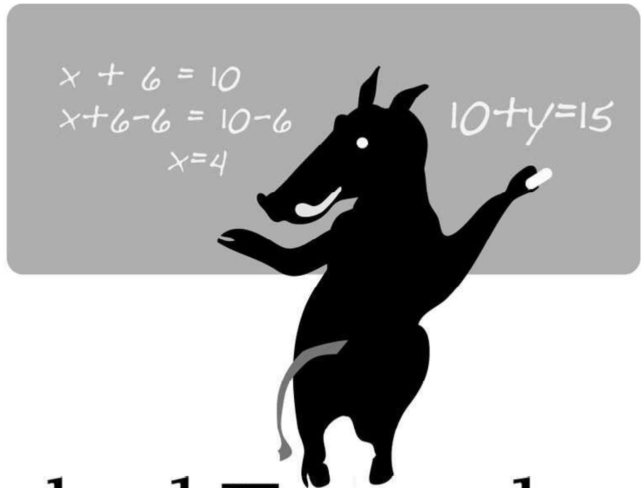
W is for Worked Examples



Acquiring skills and procedures

WORKED EXAMPLES ARE models of expert solutions. Novices can follow the expert's procedures and explanations to learn how to solve similar problems on their own.

A major challenge for instruction is how to help people get started learning (see Chapter P). Worked examples are particularly useful when novices might flounder needlessly when they have to solve problems on their own. For example, imagine you borrowed your friend's bike. It gets a flat tire. You have the tools to fix it but do not know how. What would you do?

(a) Hire someone else to fix it.
(b) Try to figure out how to fix it on your own.
(c) Observe someone else fixing a tire.
(d) Watch a video on YouTube with step-by-step instructions on how to fix a tire.

If you have the money and zero desire to dirty your hands, (a) is a good choice.

Otherwise, the better choice is (d), which is the worked example. A worked example differs from (b), which is solving problems on your own. Instead of having to figure it out, the worked example just shows you. A worked example also differs from (c), which is pure observation. Worked examples break down the steps to completing a task, and at their best, they explain the reason for each step. Highlighting each separate step helps people notice each move they need to take, and the explanation helps people understand each step so they can adapt them to their specific circumstance (which may differ slightly from the video).

I. How Worked Examples Work

In their simplest form, worked examples extend observational learning (see Chapter O). Through observation, people can learn to imitate another person. Worked examples help solve two challenges inherent to pure observation. The first is that a learner can have difficulty segmenting an observed behavior into simple, imitable components. For example, juggling happens quickly with many simultaneous moves. Should a learner pay attention to the balls in the air, the movement of the hands, the position of the juggler's legs? A worked example separates the elements, so the learner can see and practice each one. The second challenge of observational learning is that people may not know what the model has in mind. This can make it hard to figure out the purpose for a specific behavior, which leads to brittle imitation. For instance, the juggler may do certain moves with extra flair. Without knowing that this is to entertain the audience, the learner might always try to imitate the flair. A good worked example explains the goal or reasons for each component behavior. This way, learners can figure out which aspects of the behavior are critical and how they can adapt them to their own purposes.

Worked examples can also work without a human model. A worked example can show a series of algebraic transformations, one per line, without showing a person actually writing out each step. Even though there is no person, the worked example shows the steps of an expert, and ideally, it reflects the expert thinking as well.

When doing algebra, and the many other symbolic tasks in school, it is easy to forget the steps reflect someone else's thoughts about the problem. Worked examples try to make the hidden expert thinking more explicit. A good worked example shows how the expert decomposed a larger problem into subgoals and the steps taken for each. It also explains what the expert had in mind to a useful degree.

Which of the following do you find most helpful?

Example A

Solve for a:
$(a + b)/c = d$
$a + b = dc$
$a = dc - b$

Example B

Solve for a:

$(a + b)/c = d$	Try to isolate a on one side of the equation.
$a + b = dc$	Multiply both sides by c to get rid of the $1/c$ term on the left.
$a = dc - b$	Then subtract b from both sides to isolate a.

If you remember your algebra, example A is probably sufficient. It simply shows the steps, and you can fill in the reasons for each step. If you are just starting, example B is probably better. It explains the purpose of each subgoal, which may help students flexibly apply the steps to new situations that do not involve exactly solving for *a*.

Scholars who study worked examples often compare their benefits against learning by problem solving. In a worked example, people are shown what to do and why. In problem solving, people need to figure out what to do and why. A disadvantage of problem solving for beginners is that they may never actually figure out how to solve a problem, or they may waste time on false leads before finally figuring out the solution. Worked examples help ensure learners do not spend time fuddling through mistakes, because the way to solve the problem is modeled for them.

A nonintuitive finding is that, compared with problem solving, following a worked example can lead to better encoding and memory of solution procedures. The reason is that worked examples reduce cognitive load (Sweller, 1994). *Cognitive load* refers to the amount of information people need to track simultaneously to accomplish a task: more information = more cognitive load. Working memory is the memory system that enables the conscious manipulation of information (see Chapter E). Problem solving requires managing more information in working memory and increases cognitive load. People need to remember their prior tries; they need to search for the next thing to do; they need to decide on problem-solving strategies; they need to figure out which information is relevant. The result is that fewer cognitive resources are available for learning the relevant information. When people are being interviewed for a job, they can concentrate so hard on giving good answers that later in the day they cannot remember the questions or their answers. Worked examples reduce many of the extraneous demands of problem solving and thereby preserve cognitive resources needed for learning.

II. How to Use Worked Examples to Enhance Learning

Deliberate practice (see Chapter D) is for advanced performance, while worked examples are for early learning. Worked examples are useful in domains where procedural fluency is important and a goal is efficient, errorless performance (see Chapter K).

There are three ways to bolster the effects of worked examples for learning. The first is to adhere to a few design principles. The second is to set up the instructional tasks that wrap around the worked example. The third is to choose the right level of task decomposition.

CREATING WORKED EXAMPLES

To create effective worked examples, reduce distracting complexity. The goal is to avoid any extraneous cognitive load that detracts from focusing on the steps of the solution. If students are following a diagram, remove labels that are irrelevant to the worked example. Furthermore, avoid splitting attention, such as making students jump and back forth from a block of text to a diagram (Mayer, Heiser, & Lonn, 2001). Eliminate the need to search for information—if you have followed assembly instructions for furniture, you may have experienced the nuisance of shifting from the written instructions to the diagram of the next step and then to yet a third document that indexes the different screws and parts. Finally, highlight the subgoals, and consider whether it will be useful to explain their reasons. In cases where learners can (and will be able to) explain to themselves the reason for each subgoal, the answer may be no. In other cases, providing explanations can help learners understand why they are doing each step, so they can generalize to other situations.

INSULATION RESISTANCE TESTS

a) CONDUCTORS IN PERMANENT WIRING

Test : To test Insulation Resistance from conductors to earth

How conducted : i) Disconnect appliances and busways during these tests. Make sure main switch is "on" and all fuses are "in". Remove main earth from neutral bar and set meter to read insulation. Connect one lead to earth wire at MEN bar and take first measure by connecting the other lead to the active. Take next measure by connecting the lead to the neutral.
ii) If resistance is not high enough in either of the two tests in i) then measure each circuit separately.

Results required : i) At least One Megaohm
ii) Same result as i) above

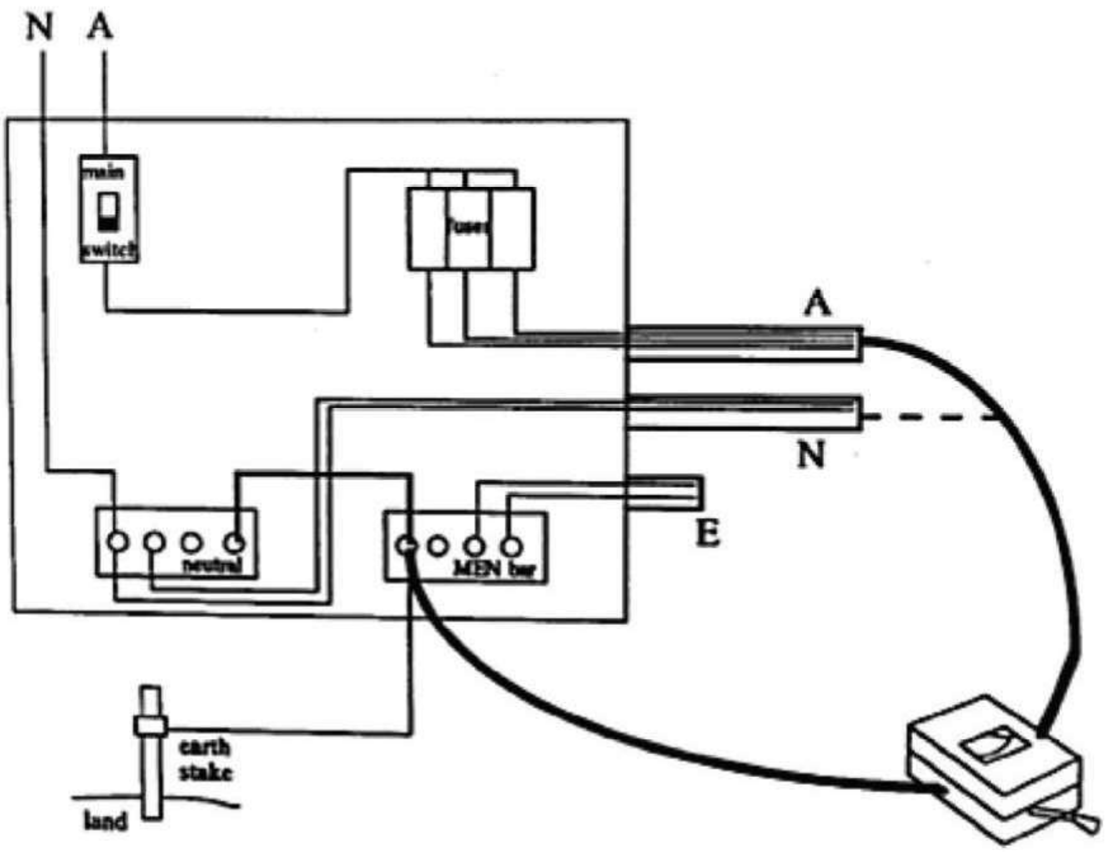


Figure W.1. Original instructions for a wiring diagram. (From Chandler and Sweller, 1991.)

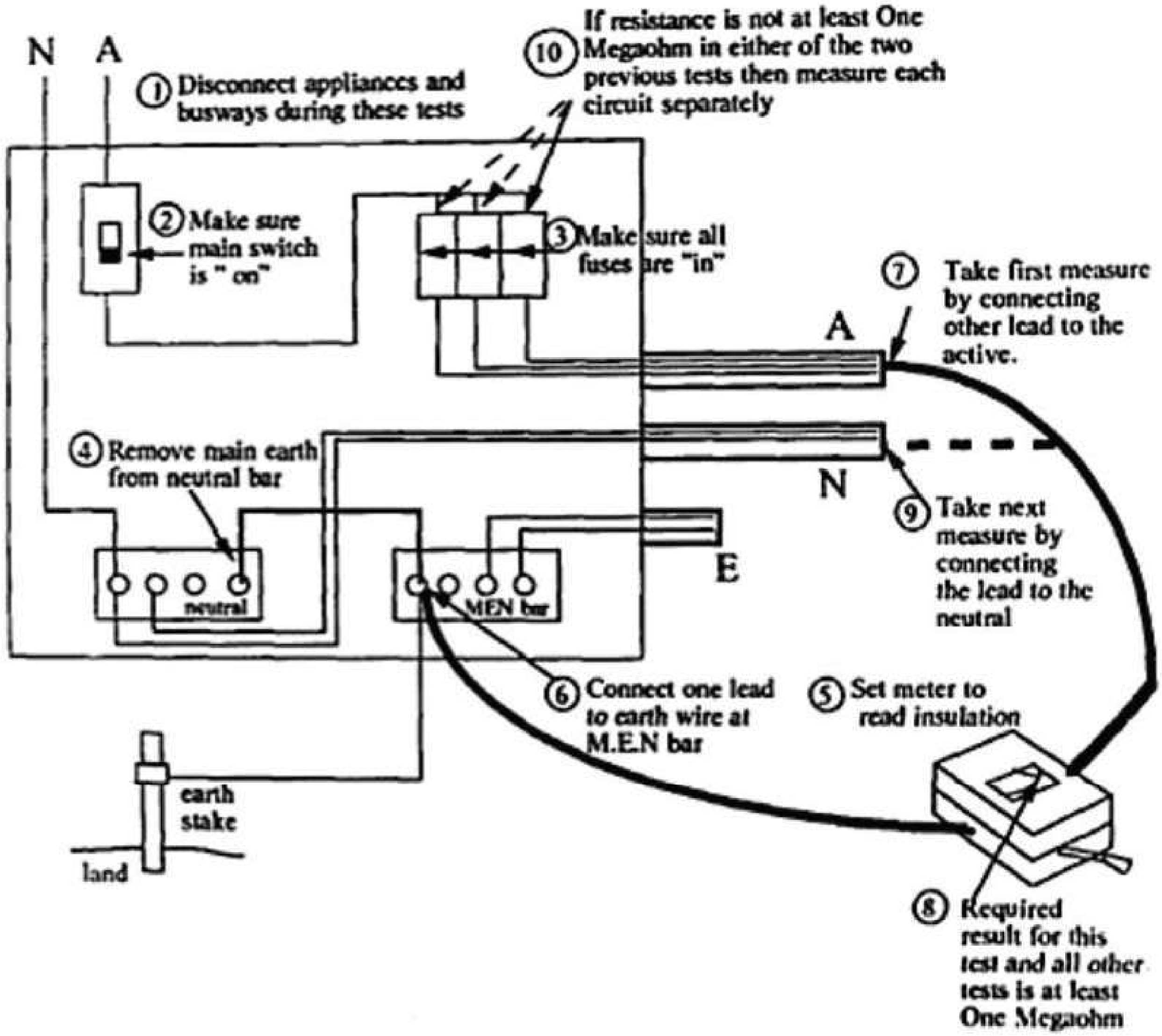


FIGURE 2 Example of the instructional format presented to the modified group of Experiment 1.

Figure W.2. Redesigned instructions to reduce cognitive load. See if you can notice the different design principles the authors used to improve the instructions. (From Chandler and Sweller, 1991.)

A wonderful example is provided by Chandler and Sweller (1991). Figure W.1 shows an original set of instructions. Figure W.2 shows how they improved the instructions. The two examples make a great pair of contrasting cases. See if you can notice whether the authors followed all the underlineddesign principles described in the preceding paragraph.

INSTRUCTIONAL TASKS

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Additional activities can enhance the benefits of worked examples. One easy trick is to interleave worked examples with problems. For example, alternate a worked example with a similar problem that students have to solve on their own. This can help motivate students to engage and understand the worked example, because they will have to solve similar problems. Moreover, solving a follow-up problem on their own helps students remember the solution better.

A harder trick is to encourage self-explanation. Self-explanation refers to the mental monolog that people use to work out the meaning of a text or diagram. For instance, people can ask themselves what-if questions to see if they have thought through the implications of what they are reading. Because worked examples typically provide procedural instructions rather than conceptual explanations, it is up to learners to make sure they understand the purpose of the procedure in a larger context. Even if a worked example includes explanations for each step, learners still need to make sure they understand those explanations. People do not always naturally self-explain, because it is effortful. Chapter S provides some examples of prompts that encourage self-explanation.

TASK DECOMPOSITION

Making a worked example that leads to flexibility depends on many decisions about the level of detail to include. Consider the differences in the following algebra transformations:

(a) $3x = 6$
$\rightarrow x = 2$
(b) $3x = 6$
$\rightarrow 3x \div 3 = 6 \div 3$
$\rightarrow x = 2$

Example (a) is appropriate for advanced students. Example (b) is better for beginners, because it shows the hidden step of dividing by 3 on both sides. For some, the following worked example (c) would be even better, because it shows why the 3s disappear:

(c) $3x = 6$
$\rightarrow 3x \div 3 = 6 \div 3$
$\rightarrow (3 \div 3)x = 6 \div 3$

→ $(1)x = 2$
→ $x = 2$

A major task for the designer of worked examples is choosing the right level of decomposition for a student's incoming knowledge. Experts can be bad at this, because they have an expert blind spot (Nathan & Petrosino, 2003). They forget what it was like to be a novice, and they do not realize how much they have chunked their knowledge where lots of substeps are combined into one big step.

When designing instruction, it is often useful to work with a content expert and play the intelligent novice. Keep asking, "Why did you take that step?" For example, "Why did you divide both sides by three?" This way you can figure out how to decompose the steps for a novice. This is a form of cognitive task analysis, where you use problem-solving interviews to try to figure out each cognitive step needed to solve a problem. Learners need to understand these steps or subgoals, so they can transfer components of the overall solution procedure to a new situation (Catrambone & Holyoak, 1990). If they do not learn the subgoals and purposes of the relevant steps, they will only be able to use the whole cloth procedure for identical problems.

III. The Outcomes of Worked Examples

The most natural outcome of worked examples is early procedural skill. Beginners learn the steps to take with no-nonsense efficiency, so they can get started with effective problem solving sooner (Salden, Koedinger, Renkl, Aleven & McLaren, 2010). From there, learners can begin to apply, refine, and customize those steps in actual problem solving.

Worked examples are especially good for well-defined domains, such as algebra, where there are known moves and clear goals. (Ill-defined domains, such as solving poverty, do not have a clear set of moves or subgoals that will achieve a solution.) Worked examples, by themselves, are not a natural fit for conceptual knowledge, because understanding concepts often requires making very many connections among ideas. Expressing all those connections in a worked example can overwhelm the simple elegance and cognitive parsimony of a good worked example. However, combining worked examples and self-explanation can support conceptual understanding.

Worked examples have shown benefits for learning over unaided problem solving in domains including algebra, geometry, physics, and computer programing (Atkinson, Derry, Renkl, & Wortham, 2000). Returning to our algebra example from earlier, here is a prototypical example of a study that uses different instructional conditions to show that worked examples are superior to problem solving.

Problem-Solving-Only condition:

(1) Solve for *a*.	(2) Solve for *h*.
$(a + b)/c = d$	$(h + k)/g = a$

Worked-Example condition:

(1) Solve for *a*.	(2) Solve for *h*.
$(a + b)/c = d$	$(h + k)/g = a$
$(a + b)/c \times c = dc$	
$a + b = dc$	
$a + b - b = dc - b$	
$a = dc - b$	

Students are typically first introduced to a topic through a lecture or reading. Then students in the Problem-Solving condition solve a set of problems as they might during homework or seatwork (or in a computerized environment). In contrast, students in the Worked-Example condition go through a set of problem pairs. In the pairs, one problem is set up as a worked example that students can follow, and the second is a similar problem the students have to answer themselves. Finally, a posttest measures their abilities to apply the solutions to relatively similar kinds of problems. Most of the time, the worked-example group comes out ahead.

IV. Can People Learn to Teach Themselves with Worked Examples?

To our knowledge, nobody has examined whether students can be taught to seek out worked examples. One reason is that people do this pretty naturally, if there are examples to be had. For example, homeowners might look up a video on YouTube about how to paint their kitchen. Someone learning to draw a cartoon might look for step-by-step instructions from a book.

People can help themselves learn better from worked examples by employing self-explanation. For example, they can try to predict the next step in problem solving and check if they are right, or they can ask themselves why a particular step in the solution is important. When worked examples are coupled with self-explanations, learners gain more (Renkl, Stark, Gruber, & Mandl, 1998).

V. Risks of Worked Examples

Most risks of worked examples can be captured by an analogy to automobile navigation systems. When a car navigation system leads drivers step by step, drivers take those steps and arrive at the desired location. However, the next time they drive to the same location, they cannot remember the steps very well on their own. Even if they do remember the steps, they cannot consider any possible variations, because they did not experience any variation during initial learning. They do not know how the navigation system made its decisions among alternative routes.

To mitigate the risk of students blindly following worked examples without remembering, it can be useful to (a) alternate worked examples and problems as described above and (b) fade worked example support. For instance, one might take a page from the generation playbook (see Chapter G) and slowly remove pieces of the worked example, which students need to fill in from memory. Alternatively, one might simply begin to withhold the worked examples or add an incentive to stop looking at the worked examples (e.g., it begins to cost players points in a game after the first two peeks at a worked example). It is a natural tendency to want to get the solution if it is available, so sometimes it takes extra steps to push students to figure it out on their own (Roll, Aleven, McLaren, & Koedinger, 2011).

To avoid the risk of students being unable to handle variation, provide students some variation during learning, for example, by showing negative instances where the solution procedure does not work. It can also be useful to provide students with two worked examples side by side, where each achieves the same outcome but through a slightly different route (Rittle-Johnson & Star, 2007).

A common risk of being told solutions is that people pay attention to the solution more than they pay attention to the context in which the solution should be applied (Schwartz, Chase, Oppezzo, & Chin, 2011). When relying on the car's navigation system, people often pay more attention to the instruction "turn left in 100 feet" than to the specific landmarks they can use to recognize when to take the turn in the future. The consequence is that they will not recognize when to use the turn-left procedure on their own. Similarly, with worked examples students may not notice the conditions that give rise to the problem, and they will fail to recognize those conditions later, and fail to apply their knowledge. One possible way to avert this risk is to use worked examples with just-in-time telling (see Chapter J): provide students with an opportunity to explore the problem space before delivering the efficient solution in a worked example.

Another risk of worked examples is that students might come to expect that they should quickly know the correct solution strategy to apply to problems. When given a difficult open-ended problem that they have not been taught how to solve, students may resist, or they may just apply what they do know instead of learning what is new (see Chapter K).

VI. Examples of Good and Bad Use

One good use is for the early introduction of procedures in homework assignments. Provide worked examples along with similar problems students have to solve themselves. For example, when trying to help students learn a new procedural skill, such as creating a histogram chart in an Excel spreadsheet, create a worked example they can follow, giving step-by-step instructions with pictures and labeling each step. Indicate how the solution could be generalized. Instead of writing, “Highlight cells C2:C4,” write “Highlight cells C2:C4, or whichever cells hold the data you want to plot.” Afterward, students should create their own chart with new data.

A bad use is to provide worked examples as part of an end-of-term problem set on material already covered. If students already have a good understanding of the material, the worked examples are unnecessary, and time spent problem solving would be more beneficial.

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W IS FOR WORKED EXAMPLES

What is the core learning mechanic?

Worked examples involve demonstrating step by step how to complete a procedural task.

What is an example, and what is it good for?

A self-help video shows how to install a faucet and explains each step of the repair. Watching the video can save novices a great deal of time learning how to install the faucet compared with the inevitable doing and undoing that happens when they try on their own.

A second application is showing the solution steps for an algebra problem.

Solve for a:
$(a + b)/c = d$
$a + b = dc$
$a = dc - b$

When people do not know how to solve problems, worked examples are useful for initial learning. They help novices attend to the key steps, which helps them solve highly similar problems later.

Why does it work?

Worked examples build on observational learning. They allow the learner to observe and imitate well-defined steps. Ideally, they also share expert thinking processes, particularly how and why to segment complex problems into subgoals. A worked example can be more efficient than problem solving for initial learning. The worked example reduces unnecessary floundering and distractions, so people can focus on the actual steps that give the right solution.

What problems does the core mechanic solve?

- Students have no idea where to start when trying to solve problems.

    - A young student has never seen a variable and confronts $3 + x = 5$.
- Students have limited time to learn a set of procedures.
    - People need to complete safety training before they can start working.
- Students observe a model behavior but cannot imitate it very well.
    - A child cannot learn how to tie a shoelace by watching adults tie their shoes.

Examples of how to use it

- If students are first learning a specific algebra operation, provide a worked example followed by a similar problem for students to solve on their own.
- When trying to help students learn a new procedural skill, such as creating a histogram chart in an Excel spreadsheet, create a worked example they can follow, giving step-by-step instructions with pictures and labeling each step.

Risks

- Students may imitate the procedures of the worked example without understanding why each step is needed.
- Students may not learn when to use the procedures shown in a worked example.