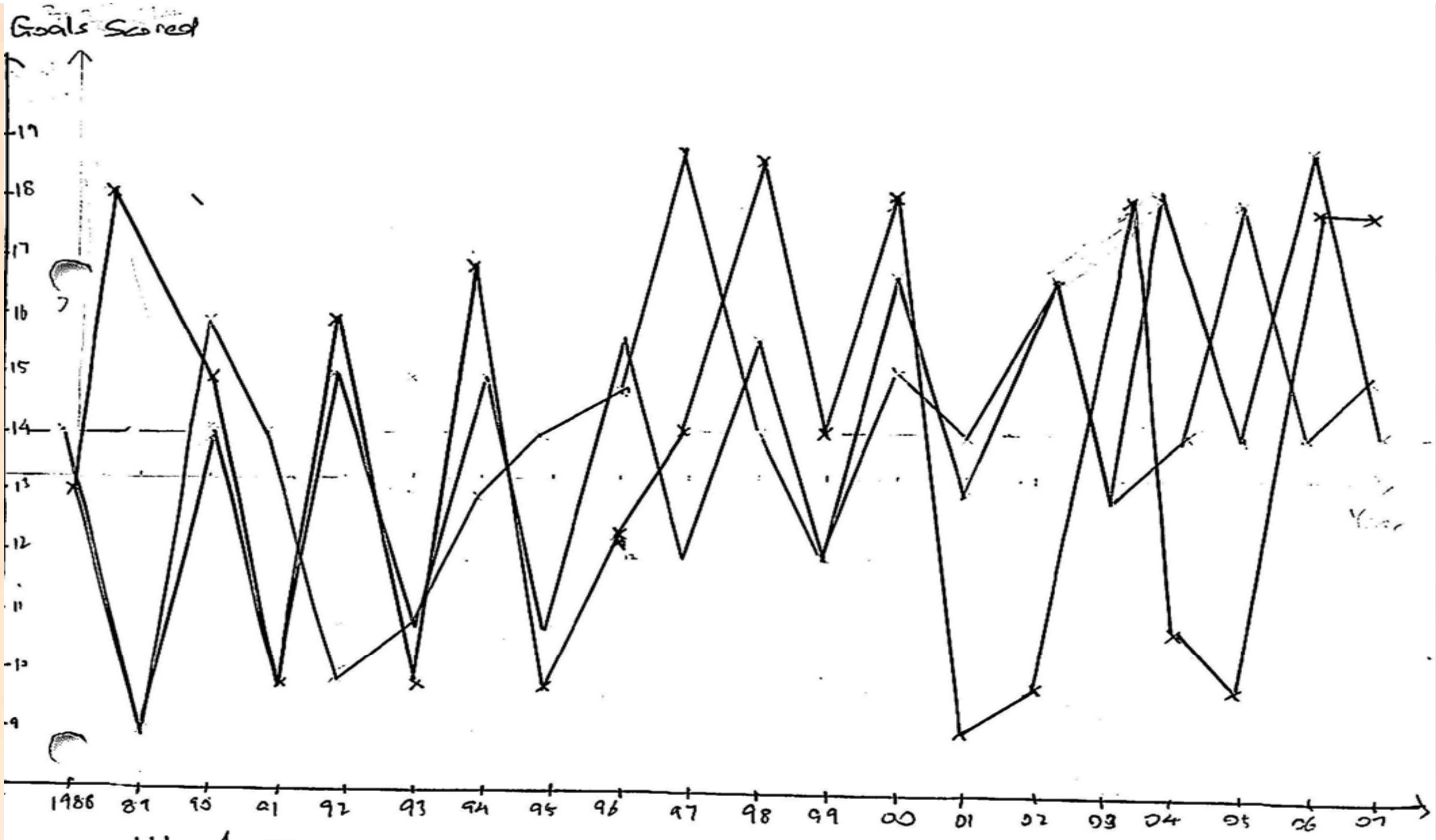
IVAN = (5+3+5+1+6+7+7+2+2+5+5+4+9+1+8+7+1+8+0) / 19

= 4.79

Sum of deviations about the mean

Year	Avg	M.A	D.B	I.R	x		
1988	14	14	13	13	0	−1	−1 [illegible]
1989	14	9	9	18	−5	−5	4
1990	14	14	16	15	0	+2	+1
1991	14	10	14	10	−4	0	−4
1992	14	15	10	16	+1	−4	+2
1993	14	11	11	10	−3	−3	−4
1994	14	15	13	17	+1	−1	+3
1995	14	11	14	10	−3	0	−4
1996	14	16	15	12	+2	+1	−2
1997	14	12	19	14	−2	+5	0
1998	14	16	14	19	+2	0	+5
1999	14	12	12	14	−2	−2	0
2000	14	17	15	18	+3	+1	+4
2001	14	13	14	9	−1	0	−5
2002	14	17	17	10	+3	+3	−4
2003	14	13	13	18	[illegible]	−1	+4
2004	14	18	14	11	+4	0	−3
2005	14	14	18	10	0	+4	−4
2006	14	19	14	18	+5	0	+4
2007	14	14	15	18	0	+1	+4

Total: [illegible] [illegible] [illegible]



— Mike Arwen
— Dave Backhand
— Ivan Right

(Idea 3) Measure Graph Length

MA $\sqrt{26}+\sqrt{26}+\sqrt{17}+\sqrt{26}+\sqrt{17}+\sqrt{17}+\sqrt{17}+\sqrt{26}+\sqrt{10}+\sqrt{10}+\sqrt{10}+\sqrt{26}+\sqrt{17}+\sqrt{17}+\sqrt{17}+\sqrt{26}+\sqrt{17}+\sqrt{26}+\sqrt{26}=83.26$

DB $\sqrt{17}+\sqrt{50}+\sqrt{5}+\sqrt{17}+\sqrt{5}+\sqrt{5}+\sqrt{2}+\sqrt{2}+\sqrt{17}+\sqrt{26}+\sqrt{5}+\sqrt{10}+\sqrt{2}+\sqrt{5}+\sqrt{10}+\sqrt{2}+\sqrt{17}+\sqrt{17}+\sqrt{2}=56.54$

IR $\sqrt{26}+\sqrt{10}+\sqrt{26}+\sqrt{37}+\sqrt{37}+\sqrt{50}+\sqrt{50}+\sqrt{5}+\sqrt{5}+\sqrt{26}+\sqrt{26}+\sqrt{17}+\sqrt{82}+\sqrt{2}+\sqrt{65}+\sqrt{50}+\sqrt{2}+\sqrt{65}+1=94.54$

∴ Dave Backhand is the most consistent player as he has the shortest 'stretched-out' graph, showing consistency over time.

Azaac Aikeen

(3)

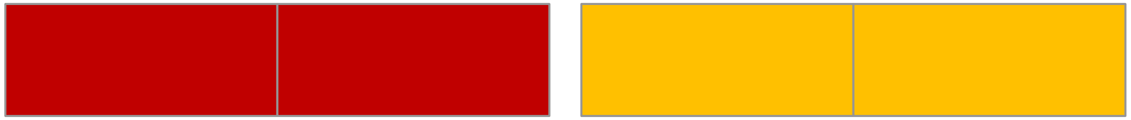
Core Mechanisms

1. Activation and differentiation of prior knowledge
2. Attention to critical conceptual features
   1. Difference between the mean and consistency
   2. Difference between a qualitative and a quantitative representation
   3. Why must deviations be positive?
   4. Why do we add all the deviations? Why not multiply them?
   5. What is the need for a fixed reference point?
   6. Why is mean a good fixed reference point?
   7. Why must we divide by *n*? …and so on…

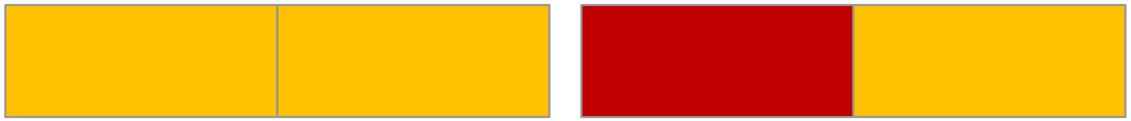
Productive Failure vs. Direct Instruction

Target Concepts:
1. Average Speed (Kapur, 2010; Kapur & Bielaczyc, 2012)
2. Standard Deviation (Kapur, 2012)

Productive Failure Students generate multiple representations and solution methods, followed by instruction



Direct Instruction Teacher explains concept, models problem solving, uses worked-out examples, practice and feedback



Dependent Variables:
1) Procedural Fluency
2) Conceptual Understanding
3) Transfer

Summary of Key Findings

- PF outperformed DI on conceptual understanding and transfer without compromising procedural fluency (Kapur, 2010, 2012; Kapur & Bielaczyc, 2012)
- The marginal gain of providing cognitive support for PF groups during the generation phase was not significant (Kapur, 2011)
- Teachers consistently underestimate students' ability to generate RSMs
- Students that seem strikingly dissimilar on general and math ability (PSLE) appear strikingly similar in terms of their generative capacity (Kapur & Bielaczyc, 2012)
- RSM diversity significantly correlated with learning gains (Kapur, 2012; Kapur & Bielaczyc, 2012)
- PF teachers consistently report that they are stressed and stretched to work with students' ideas... BUT, they themselves understood the math better...

Explaining Productive Failure

- Activation and differentiation of prior knowledge
- Attention to critical features
- critiquing, explaining, elaborating
- Owning...want to see the canonical solution
- Becoming flexible and adaptive
- Learning about math and what math is about

Further Questions

1. Exposure to student-generated RSMs

Core mechanism of activation and differentiation: Is it really necessary for students to generate the RSMs or can these be given to them as worked-out examples to study and evaluate?

Is learning from our own failure better than learning from others' failure, that is, vicarious failure?

2. Attention to Critical Features

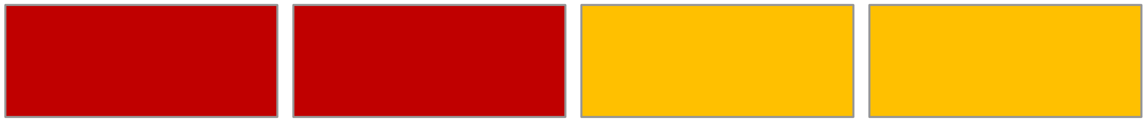
Core mechanism of attention to critical features: Do students really need to generate before receiving the critical features, or would telling the critical features without any generation work just as well?

Productive Failure vs. Vicarious Failure

Target Concept: Standard Deviation
N = 64, 9th-grade math students from 2 intact classes
Pre-post, quasi-experimental design

Productive Failure Students generate multiple representations and solution methods, followed by DI

four, 50-min periods



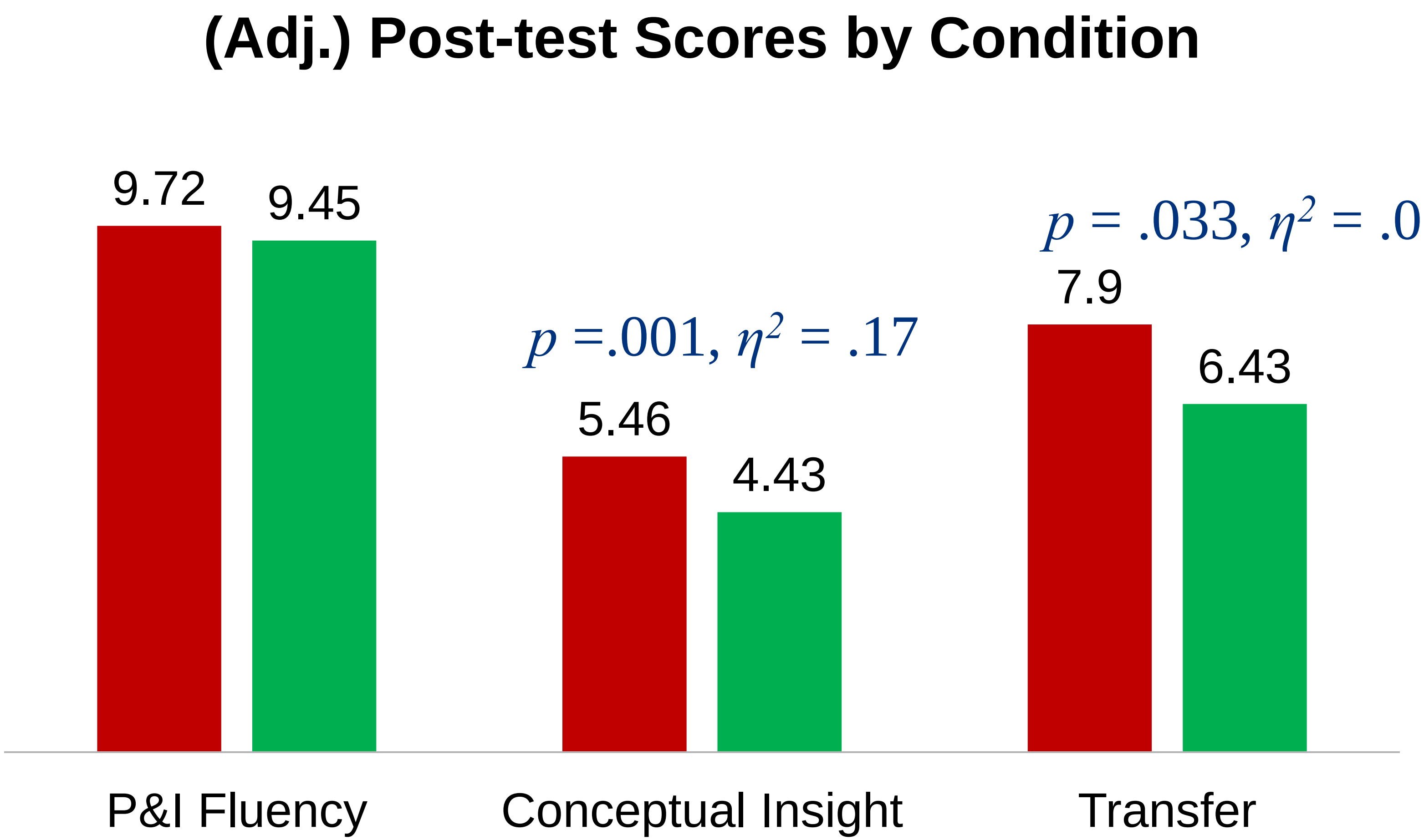
Vicarious Failure Students study and evaluate student-generated RSMs, followed by DI

four, 50-min periods

DVs:

1) Procedural Fluency
2) Conceptual Understanding
3) Transfer

Results: PF vs. VF

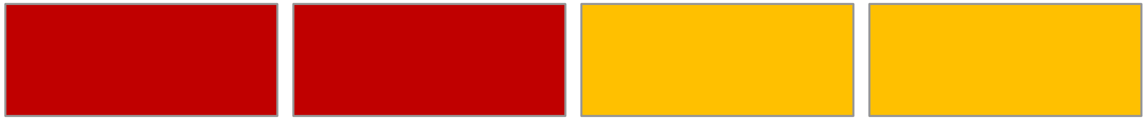


Productive Failure vs. Strong-DI

Target Concept: Standard Deviation
N = 59, 9th-grade math students from 2 intact classes
Pre-post, quasi-experimental design

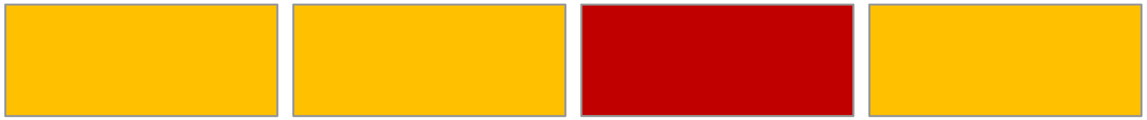
Productive Failure Students generate multiple representations and solution methods, followed by DI

four, 50-min periods



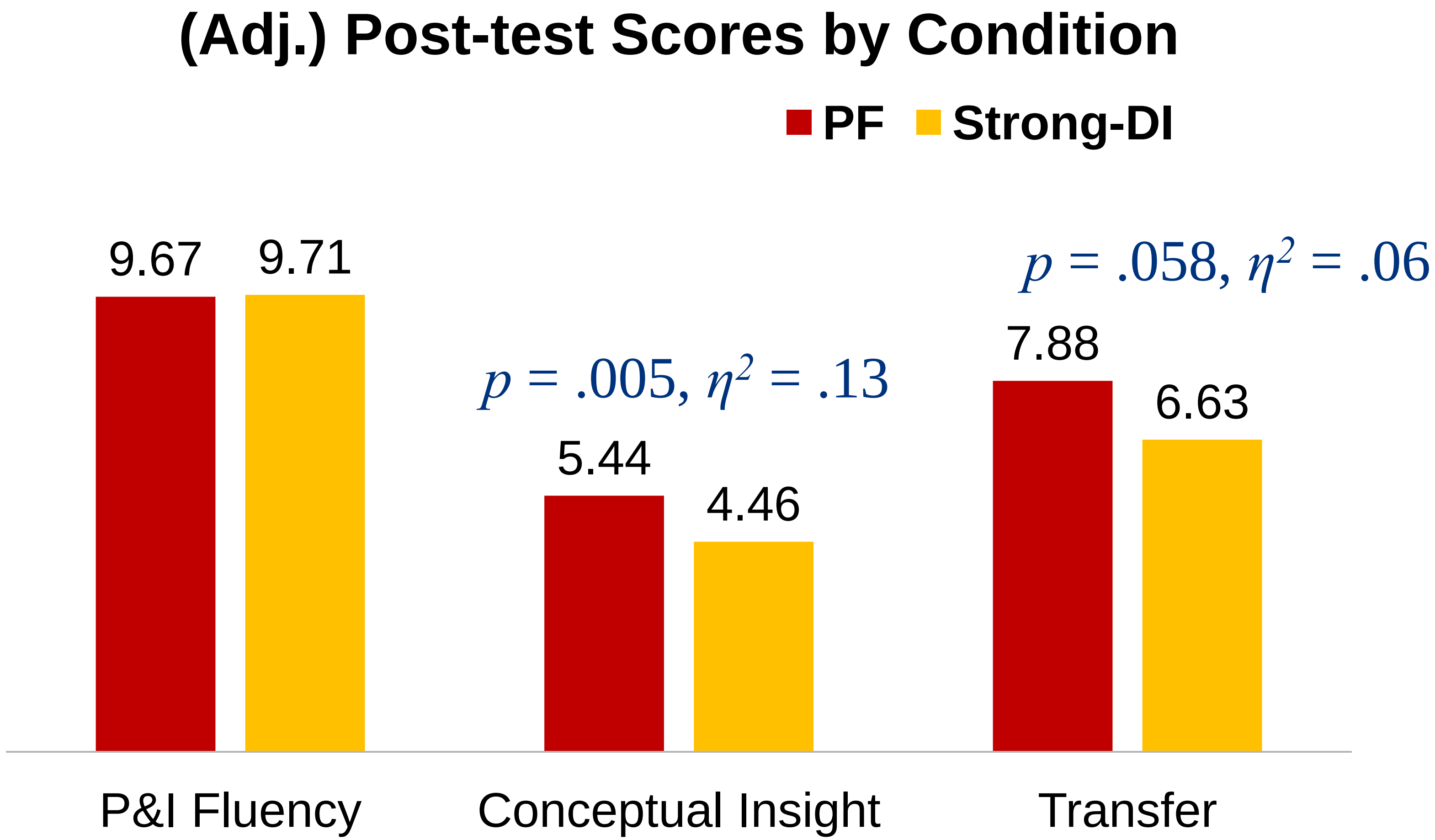
Strong-Direct Instruction Teacher explains concept with explicit discussion of critical features, worked-out examples, practice and feedback

four, 50-min periods



DVs:
1) Procedural Fluency
2) Conceptual Understanding
3) Transfer

Results: PF vs. Strong-DI



Future Work

1. Unpack design components, e.g.,
   - Role of prior knowledge
   - Role of teacher
   - Role of collaboration
2. Examine what kinds of support may further enhance the generation and exploration phase
3. Examine different ways of designing the consolidation and knowledge assembly phase
4. Examine effectiveness in other domains (e.g., science, writing, etc.)
5. Examine the role of productive failure in problem finding contexts...

Cognitive Load Theory

"Controlled experiments almost uniformly indicate that when dealing with novel information, learners should be explicitly shown what to do and how to do it" (p. 79; Kirschner et al., 2006)…

Cognitive Load: un-guided or minimally-guided instruction increases working memory load that interferes with schema formation…

Substantive empirical support (Sweller & Copper, 1985; Carroll, 1994; Paas, 1992; Klahr & Nigam, 2004)

compared some version(s) of a worked example or strong instructional guidance condition with a pure problem-solving or discovery condition.

Conclusion: there is little efficacy in letting learners solve problems that target novel concepts…

Cognitive Load Theory

It is not surprising that students in the pure problem solving condition did not learn as much as those in the strongly-guided condition…

But, this do not necessarily imply that there is little efficacy in letting learners solve novel problems on their own

To determine if there is such an efficacy, a stricter comparison is needed:

Direct instruction vs. students first solve novel problems on their own followed by some form of structure

Cognitive Load Theory

"Any instructional theory that ignores the limits of working memory when dealing with novel information or ignores the disappearance of those limits when dealing with familiar information is unlikely to be effective" (p. 77; Kirschner et al., 2006)

Constraints of working memory contingent upon:

- novelty of information / concept being learnt vis-à-vis what students know about the concept
- interaction between working memory (WM) and long term memory (LTM)

working memory constraints?

How is novelty defined?

canonical: students do not have the canonical formulation in the LTM, therefore the concept is novel

non-canonical: students may not have the canonical formulation but may have some prior or intuitive ways of thinking about the concept in the LTM

If so, could we not to design tasks and activity structures to activate this knowledge in the LTM, and

By activating and working with these priors in the long-term memory, leverage the “expandable” aspects of WM capacity?

In ending...

Learning vs. performance…

Productive Success	Productive Failure
Unproductive Success	Unproductive Failure

THANK YOU!