Lessening the gap: Worked examples, self-explanation, and metacognition across levels of expertise in math learning

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Background

Worked examples (WEs)–step-by-step solutions to a problem–are popular in classrooms and online (Chegg, PhotoMath, Slader) despite drawbacks for learning, transfer, and metacognition.

WEs are often used in conjunction with problem-solving (PS) and self-explanation (SE); each have strengths and limitations.

	WE	PS	WE + PS	WE + SE
Access to accurate information	✔	✖	✔	✔
Generation	✖	✔	✔	✔
Attention directed to deep structural explanations	✖	✖	✖	✖
Metacognitive accuracy[3]	✖	?	✔	?

Poor metacognition → impaired self-regulation and learning[2]

Do **structured self-explanations** improve metacognitive monitoring and learning?

Procedure

2 lesson videos

Global Judgment of Learning (JOL)
What percentage of problems do you think you could you answer correctly if you were to take a test on this material right now?

12 Practice Problems
Worked Example vs. Self-Explanation vs. Structured Self-Explanation

Global and By-Topic JOLs
What is the likelihood that you could correctly answer a problem like this on the final test?

Math Self-Efficacy Rating Scale

21-Problem Transfer Test
20 isomorphic to practice problems; 1 further transfer

Sample Practice Problem and Responses

Undergraduate Participants: 125 novices (no college-level statistics experience) and 125 experienced students (1 college-level statistics course)

You pick a card from a typical 52-deck set, and you know that it is black. What is the probability that it is a spade?

WE

$P(S|B) = P(S \cap B) / P(B)$

$P(S \cap B) = P(S) = 1/4$
$P(B) = 1/2$

$P(S|B) = P(S \cap B) / P(B) = (1/4) / (1/2) = 1/2$

WE + SE

Explain why the problem was solved this way:

Sample answer #1: When you divide the desired outcome by the total possible outcomes, you are dividing the probability of getting a black spade by the probability of getting a black card, since it is not possible to get a red card.

Sample answer #2: The probability that it is a black card given that it is a spade is the equivalent of taking the probability that it is both a black card and a spade divided by the probability that it is a black card.

WE + SSE

Why do we divide by P(B) and not P(S)?

Sample answer #1: Adding would be separate units, and combining them in the notation is more fitting to the problem.

Sample answer #2:We divide using P(B) because we already know P(B) and are trying to find P(S)

Why multiply and not add P(S) and P(B) to obtain P(S∩B)?

Sample answer #1: Adding would not give us the right answer.

Sample answer #2: We multiply because we want to find the probability of the events occuring at the same time

Why does it make sense that the conditional probability with the two events (P(S|B)) is greater than the joint probability (P(S∩B))?

Sample answer #1: It's greater because "or" is more than "and".

Sample answer #2: It makes sense because both events occurring separately is more common than jointly

Expected Results

1. **WEs** exacerbate the learning and metacognition gap between experts and novices
2. **SEs** encourage novices to activate prior knowledge, identify misconceptions, and generate arguments more than WE[4]
3. **SSEs best reduces gaps**: novice learners focus on deep principles, make connections to prior knowledge, generate information, and have their subjective experiences of difficulty reflect their actual understanding[4]

Transfer Test Problems

Practice Problem: A given problem about illnesses.

4 Types of Transfer Test Problems:

	Structurally similar	*Structurally different*
Superficially similar	Given problem about illness	And problem about illness
Superficially different	Given problem about machines in a factory	And problem about machines in a factory

Experts: Focus on conceptual structure & implicit features for transfer[1,4]

Novices: Focus on surface or explicit features of problems

Real-world transfer:

Maria tested for a disease and received a positive result. About 1 in 2000 people have the disease, whereas the false positive rate is 5%. She is certain she has the disease and awaits further testing. How concerned should she be about the result?

Sample answer #1: She should not be too concerned, since the percentage of people with the disease is much lower than the false positive rate. It is likely she does not actually have the disease, and that the test is mistaken.

Sample answer #2: Maria should be concerned but should get more testing because 100 people who do not have the disease are told they have it.

Help us construct a scoring scheme for test problems!

		Type of error			
Problem work	Correct answer	Incorrect divisor	Incorrect division order	Incorrect operation	Calculation error
$P(S|B) = P(S \cap B)/P(S) = (1/4)/(1/3) = 1/2$	N/A	-2	N/A	N/A	-1

References

[1]Chi, M. T. H., et al. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive Science, 13*(2), 145-182,

[2]Hausman, H., Myers, S. J., & Rhodes, M. G. (2021). Improving metacognition in the classroom. *Zeitschrift für Psychologie, 229*(2), 89.

[3]Prieto, M., Hausman, H., Myers, S. J. & Rhodes, M. G. (2021, November). Worked Examples Impair Metacognitive Monitoring. Virtual poster presentation at the Harvard Women in Psychology Trends in Psychology Summit.

[4]Richey, J. & Nokes-Malach, T. (2013). How much is too much? Learning and motivation effects of adding instructional explanations to worked examples. *Learning and Instruction, 25*, 104-124

Abstract

In STEM, experts focus on the conceptual structure of problems, whereas novices focus on superficial, irrelevant, features. I aimed to improve college students' statistics learning. Participants watched a lesson on conditional probability, practiced problems through one of three methods, predicted their test performance, and took a transfer test. Worked example (WE) practice entailed studying problems' step-by-step solutions. Self-explanation (SE) involved explanations of each WE solution. Structured SE (SSE) practice required explanations about key WE solution steps. I predict that SSE practice will lead to the highest test performance and most accurate test predictions by shifting attention to deep problem structure.