What can transfer teach us about effective instruction?

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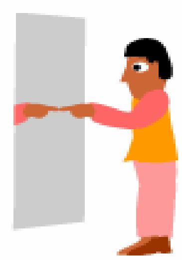


Outline

- → The Problem of Transfer
- The Root of the Problem
- Issues of Instruction Involving Mathematics
- Returning to the Issues of Transfer
- Summary

What is transfer?

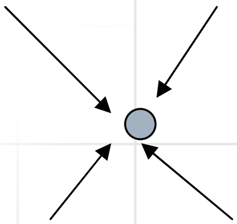
- Application of learning gained in one situation to another.
- A couple of examples…

Example #1 (Ross)

- Students learned:
  - Combinations using cars as example.
  - Permutations using marbles as example.
    - Design was crossed, but just describe one condition.
- Post-test:

	Combinations	Permutations
Marbles	**P**	**P**
Cars	**C**	**C**

Example #2 (Gick and Holyoak)



- Students received a packet of problems.
  - First problem involved "fortress" problem.
    - Eventually told/shown answer.
  - Second problem was a "filler".
    - Eventually told answer.
  - Third problem was "radiation" problem.
    - Isomorph of "fortress" problem. Would they transfer?

- Very few transferred converging forces solution.
    - When told fortress was relevant, then they transferred.
    - Thus, they knew solution but did not apply it.

Problem of Transfer

- Inert knowledge.
  - People know the answer, but they do not use it.
- One cause: People pay attention to “surface” features.
  - Negative transfer based on surface (marbles v. cars).
  - Failed transfer if surface differs (radiation v. fortress).
- Similar results have led many to the conclude that transfer is rare.

Why we should care about transfer?

- If transfer is rare, then we are in trouble.
  - People need to transfer from class to class, school to home, home to school.
  - A conversation with superintendents.

- Why is transfer rare? And, is it really?
  - It is rare by one definition.
  - This definition is what causes instruction to make it rare.
  - I have a conspiracy theory.

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The Root of the Transfer Problem is Bigger than Transfer.

- Much of the psychological literature on learning has emphasized efficiency
  - Faster and more accurate retrieval and application of previously learned behaviors.

- Efficiency's long, dominant history in psychology and the USA…

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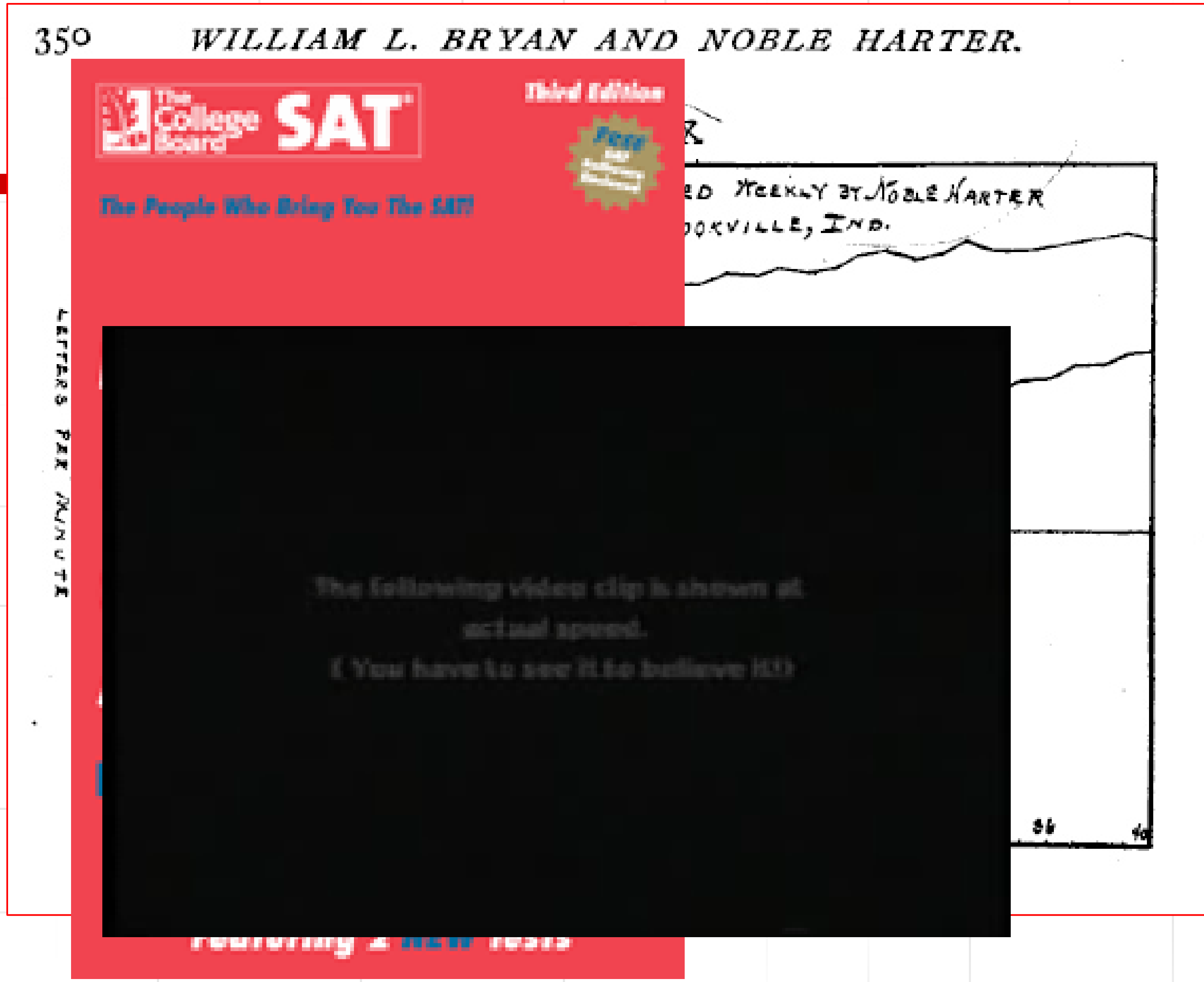


Efficiency is important

- 99.9% = failure for orchestral musician.
- Improved efficiency frees up cognitive resources.
- Important for routine tasks.
- Most learning assessments are about efficiency
  - Speed, accuracy, consistency, 1st-try positive transfer

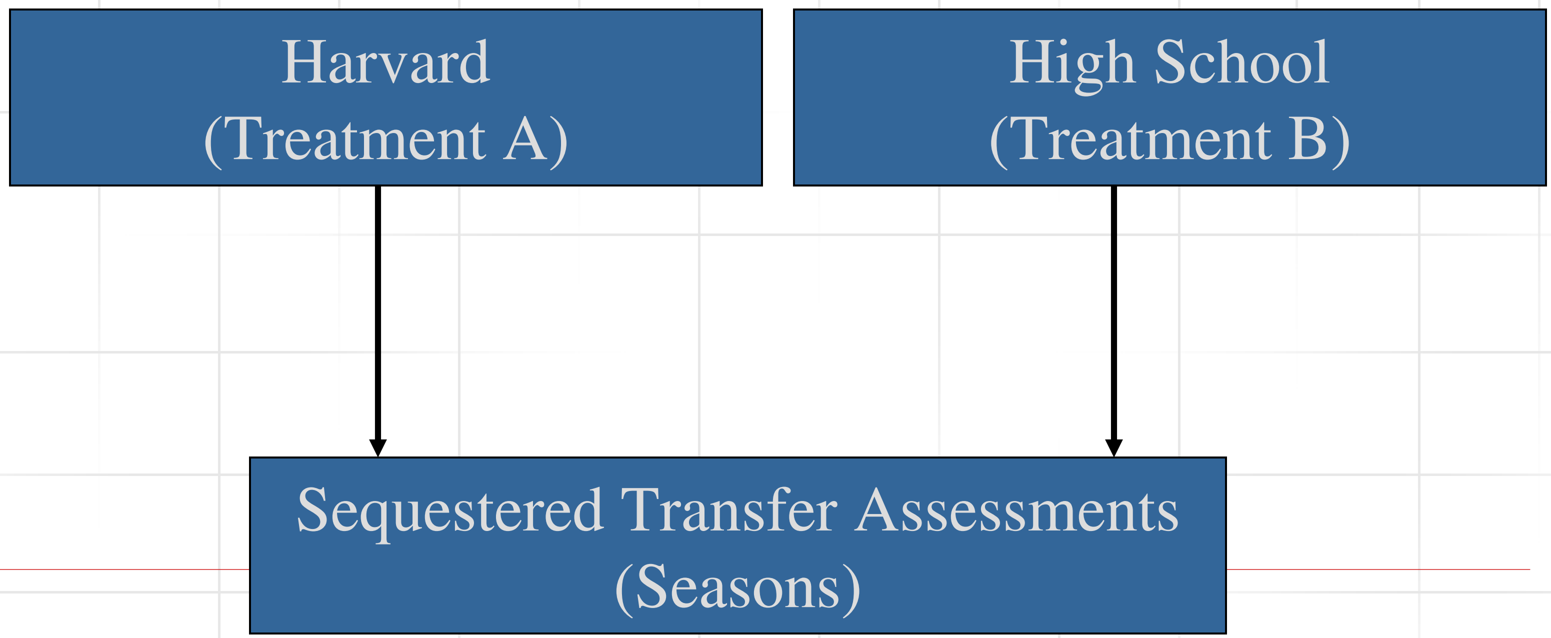
Efficiency emphasis shows up in transfer.

- Detterman from Transfer on Trial.
  - "…most studies fail to find transfer …and those studies claiming transfer can only be said to have found transfer by the most generous of criteria and would not meet the classical definition of transfer."

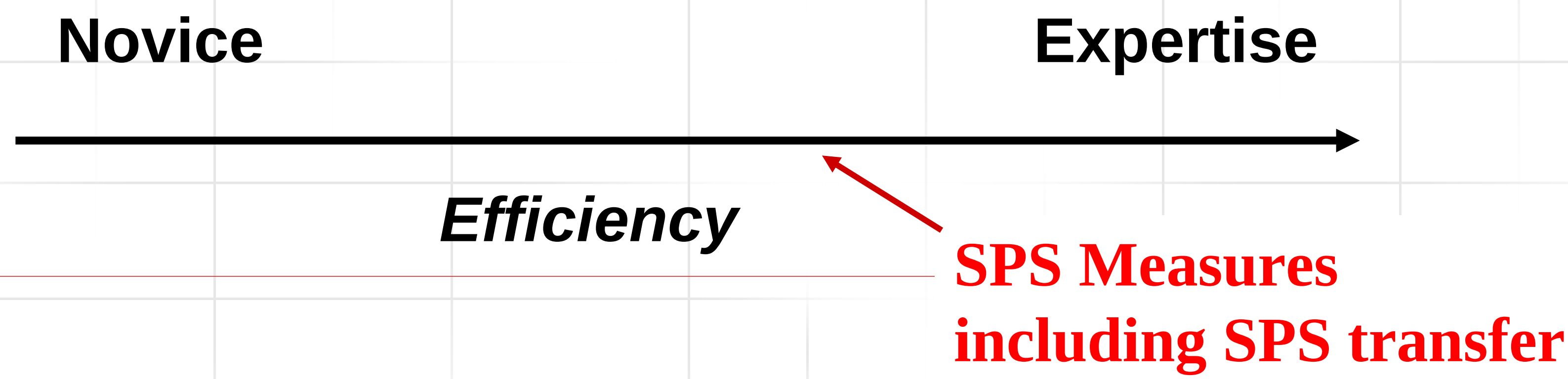
- Classic "stimulus generalization" view – efficient replication of old behavior in a new situation.

Assessing Efficiency Takes a Particular Format.

- Sequestered problem solving assessments (SPS)
  - Harvard students on the seasons.

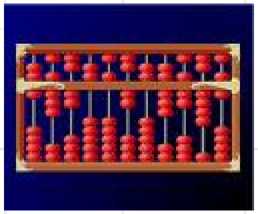


Common View of Expertise



Expertise as High Efficiency

- Giyoo Hatano examined highly efficient experts.
- Study of abacus masters
  - Prodigious digit spans and arithmetic abilities
    - Even without the abacus.
  - Hearing 1 number every 2.5 secs, could solve:



28,596 + 847,351,654 – 166,291 – 324,008,909 + 74,886,215 – 8,672,214 + 54,221 – 91,834 – 103,682,588 + 17,274 – 212,974,008 + 4,081,123 – 56,315,444 + 897,294 – 380,941,248

  - But only average spans for remembering letters or fruits
  - Running a mental simulation of manipulating an abacus.

Hatano's Conclusions

- Culture expanded a fixed cognitive capacity
    - working memory (measured by digit span)
  - Expertise is due to the internalization of cultural tools and practices.

- Abacus masters continued learning was relatively narrow.
  - Increased efficiency in a stable environment.
    - Easily disrupted, and masters did not like to be disrupted.
  - Abacus masters only learned one tool.
    - Did not build on expertise to learn other mathematics.

- Abacus masters displayed **routine expertise**.
  - A high level of efficiency at a recurrent task.

Hatano distinguished two types of expertise.

Adaptive Expertise

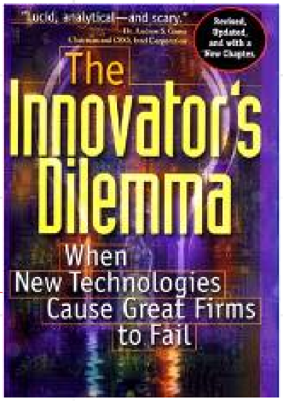
Novice **Routine Expertise**

Efficiency

Efficiency is not enough for adaptive expertise.

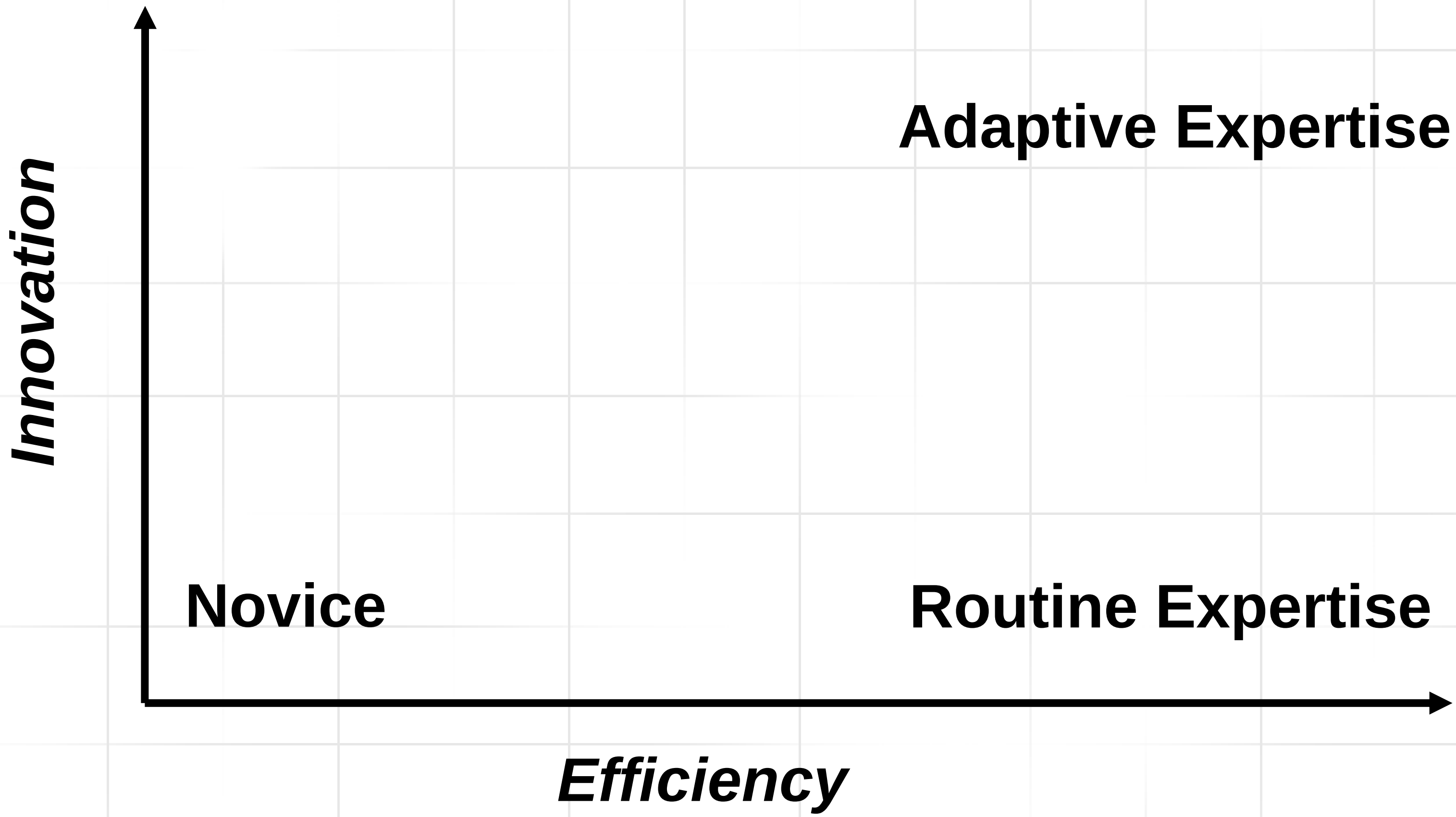
- Adaptive expertise: Abilities to learn and change behavior – not replicate it.
  - Seems more like what the superintendents were after.
- Perils of an over-emphasis on efficiency for learning.
  - People can miss a learning opportunity, because they assimilate to efficient schemas and miss what is new.
  - When taught efficient solutions, people focus on solution and not the problem for which it is a solution.
- Businesses worry that too much emphasis on efficiency reduces future competitiveness. Hard to let go of prior successes.
  - Intel's 3-month product release cycle.

- Propose a second dimension to learning: **Innovation**
  - Different from repeating an old behavior or idea more efficiently.
  - Innovation involves generating new behaviors, situations, ideas.
    - Includes discovery, creation, inquiry, invention, concept change…



Two dimensions of learning.

w/ John Bransford

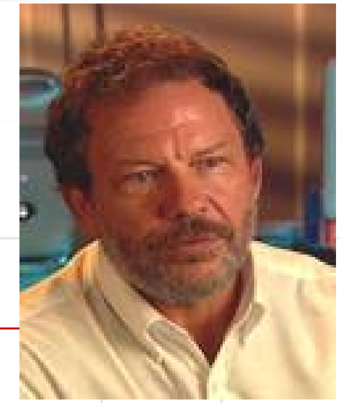


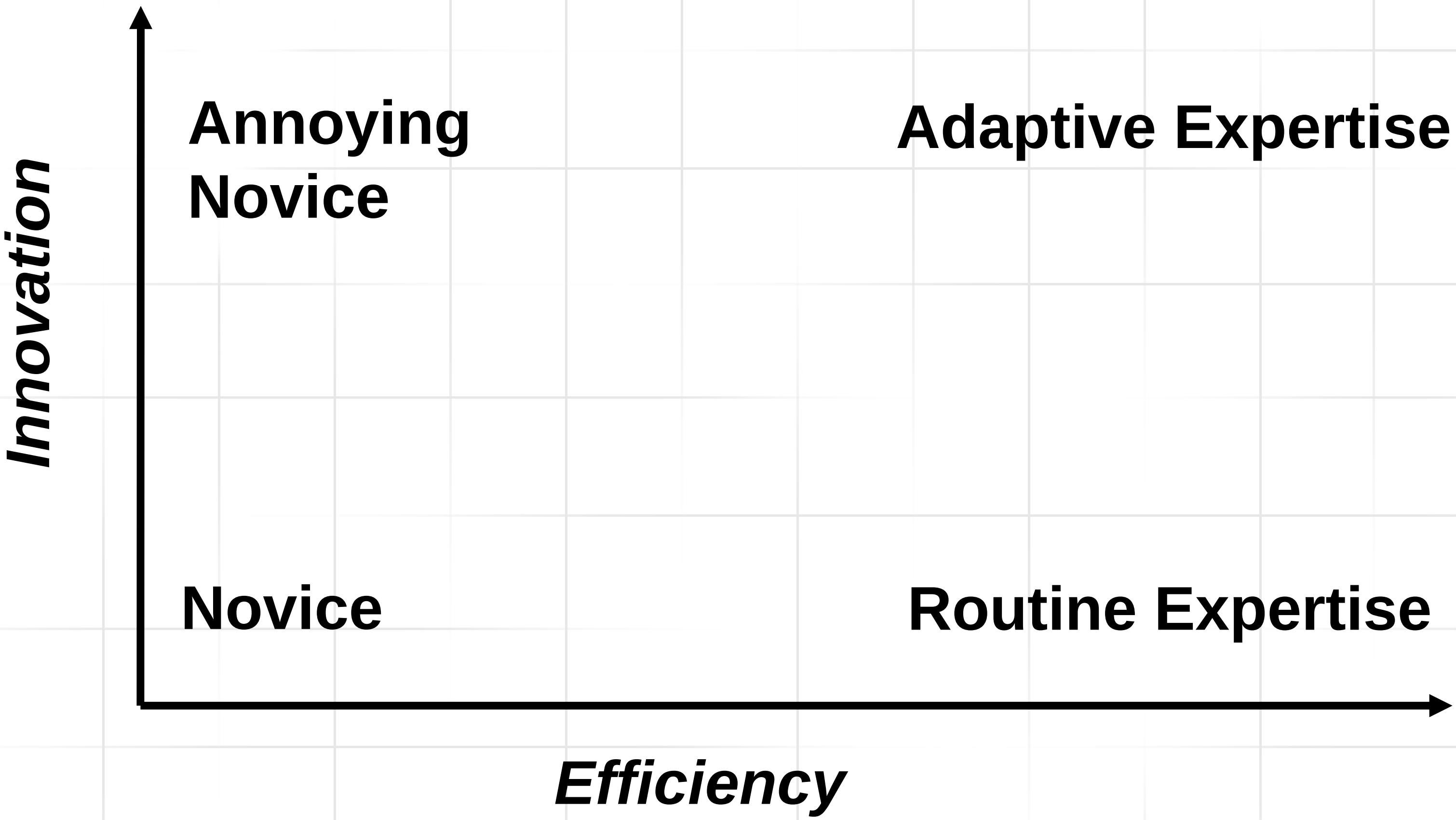
Innovation

- Innovation involves generation of new ideas
  - Rather than refinement of pre-existing ones.
- Efficiency & innovation often seen as opposites.
  - Myth of creative person versus drudge.
  - Need a balance of efficiency and innovation.
- Adaptive experts are presumably high on both.
  - A strong set of efficient schemas to draw upon.
    - 10-year rule to innovative expertise.

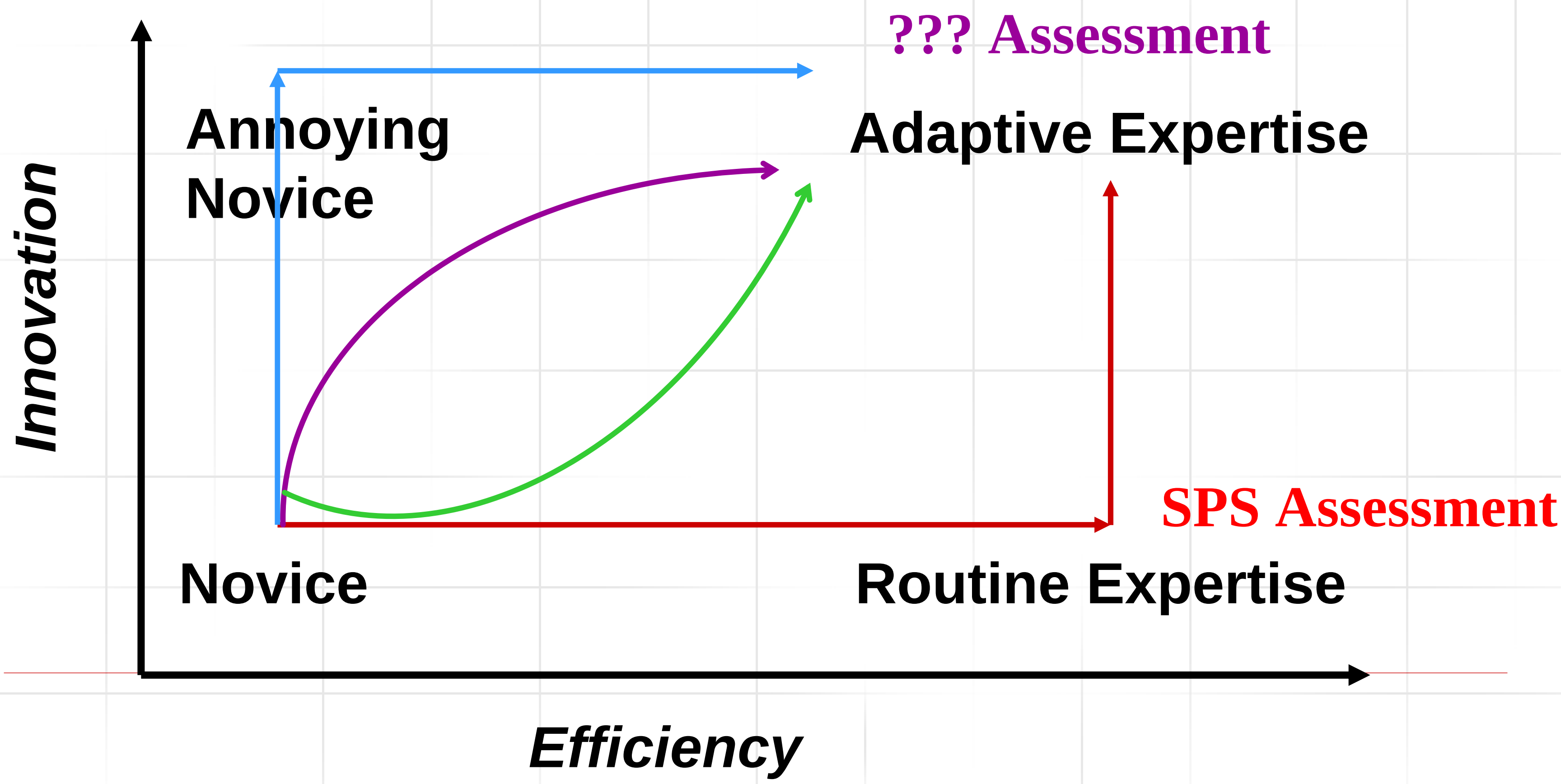
Two dimensions of learning.

w/ John Bransford



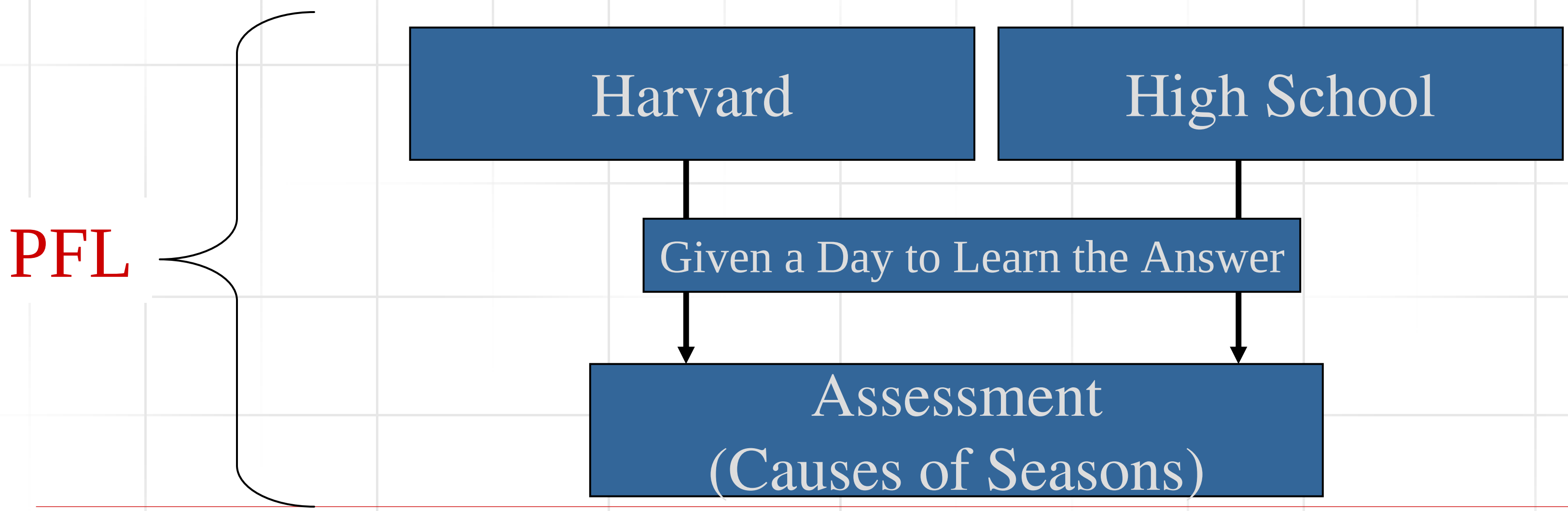


Which of the following trajectories is ideal?
How can we find out?



An alternative type of assessment

- Preparation for Future Learning (PFL)
  - Opportunity to learn and adapt during the assessment.
  - Include resources so they can learn something innovative (to them).



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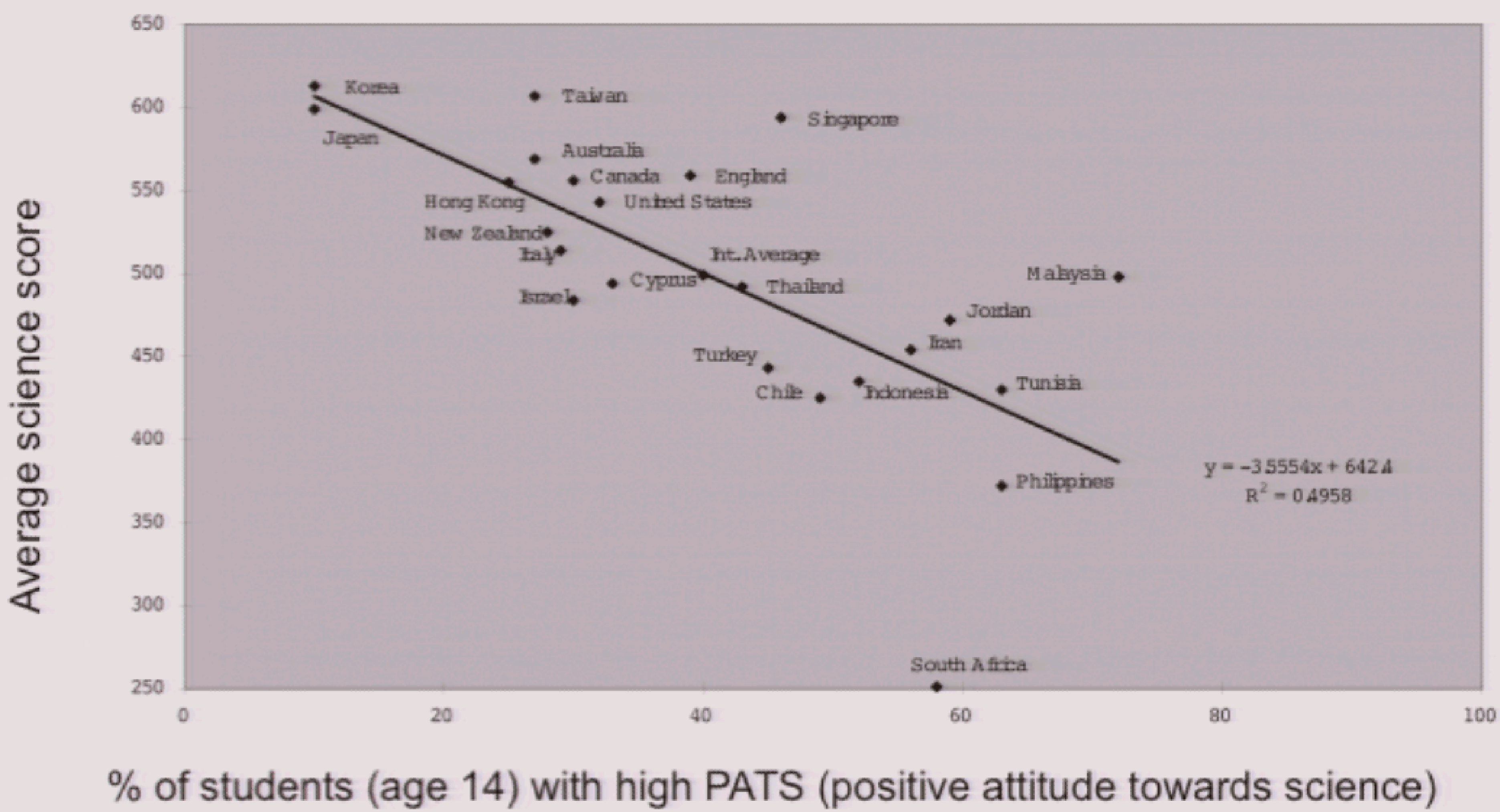
Math in Science

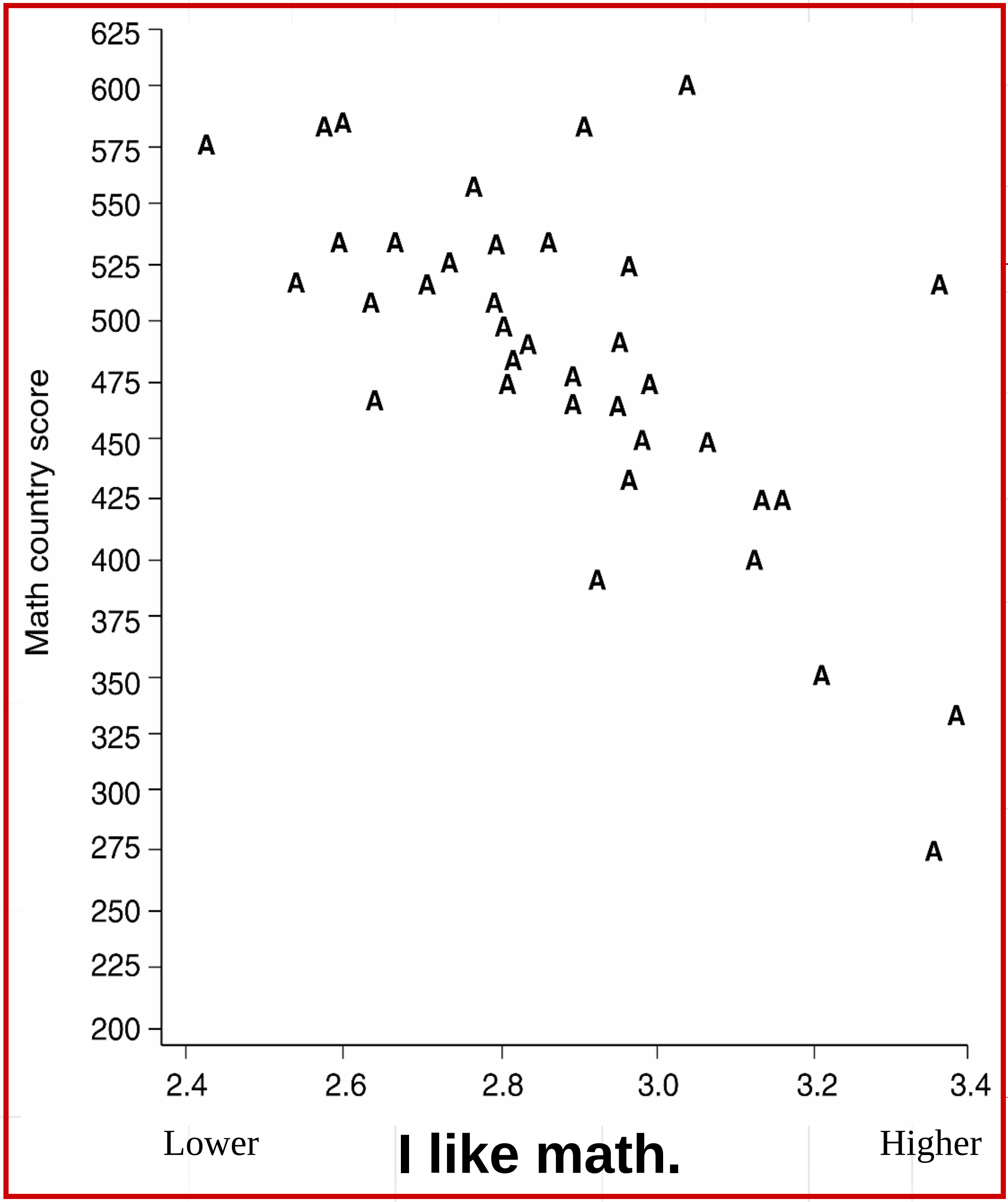
- Nobel physicist Richard Feynman (1965):
  - *"… it is impossible to explain honestly the beauties of the laws of nature in a way that people can feel, without their having some deep understanding in mathematics. I am sorry but this seems to be the case"*

- Where have we gone wrong…

Science attainment and attitude

(from TIMSS, 1999)





Possible Explanations

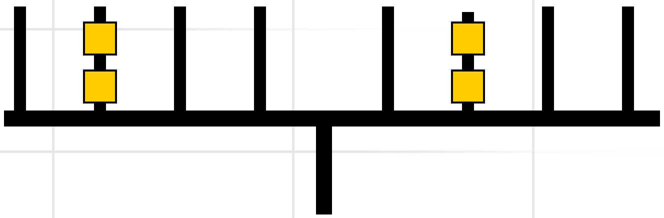
- Students burn out.
  - Informal activities in countries with the top scores are often "math clubs" and such.
- Students in top countries, see more students ahead of them and lose interest.
  - 498 achievement →
  - Hong Kong: Negative attitude
  - Malaysia: Positive attitude
- Japanese student: "The point is to pass the tests and get into college. Once you are in, you stop trying to learn."

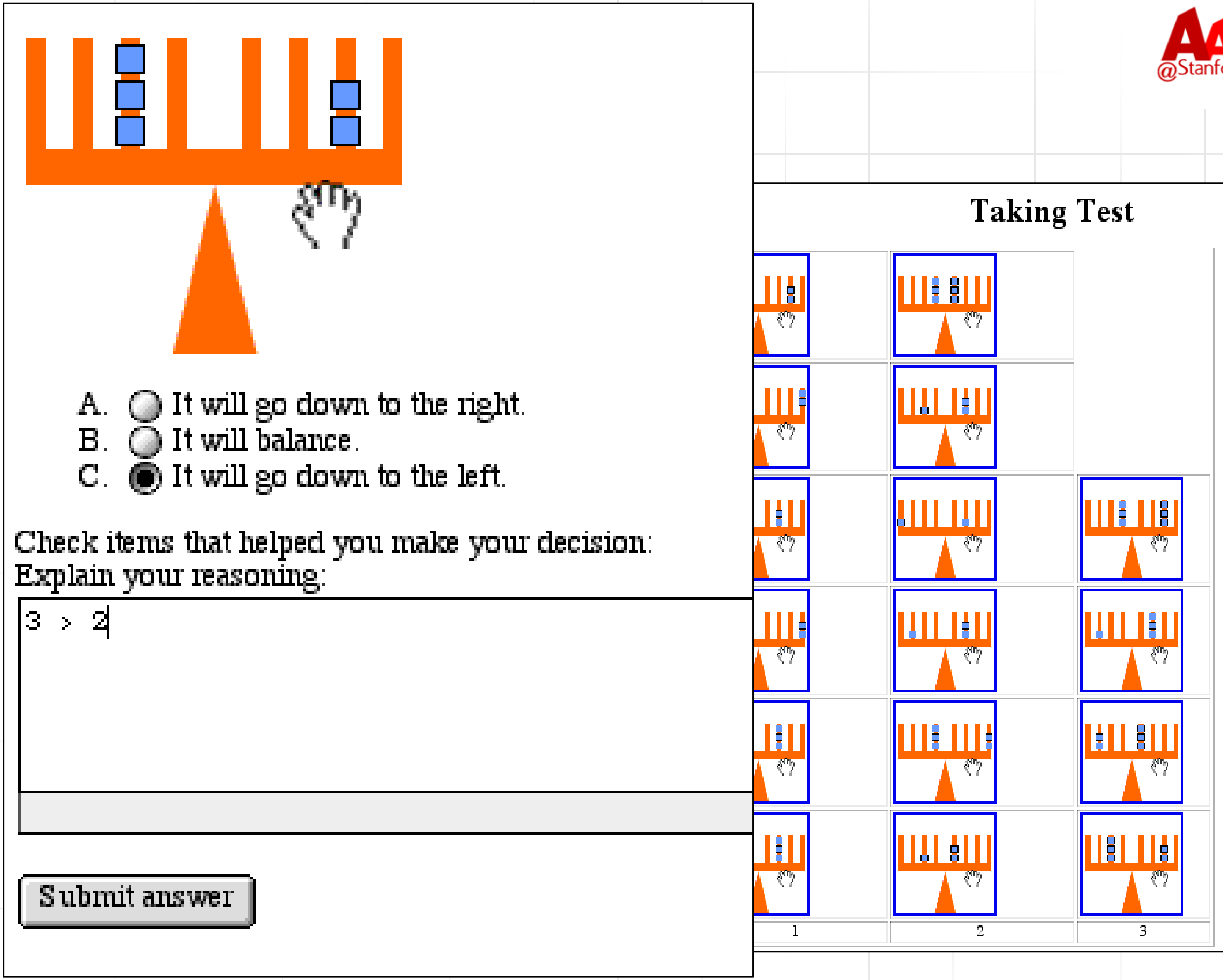
Mathematics in science.

- Math in science often taught as an “efficient” way to solve problems.
  - The emphasis is on efficient application of formulas/procedures.
  - Looks good on SPS assessments, so teachers keep doing it.
  - Leads to symbol pushing to compute an answer.
  - Miserable transfer because people focus on procedure, not situation.
- What if math arose through an innovation trajectory?
  - For many domains, the problem is not intuition so much as the sheer complexity.
  - Students might find math helps them understand structure and manage complexity.
- Use a classic developmental task to show that in a context of innovation, math can help.

Siegler's 5 Rules

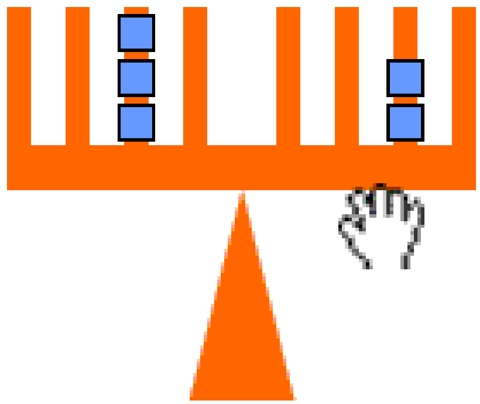
- Rule 0: No Rule
- Rule 1: Use Weight Only
- Rule 2: Use Distance IF Weights Equal
- Rule 3: Use Distance & Weight
- Rule 4: Use Distance X Weight




A. It will go down to the right.
B. It will balance.
C. It will go down to the left.
Check items that helped you make your decision:
Explain your reasoning:
3 > 2
Submit answer
Taking Test
1
2
3

Feedback

The correct answer is: It will balance.



Thanks for your answer.

Sorry. Look again.

Your explanation: 3 > 2

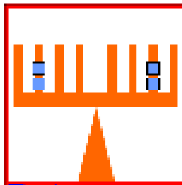
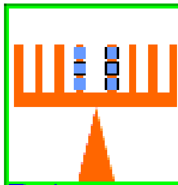
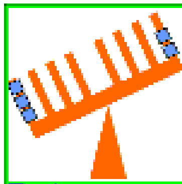
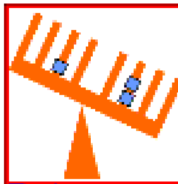
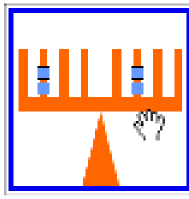
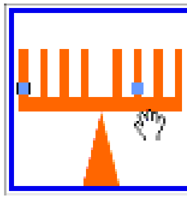
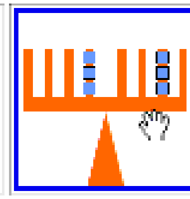
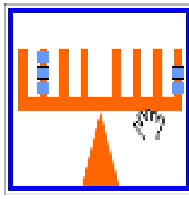
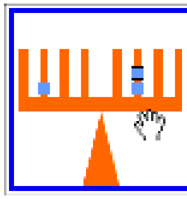
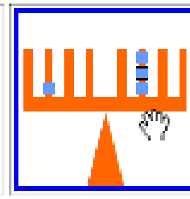
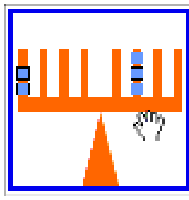
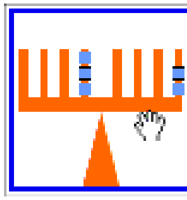
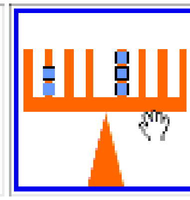
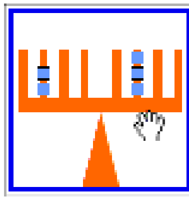
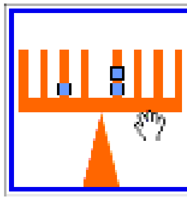
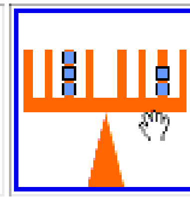
Can you explain why this is the answer?

It balances because

3 x 2 = 2 x 3

Submit answer

Taking Test

Level 1	 Review	 Review	
Level 2	 Review	 Review	
Level 3			
Level 4			
Level 5			
Level 6			
Question Number	1	2	3

Experiments

- Simple Conditions
  - Justify Answer with **Words**
  - Justify Answer with **Math**

- We thought that **math** condition would:
  - Provide some “tools” that children could use to help innovate a new understanding.

Benefits of mathematics.

Problem 3	Correct Choice	1st Explain:	**3 > 2**
Problem 8	Wrong Choice	1st Explain:	**3 + 3 = 4 + 2**
		2nd Explain :	**3 – 3 = 4 - 2**
Problem 9	Wrong Choice	1st Explain :	**3 1 2 2**
		2nd Explain :	**<blank>**
Problem 10	Correct Choice	1st Explain :	**??? 3 x 1 < 2 x 3**
Problem 11	Correct Choice	1st Explain :	**4 x 2 > 2 x 3**

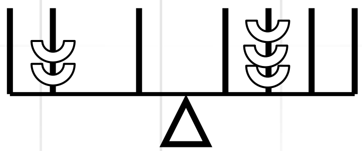
Problem 9	Wrong Choice	1st Explain :	**More weight**
		2nd Explain :	**More distance**
Problem 10	Wrong Choice	1st Explain :	**More distance**
		2nd Explain :	**More weight**

What math brings…

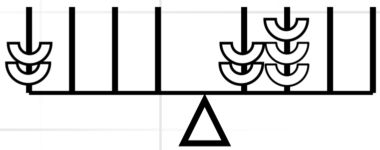
- Common ontology
  - Weight and distance can be unified via number.
- Compactability (Bruner)
  - Working with symbols easier than maintaining precise imagery.
- Ready made structure from math.
  - Addition, subtraction, multiplication, etc.
- Technology for trying things out
  - Failure may be a pre-requisite of learning, but a failure does not tell one what to do next.

Not simply pushing numbers.

- On posttest, **math** kids did much better (even young kids who did not figure out metric proportions).
- Math kids did not “fall” for this question by just counting pegs and weights.



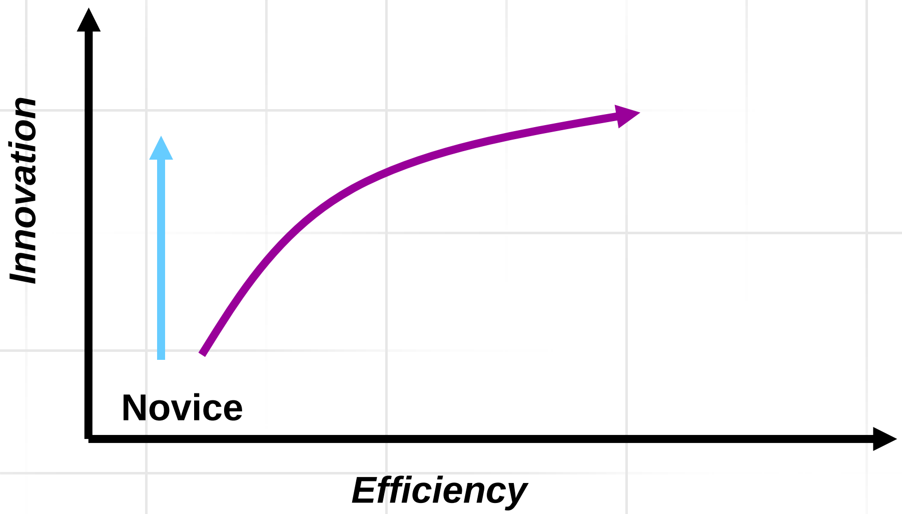
- Math kids also better for more complex problems.



- Not an issue of intuition or qualitative knowledge – kids knew balance.
- An issue of complexity – math helped them organize into structure.

Innovation and Efficiency

- Kids were on a pure innovation trajectory.
- Not an ideal model of instruction.
- Need to balance innovation and efficiency experiences.



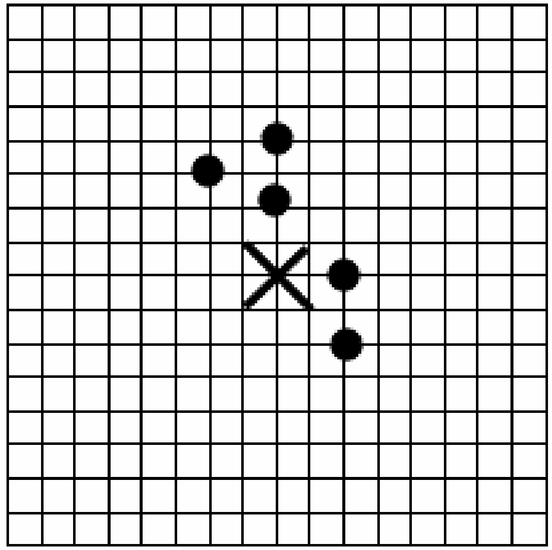
Learning about Variability

(w/ Taylor Martin)

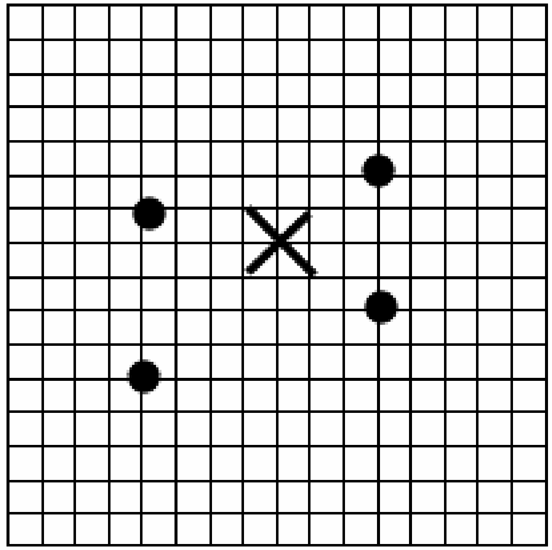
- Taught 6 classes of 9th-grade algebra
  - Good kids, good school.
  - Pre-posttest.
  - 6-hours total instruction.
- Started with innovating graphs for data.
- Students learned traditional graphs (e.g., histograms).
- Moved to formulas for variability.

Invent a reliability index for pitching machines.

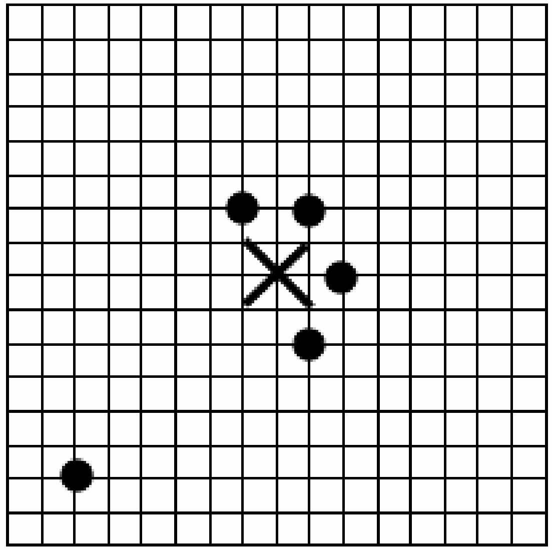
Contrasting Cases



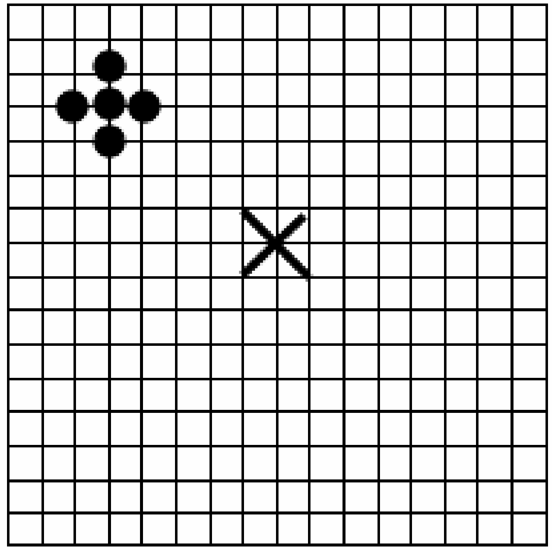
Ronco Pitching Machine



Big Bruiser Pitchomatic



Fireball Pitchers



Smyth's Finest

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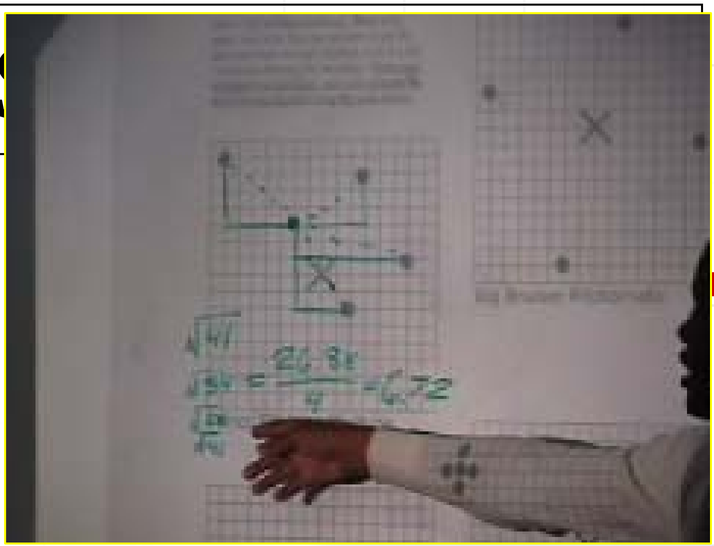
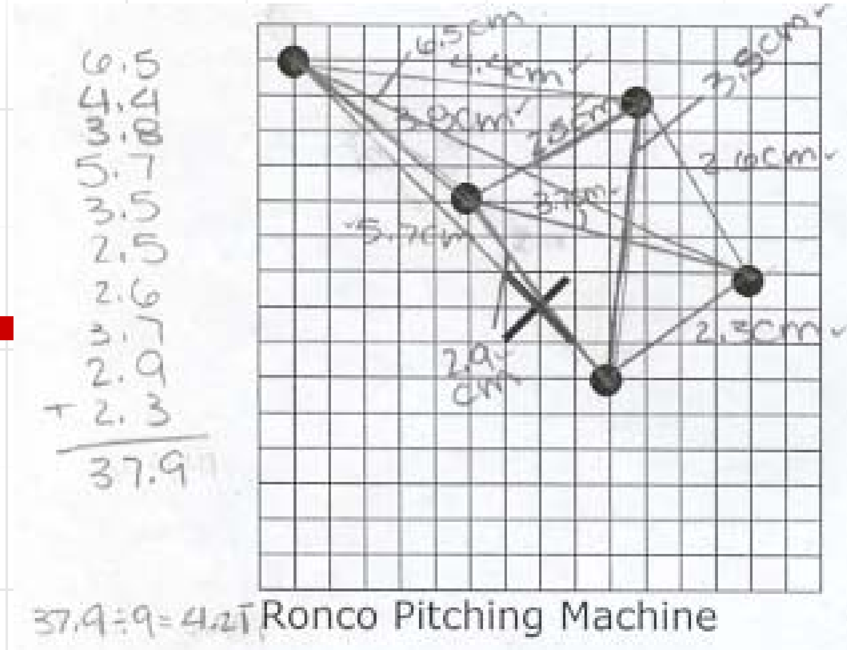
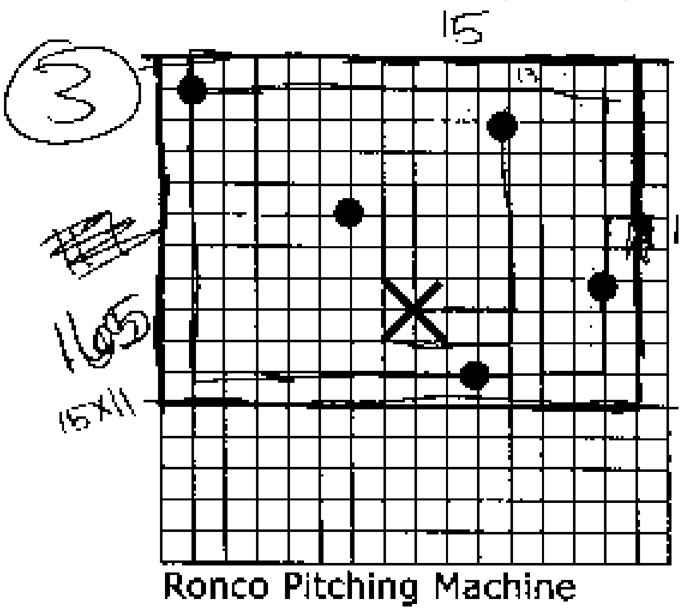
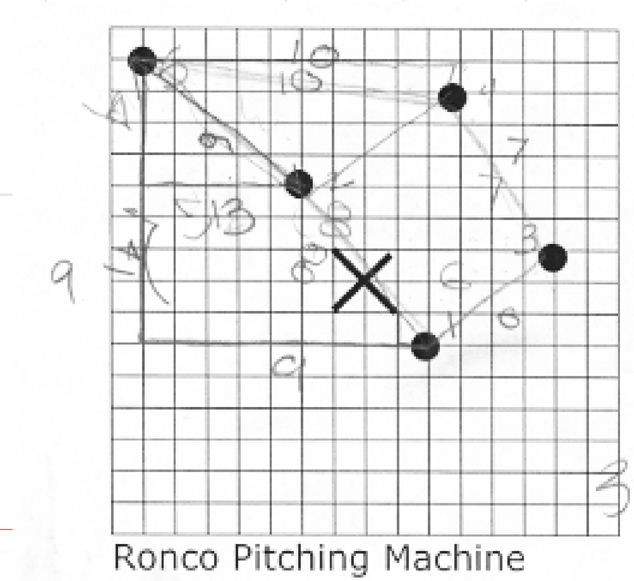




Pair-wise Distances Solution



Area solution



Perimeter Solution

Prepared to Learn

- Students rarely invented a general, efficient solution.
- Innovation activity
  - Helped them notice critical features.
  - Helped them see what structural work math needs to do.
  - Prepared them to learn efficient solution, in this case through direct instruction.
- Received a 5-minute lecture on mean deviation
- Practiced using for about 15 minutes.

- Posttest showed excellent results.

Positive effects of approach

- Compared to college students who took a semester-long course, 9^{th}-graders could:
  - more efficiently compute variability.
  - better explain why formula divides by ‘n’.
  - spot issues of variability in a transfer situations.
  - innovate a way to handle bi-variate data.

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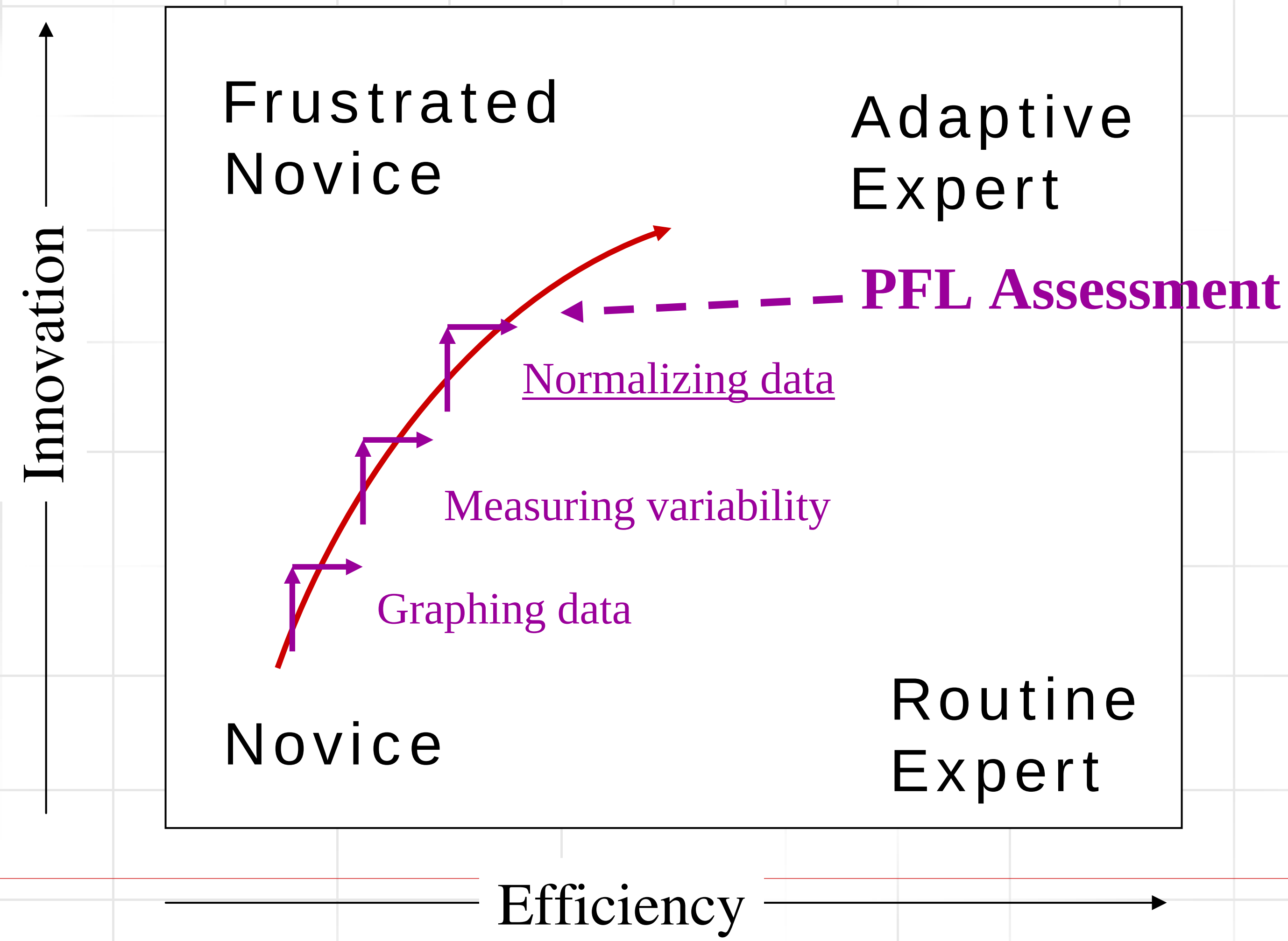
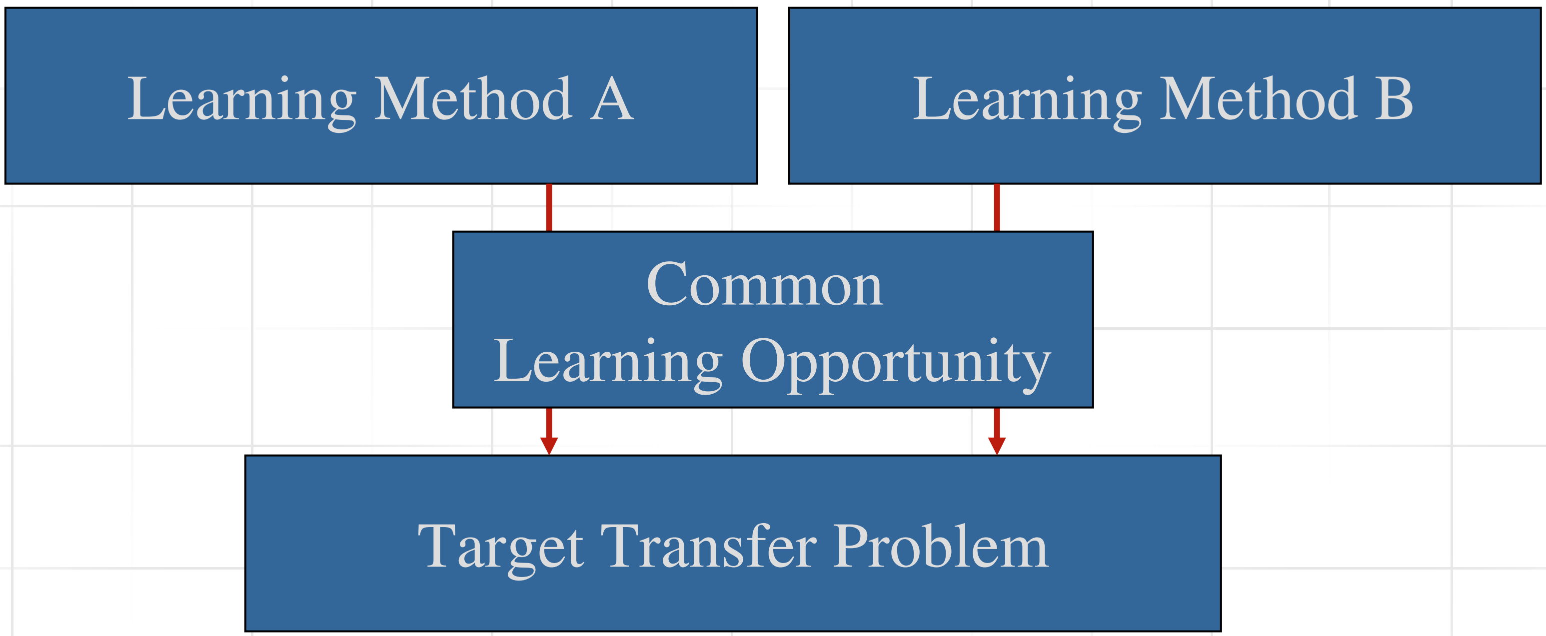

Frustrated Novice
Adaptive Expert
PFL Assessment
Normalizing data
Measuring variability
Graphing data
Novice
Routine Expert
Innovation
Efficiency

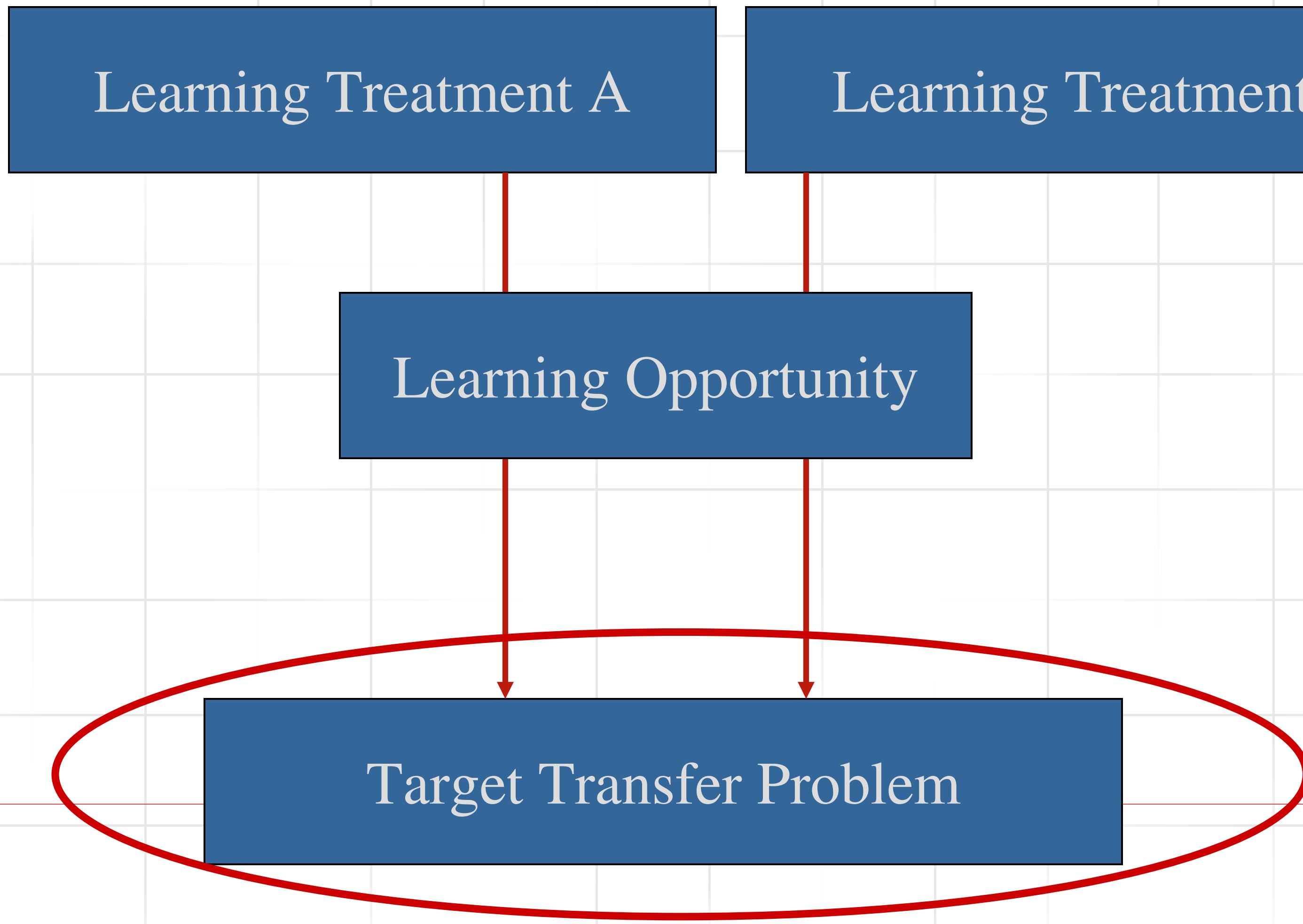
A controlled experiment

- Last day of instruction with same 9th-graders.
- Students split into two instructional treatments.
- Examined a PFL measure of transfer on a big test a week later.

Double Transfer Method
(for doing PFL assessments)



Target Transfer



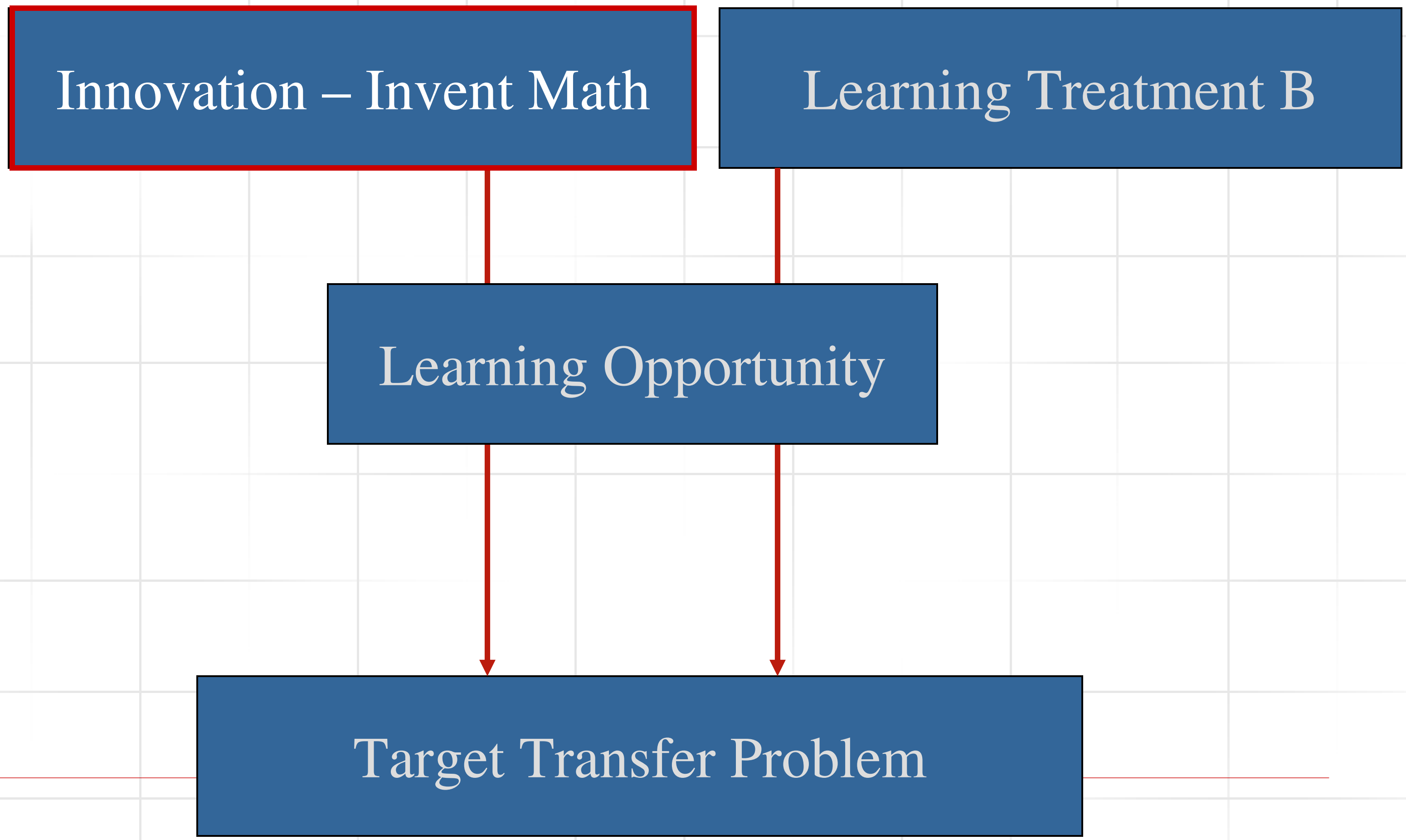
An example of a target transfer task

- Who got the better grade.
  - Robin: 88 pts. Her Class Avg = 74, Var = 12
  - Susan: 82 pts. Her Class Avg = 76, Var = 4

- To decide who did better, need standardized scores.

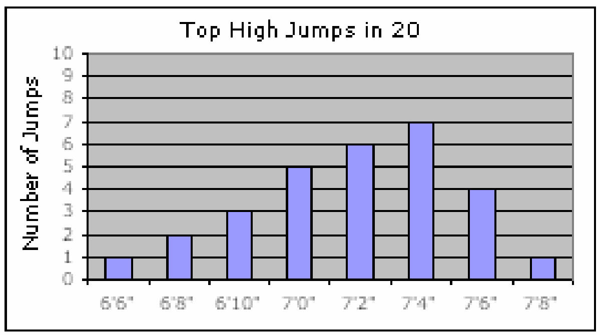
- Procedure to compute standardized scores.
  - (Score – Mean) / Variance
  - (88-74)/12 versus (82-76)/4
  - 1.083 versus 1.5

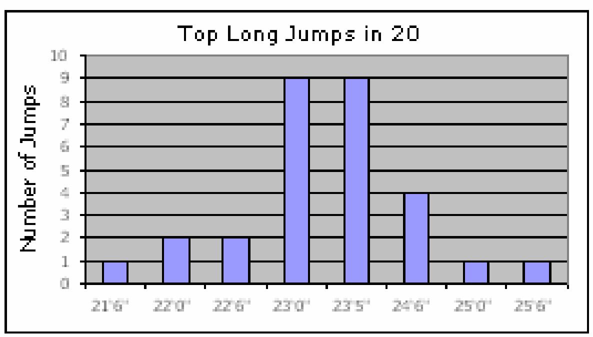
Instructional Conditions



Bill and Joe are both on the U.S. Track Team. They also both broke world records last year. Bill broke the world record for the High Jump with a jump of 8 feet. Joe broke the world record for the Long Jump with a jump of 26 feet, 6 inches. Now Bill and Joe are having an argument. Each of them thinks that his record is the best one. You need to help them decide. Based on the data below, invent a procedure to decide if 8' shattered the high jump record more than 26'6" shattered the long jump record. Your procedure should generate a comparable score for each person.

Top High Jumps in 2000		Top Long Jumps in 2000	
Height	*# of jumps*	*Length*	*# of Jumps*
6'6"	1	21'6"	1
6'8"	2	22'0"	2
6'10"	3	22'6"	2
7'0"	5	23'0"	9
7'2"	6	23'5"	9
7'4"	7	24'6"	4
7'6"	4	25'0"	1
7'8"	1	25'6"	1
8'0"		26'6"	





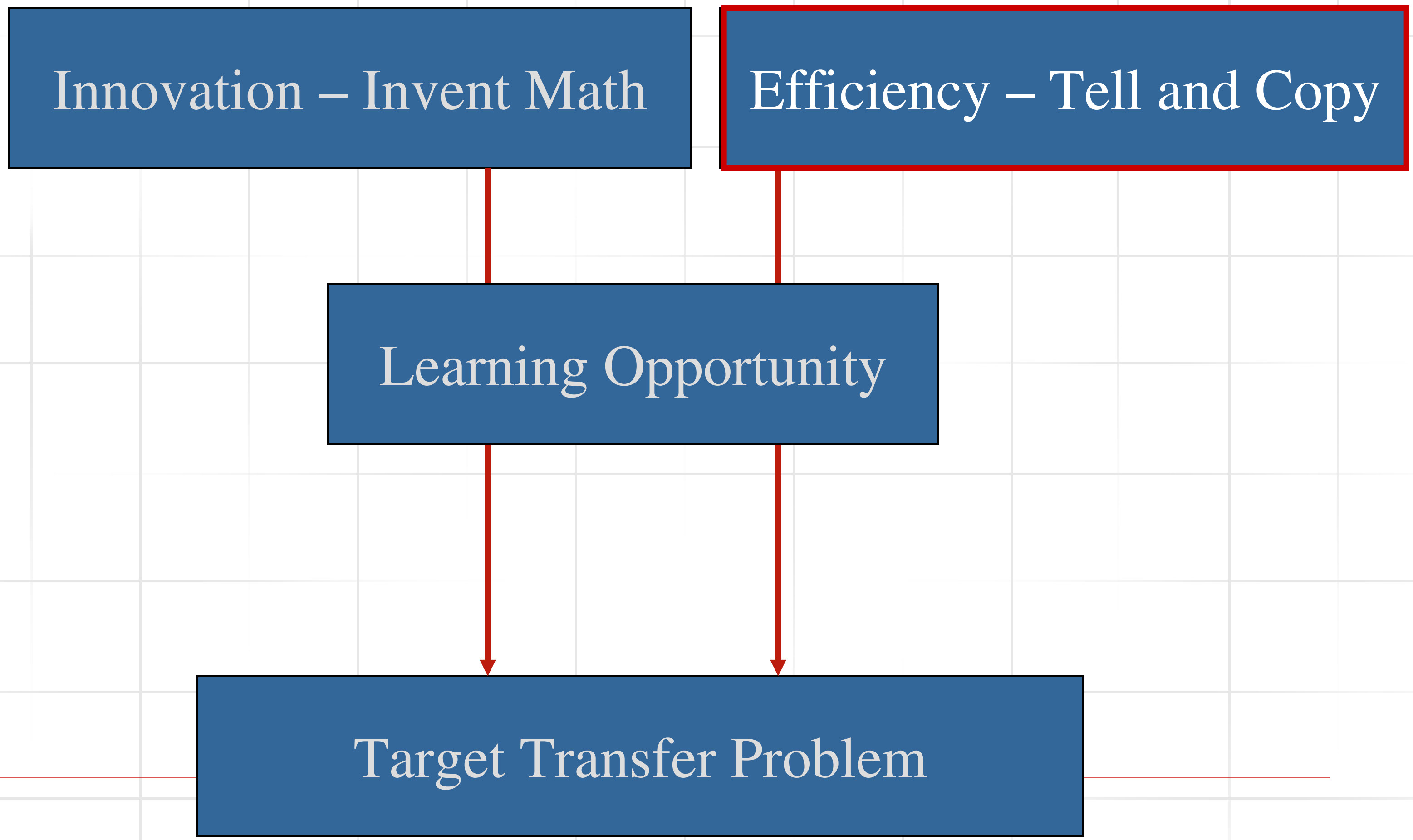
- Did high jumper or long jumper break world record by more?

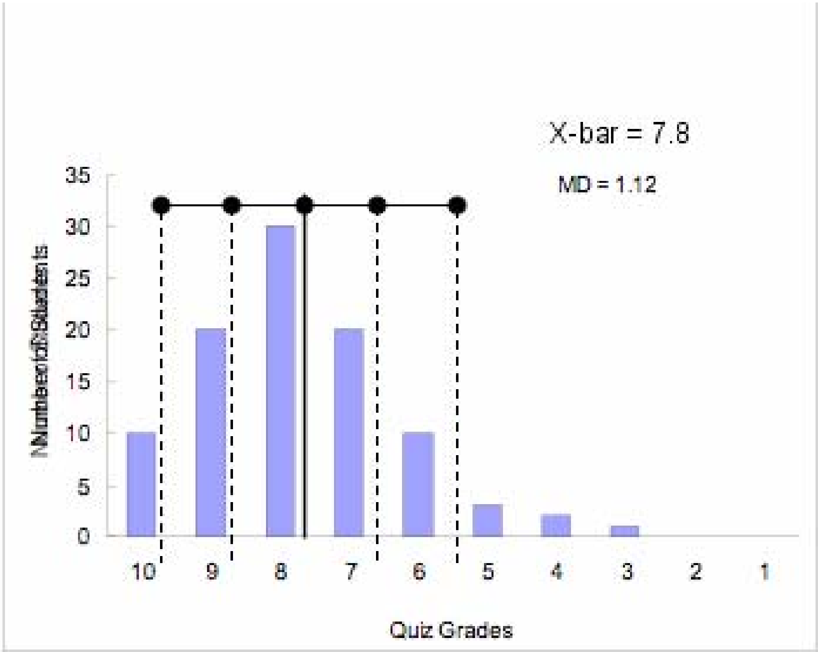
-Students worked 30min

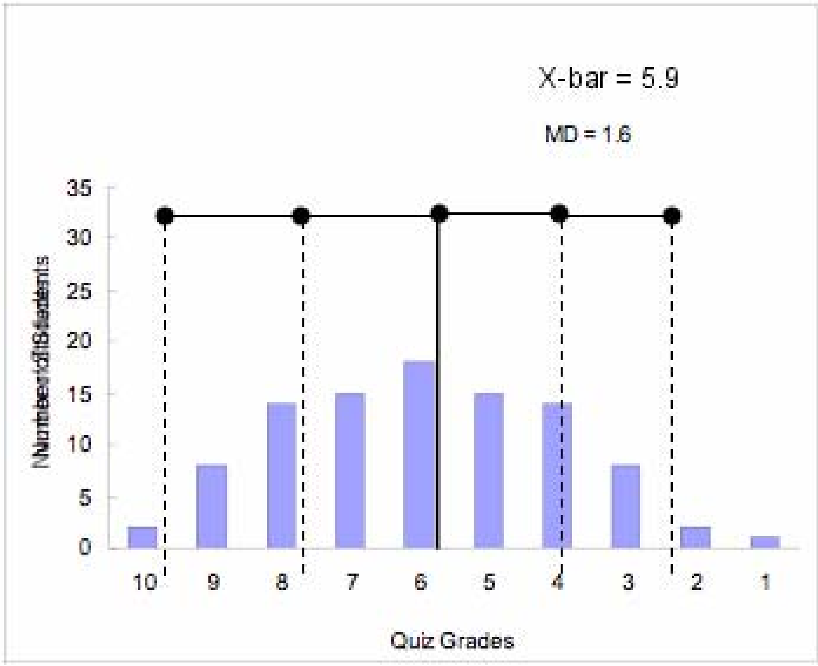
- Nobody solved.

- Seemingly inefficient!

Instructional Conditions





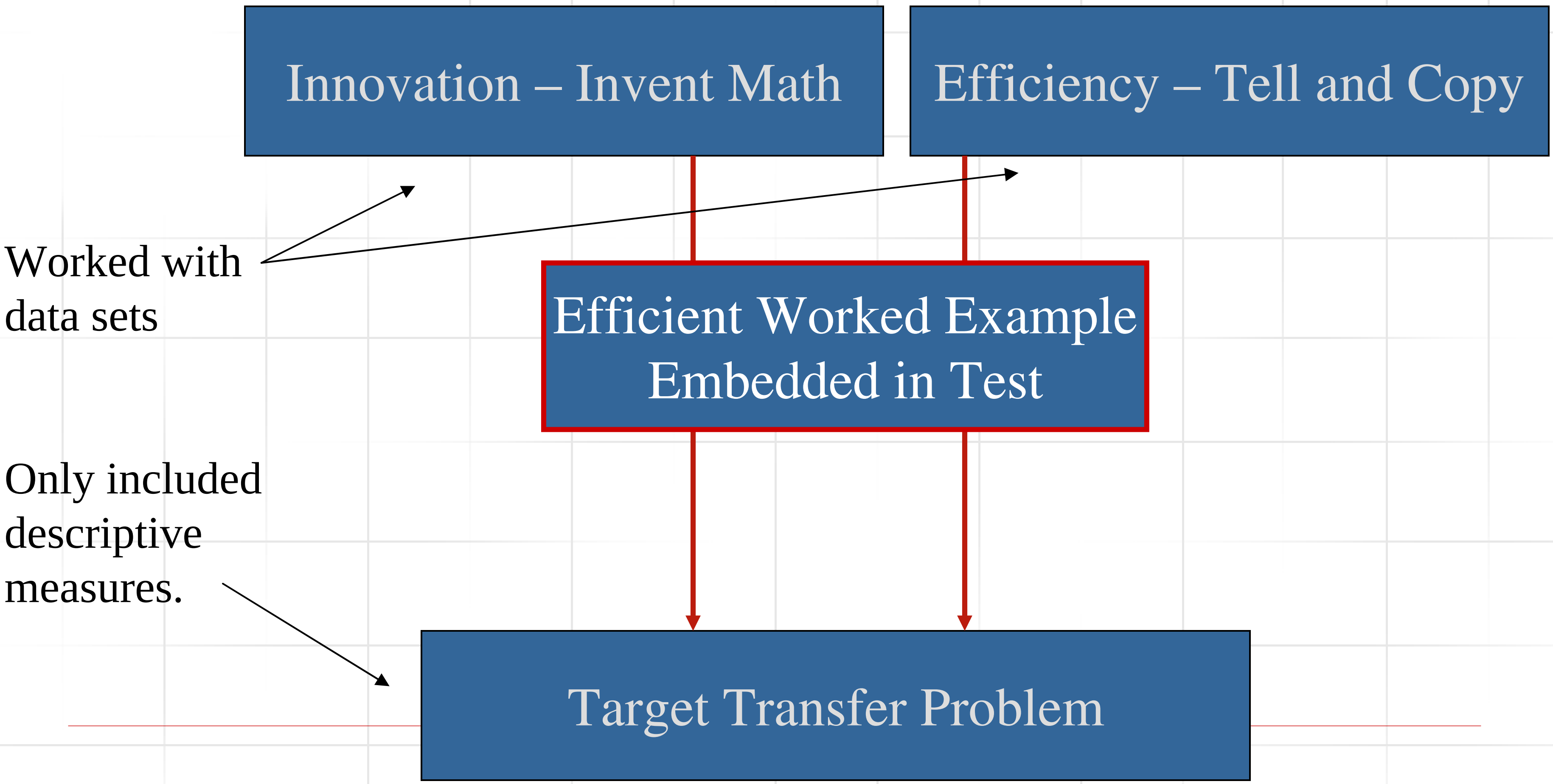


1) Shown a visual procedure.

2) Received data sets.

3) Copied (practiced) procedure and received correction (30 min)

Learning Resource for PFL Transfer



Embedded Resource:

In the middle of a large test a week later, students received a problem that provided a worked example.

It showed a procedure for standardizing scores.

Students followed to see if Alicia was better at steals or assists in basketball?

STANDARDIZED SCORES

Sometimes we want to compare things that have been measured in different ways. A *standardized score* lets us do that. For example, in a basketball game, Veronica scored 12 points and got 6 rebounds. She wants to know if she's a better scorer or rebounder. Here are the number of rebounds and points for each of the players in the game:

	Points	Rebounds
Veronica	12	6
Julie	3	8
Cheryl	8	6
Rose	6	3
Sarah	18	6
Jessica	6	2
Celina	10	6
Lisa	8	4
Teniqua	11	6
Aisha	18	3

To determine if Veronica is a better scorer or rebounder, we have to look at what the other players did to see if it is harder to score 12 points or get 6 rebounds. To figure this out, we calculate a standardized score. To calculate a standardized score, we find the average and the mean deviation of the group of scores. The average tells you what the typical score is, and the mean deviation tells you how much the scores varied across the players. Here are these values:

	Points	Rebounds
Average	10	5
Mean Deviation	25	4

The formula for finding Veronica's standardized score is her score minus the average, divided by the mean deviation. We can write:

$$\frac{\text{Veronica's score - average score}}{\text{mean deviation}} \quad \text{OR} \quad \frac{\text{x - mean x}}{\text{mean dev x}}$$

To calculate a standardized score for Veronica's point total, we plug in the values:

$$\frac{(12 - 10)}{25} = 0.08$$

Here is the calculation that finds the standardized score for Veronica's 6 rebounds.

$$\frac{(6 - 5)}{4} = 0.25$$

Veronica is a better rebounder because she had higher standardized score for rebounding.

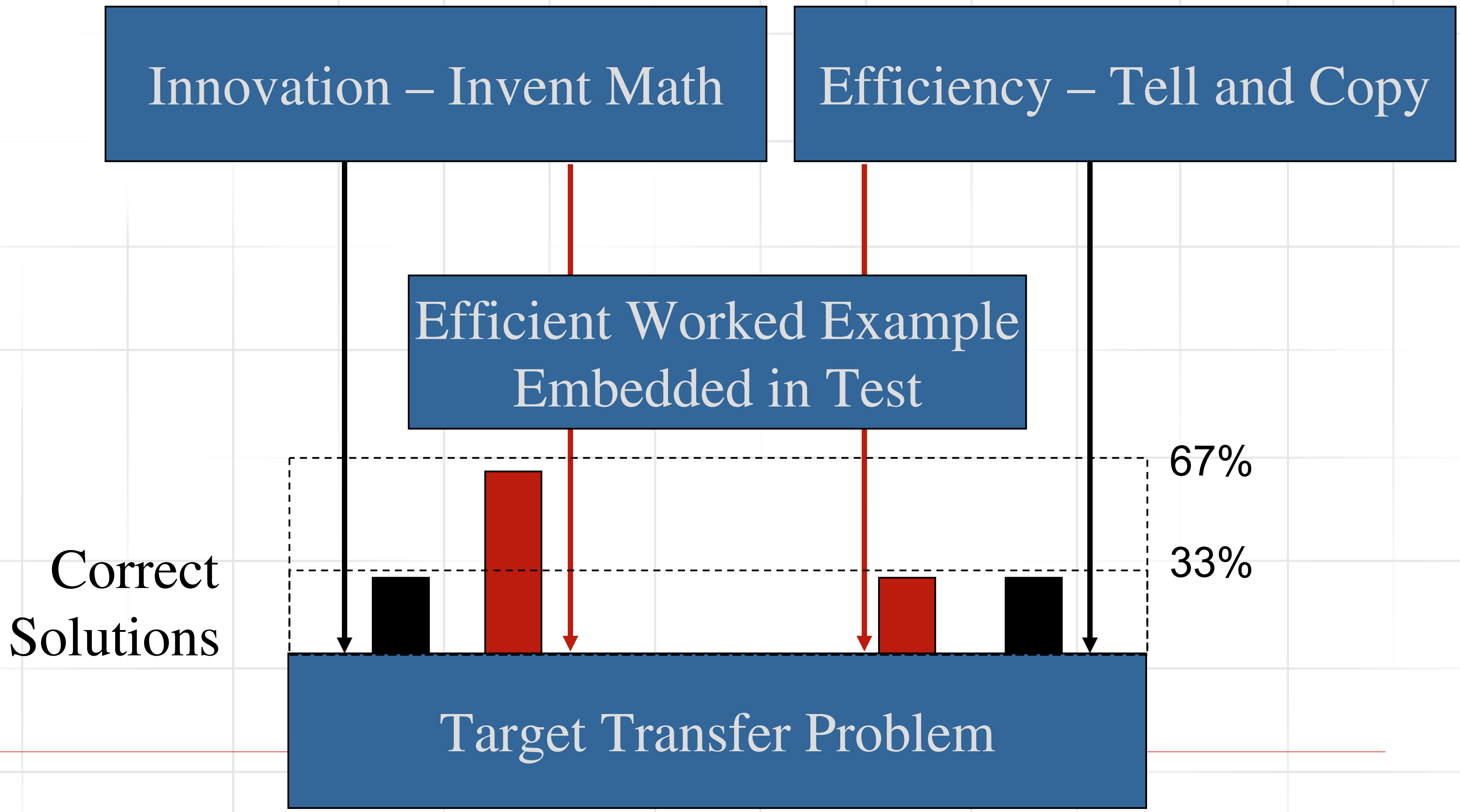
- Rose, the point guard on the team, wants to know if she was better at assists or steals. Rose got 5 assists and 2 steals in the game. The average and mean deviations for steals and assists were:

	Steals	Assists
Average	1	3
Mean Deviation	0.5	2

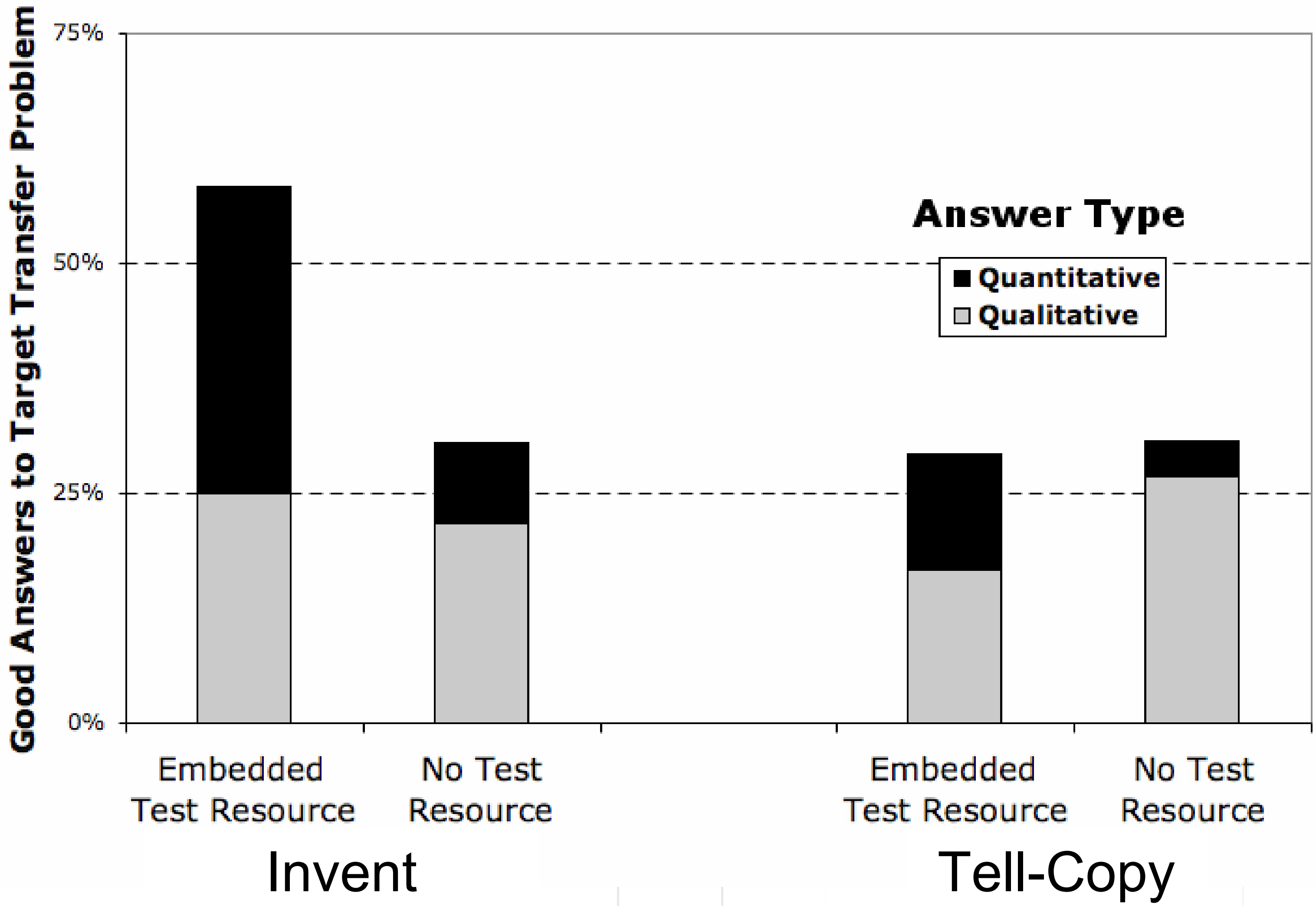
Calculate standardized scores for Rose's steals and assists and decide which she did better at.

- 90+ % correctly solved worked example in test.
- Did students blindly copy worked example or did they learn from it to find standardized scores on target transfer problem a few pages later?
- Target transfer problem did not have the same surface features as the instructional problem or the worked example.
  - Different topic (grades v. sports).
  - Different visual appearance.

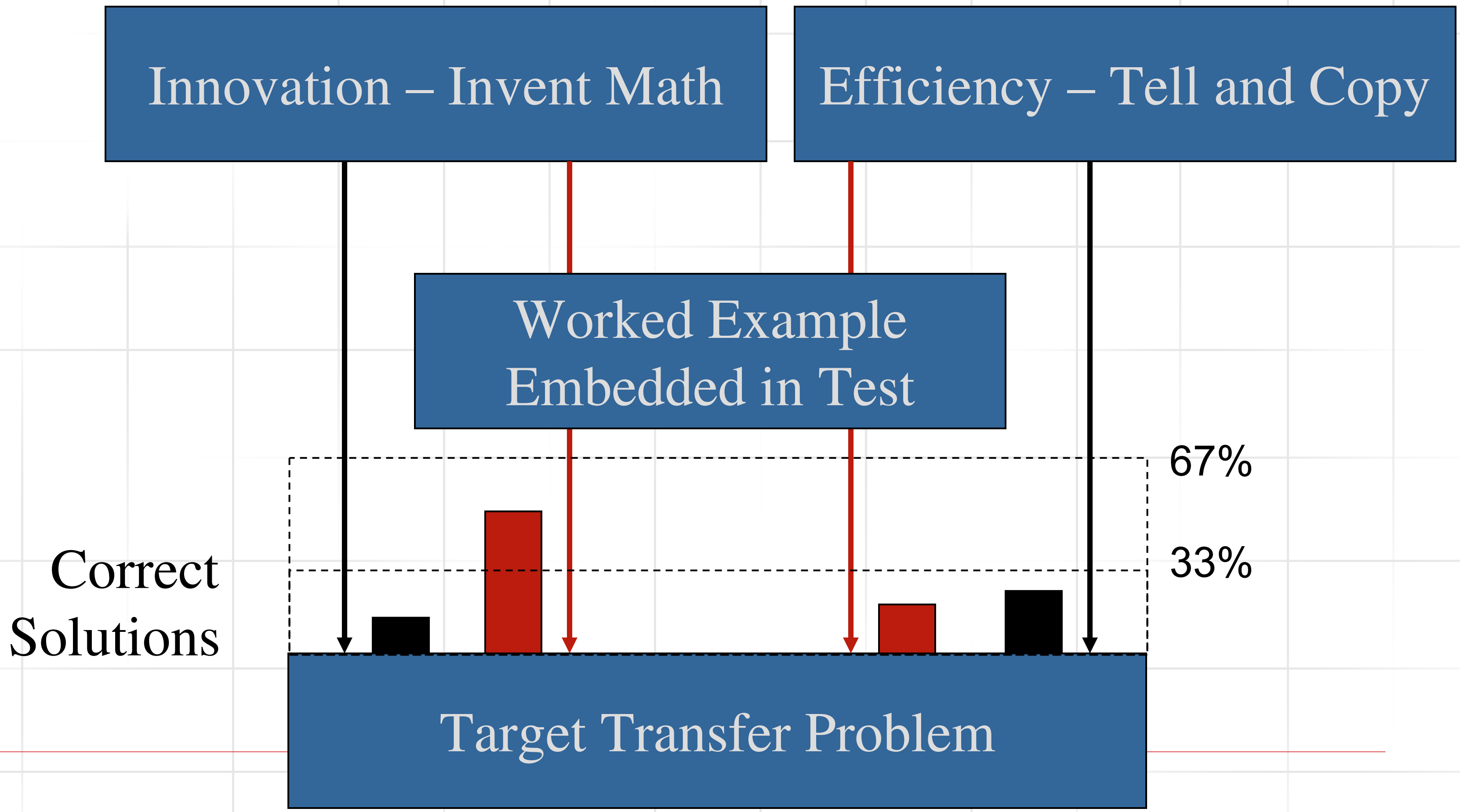
Full Experimental Setup



Broken out by answer type



Teacher Replication

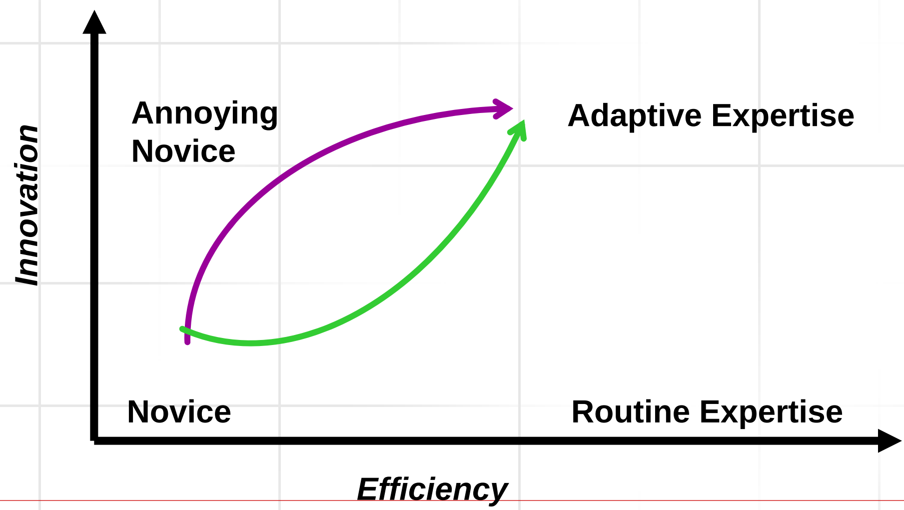


Summary

- Generated evidence that PFL transfer measures reveal the hidden value of innovation experiences.
  - Had we not assessed abilities to learn from a resource, innovation experiences would have seemed useless.
  - Had we not created "innovation" instruction, benefits of PFL measure would have been missed.

- Innovation "pre-activities" help maximize benefits of worked example for transfer:
  - Activities that involve innovation of math prepared students to learn the power of the efficient solution in worked example and transfer to a new problem context.

Answering a question and making a point.



Why innovation goes first.

w/ David Sears

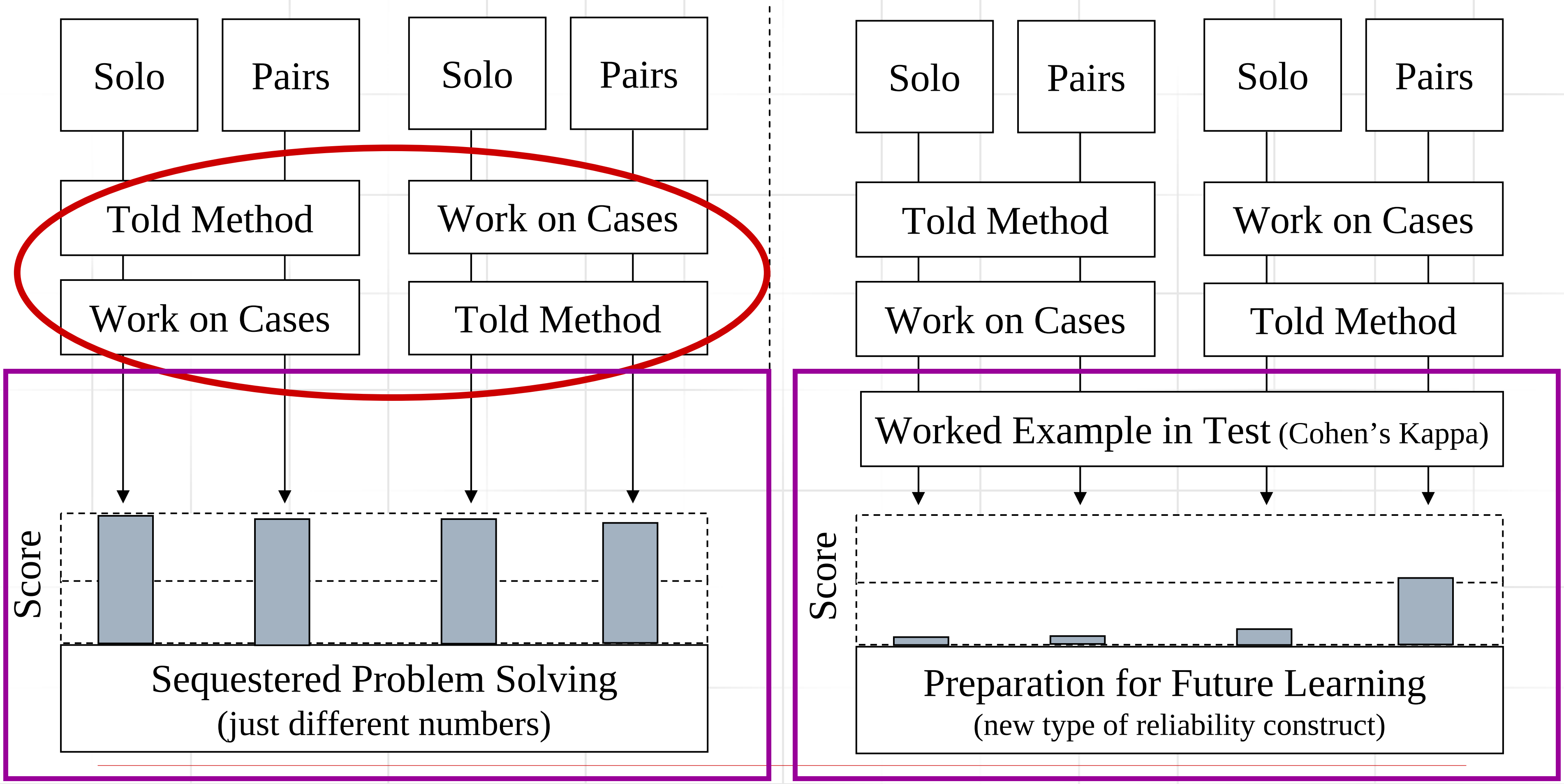
- College students learning Chi-Square logic
  - ($\chi^2 = \Sigma (E - O)^2/E$)
- Worked with a progressions of cases like the following…

Compute an index to indicate if there are different preferences.

	Candy	Chocolate
Children	6	**14**
Adults	**16**	4

	Apples	Oranges
Pigs	**14**	6
Horses	**16**	4

Overall Design & Results

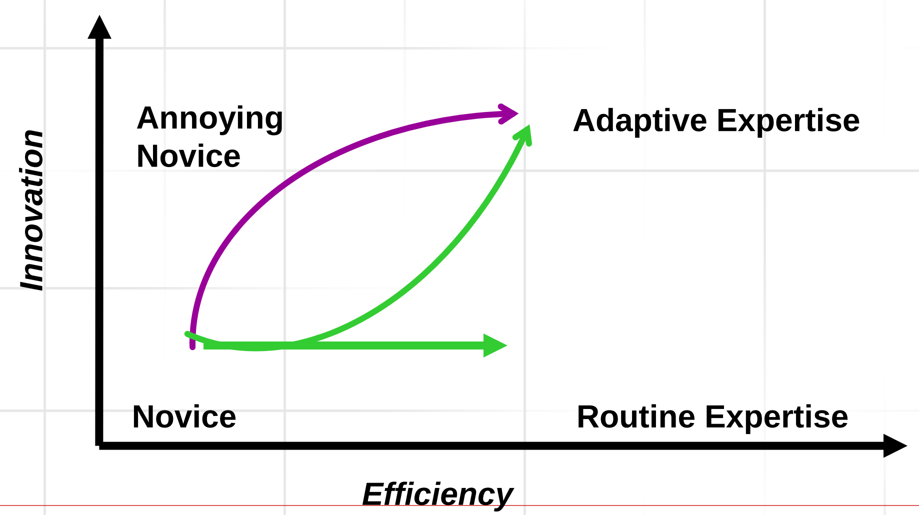


Measure of Procedural Efficiency

Measure of Adaptiveness

Putting PFL measures to work.

- Innovation-first can become efficient.
- Efficiency-first turns into efficiency only.



Outline

- The Problem of Transfer
- The Root of the Problem
- Issues of Instruction Involving Mathematics
- Returning to the Issues of Transfer
- → Summary

History of SPS Measures of Transfer

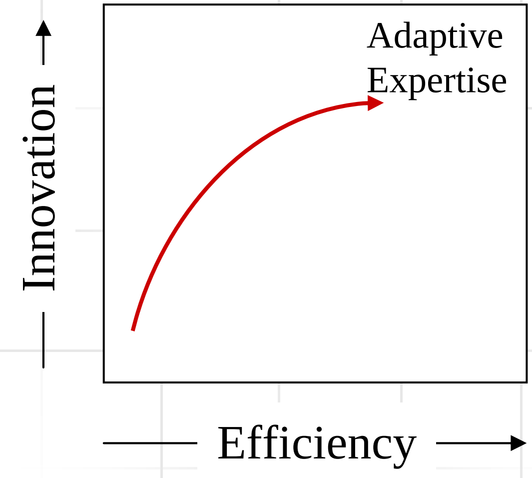
- Transfer tests often take the form of sequestered problem solving (SPS)
  - Students blocked from learning resources, because they contaminate results.
  - Typically, these evaluate efficiency at problem solving
    - replication of behavior in a new context.
  - Misdiagnosis of the value of innovation activities.
    - Many discovery curricula use “efficiency” measures.
    - This is a mismatch between instruction and assessment.
    - Often leads to “Wouldn’t it be more efficient to just tell them.”
  - Research using SPS measures cannot directly address important goals of education.

PFL Measures of Transfer

- Assessments of preparation for future learning (PFL) or "dynamic assessments."
  - More sensitive to early forms of knowledge.
  - Better reveals limitations and strengths of instruction.
  - More ecologically valid.
    - SAT is a proxy for assessments of readiness to learn.
    - Teaching to the test would be good.
    - It is what we care about.
- Might be useful for evaluating "student-centered" projects…
  - Students should be more prepared to learn after a project, simulation, etc.

Instruction for Transfer

- Proposed an optimal trajectory for learning.



- Showed the hidden efficiency of student innovation.
  - Given the right innovation activities:
    - Students transferred to continue learning.
    - Students were also more efficient in the long run.
    - Presumably on a trajectory to adaptive expertise.

- Thank you.
- Select papers at: <aaalab.stanford.edu>, or by request: *daniel.schwartz@stanford.edu*