Worked Examples

Design a Course

How to Teach

How People Learn
- Metacognition
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- Worked Examples

Create an Inclusive Classroom

Assess Student Learning

Assess & Improve Your Teaching

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Lessons Learned from Remote Teaching & Learning

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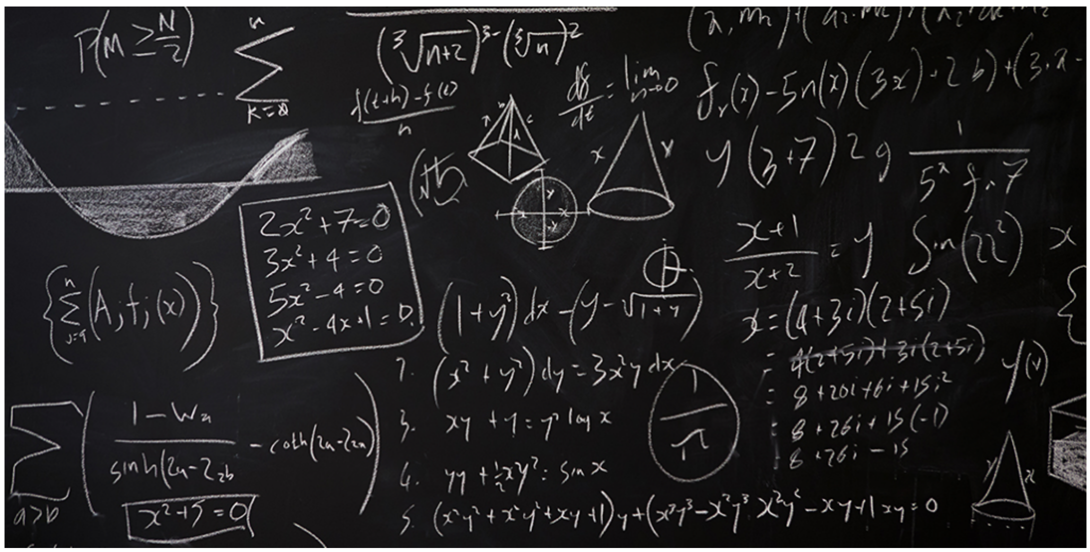
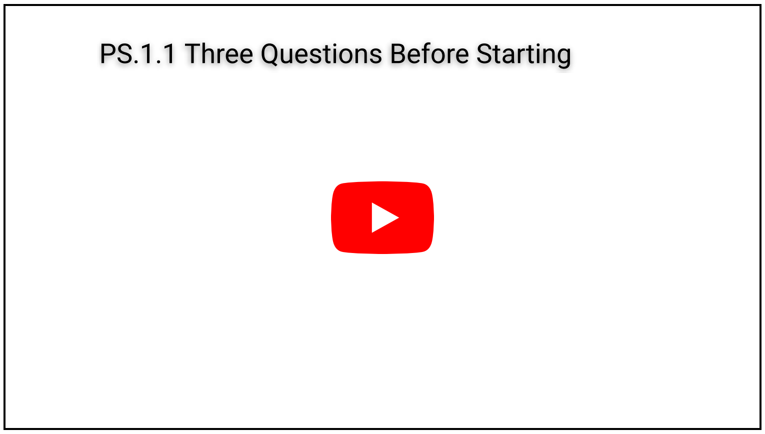


What are worked examples?

Worked examples are step-by-step illustrations of the process required to complete a task or solve a problem. In a worked example, students are provided with the task or problem formulation, the procedure or the step-by-step process for solving the problem, and the solution. **When using worked examples effectively, instructors engage students in self-explaining these procedures or solutions, encouraging them to reflect more deeply on the principles illustrated in the worked example.** Worked examples can be designed to teach well-structured tasks, such as applying Newton's Second Law, as well as more ill-structured tasks, such as constructing an argument, modeling biological pathways, or devising a mathematical proof (Renkl, 2023).



__In 8.01-Classical Mechanics__, videos of worked examples are embedded within the weekly learning sequence of the course as shown in this video which illustrates three important questions to ask when approaching kinematic problems. You can see additional examples of how worked examples are used in this course by going to its MIT Open Course Ware page.]

Worked examples are useful in the initial acquisition of cognitive skills because they allow students to understand principles and their applications more deeply before applying them on their own (Renkl, 2014b). Worked examples have shown to be particularly effective for novice learners, who may experience high levels of cognitive load when learning new concepts and procedures simultaneously (Renkl, 2014a). In fact, worked examples tend to be more **efficient and effective** for initial skill acquisition compared to problem solving (Renkl, 2014a). If designed well, worked examples can provide models for learners to follow when tackling similar problems, allowing them to transfer knowledge from one task to another (see Caveats section below).

maybe hint for worked example, generate new problem of same solution type

Worked examples can be applied to a wide range of disciplines and contexts beyond STEM.

Worked examples can be created for any procedural task. For instance, in the field of law, worked examples have been used to teach students how to reason through legal cases and construct legal arguments (Nievelstein *et al*., 2013; Schworm & Renkl, 2007), while worked examples have similarly been used to assist learners in understanding negotiation strategies (Gentner *et al*., 2003). In language and literature, worked examples can be used to help students write essays or understand different writing styles (Kyun *et al*., 2013), while in the arts, worked examples have been used to teach students to differentiate between artistic styles (Rourke & Sweller, 2009).

Furthermore, worked examples can be used inside and outside of class time and for a variety of class types. For instance, during class, instructors can either demonstrate a worked example interactively or provide students with a written worked example for students to work on individually and/or in groups. Outside of class, worked examples can be provided for students to study on their own time (see Caveats section for what to avoid when implementing worked examples). In lab-based courses, for example, instructors can convert any demonstration, which is often performed when modeling a procedure, into an effective worked example by asking students to reflect on specific and important aspects of the demonstration (e.g., Why would you do X instead of Y first? What are the advantages and disadvantages of using this type of protocol for isolating X?).

Why are worked examples important?

Early research conducted by Sweller and Cooper (1985) showed that after an initial introduction to a series of algebraic problems, replacing practice problems with worked example counterparts resulted in higher learning gains. The worked example condition was also more efficient; learners given problems to solve took almost six times longer to complete the learning sequence and had more errors than those provided with worked examples to study from. Subsequent studies have supported the finding that if implemented well, studying worked examples is more effective in the initial stages of learning than learning primarily through problem solving (Figure 1 and Salden, Koedinger, Renkl, Aleven, & McLaren, 2010). Though students may usually be provided with examples or demonstrations in the initial stages of learning, the number of worked examples is typically low and insufficient for learning underlying principles. These demonstrations are also often done passively with little student engagement, which does not lead to deep learning and neutralizes the worked example effect. In fact, when implementing worked examples with features that get students to actively study the solutions (see the Caveats section for more), the worked example effect nearly doubles (Hattie, 2009).

*Figure 1. **Worked example problems result in faster learning and better performance in comparison to problem solving.** After an initial period of instruction where the theory for solving certain geometry problems was explained and illustrated with worked examples, students were randomly placed in problem-solving conditions (PH and PL) or worked example conditions (WH and WL). In the problem-solving conditions, students were given a series of geometry problems to solve, and after the students attempted the problems, they could study their solutions. In the worked example conditions, students were given the exact same series of problems with their solutions upfront and instructed to study them. The problem-solving and worked example conditions came in two flavors: low-variability and high-variability. The low-variability problems (PL = problem solving with low-variability problems and WL= worked examples with low-variability problems) only differed in values, whereas the high variability problems (PH = problem solving with high-variability problems and WH= worked examples with high-variability problems) differed in values and problem format. The worked example conditions (both low and high variability) required less instruction time and also yielded better performance at the end of the intervention than either of the problem-solving conditions. Problem variability also had a substantial influence in the worked example condition, with higher variability worked examples resulting in better performance as well. Adapted from Paas, F. G. W. C., & van Merrienboer, J. J. G. (1994).*

Why are worked examples more effective for initial skill acquisition than practice?

When introducing a new task or skill, it may seem counterintuitive to provide students with worked examples to study instead of giving them practice time to solve or complete the task. When students are introduced to a new task, they often do not have a firm grasp of the material and principles being represented in the task and may resort to ineffective problem-solving strategies such as aimless trial-and-error or plug-and-chug (Renkl, A., 2023). Trial-and-error involves trying various solutions without a proper problem-solving strategy, while plug-and-chug involves looking for existing problems with similar surface-level features without considering if their underlying structure aligns with the current problem. For example, when faced with a mechanics problem presented in the context of an inclined plane, novice students may search for another “inclined plane problem” without considering whether the underlying concept is the same (Figure 2 and Chi *et al*., 1989).

Figure 2. ***Differences in categorization of physics problems between novices and experts.*** *Novice students tend to categorize example physics problems such as the two different examples represented in this figure, based on their literal features: "inclined plane problems." In contrast, experts tend to categorize problems based on their deep structure: illustration of physics concepts such as conservation of energy as shown in this example. Adapted from Chi, M.T.H., Feltovich, P.J. and Glaser, R. (1981).*

These ineffective problem-solving strategies are taxing on cognitive load because they lead students down unproductive paths while already processing a lot of new information, including understanding newly introduced concepts and making sense of the problem being presented. Engaging prematurely in problem solving without fully understanding the task domain and procedure leaves little working memory capacity for learners to understand the validity of a particular solution or the ability to integrate new knowledge for future use (Sweller, 1988).

Providing step-by-step illustrations of a solution or procedure in worked examples reduces cognitive load by allowing students to focus their cognitive resources on understanding the principles illustrated in the solution. Therefore, providing worked examples for students to study can help them understand the principles and strategies needed to approach the task effectively, without overtaxing cognitive load (Clark & Mayer, 2011).

As learners become more proficient, educators can transition to more practice exercises and tasks to help students automate problem-solving strategies or procedures (see Caveats section below). In fact, when students have sufficient prior knowledge about the specific task or problem, asking students to study worked examples can decrease competence in performing said task (often called expertise reversal, Kalyuga & Renkl 2010). It is important for instructors to balance the use of worked examples with independent practice to maximize learning outcomes for students at different stages of proficiency within a learning sequence.

Examples

7.013 – Introductory Biology

During recitations, students were provided with a handout containing worked examples. The teaching assistants (TAs) would lead the class through at least one of the worked examples, step by step, to ensure that students understood the problem-solving strategies illustrated in those worked examples. Then, students were given a set of slightly more complex but similar additional problems to solve independently. One or several students would then volunteer to guide the class through the steps they used to solve these additional problems. By incorporating both worked examples and problems to solve for a given concept, students had the opportunity to more deeply understand the concepts learned, and instructors could better monitor progress by observing what happened when the surface features and the complexity of the problems changed.

21A.819.1X – How To Conduct Conversational Social Science Research

Students were provided with two examples of an informal interview protocol and informed which one was well constructed and which was not. After reading both worked examples, students were asked to annotate each example and provide suggestions for improvement. They were then able to review the instructor's own annotations and explanations for suggestions. By beginning with the knowledge of which examples demonstrated good or poor interview protocol (correct and incorrect worked examples), students could engage more meaningfully with the worked examples, reflecting on their annotations and exploring their reasoning for suggested improvements. Using incorrect worked examples, either alone or in combination with correct examples, has been shown to be more effective than using correct worked examples alone (Booth *et al*., 2013).

Figure 3. Worked examples used in 21A.819.1X. *Students are presented with two interview protocols and told which one is well-constructed and which is not. After making their own annotations, students are able to see the instructor's annotations (as shown in the white box in this image) which explain the rationale for why these are good or bad examples.*

The instructors in this course also utilized worked examples of interview techniques by providing example videos of interviews. One video demonstrated good interview techniques (a correct worked example), while the other demonstrated poor interview techniques (an incorrect worked example). After watching these videos, students were asked to assess them for improvements regarding best practices in conversational interviewing. They were then able to compare their assessments with the instructor's explanations, designed to help reinforce their understanding of effective interview techniques.

Caveats (and how to address them)

Worked examples effectively teach new tasks or solve new problem types. However, the worked example effect can be negated if certain design features are not considered. Here are some concerns that instructors have often brought up about worked examples and strategies for ameliorating them:

1. Students might passively read solutions without extracting underlying principles.

While worked examples have shown to be effective, their effectiveness depends on students cognitively engaging with them. Unfortunately, worked examples are often presented passively, without requiring engagement. Research shows that few students will naturally engage in self-explanation strategies when studying solutions. To address this issue, it is recommended that students be encouraged to self-explain the solutions. This can be accomplished in a variety of ways using self-explanation strategies. For example, instructors can present a solution step by step and embed pertinent questions that help students reflect on the deeper structure of the problem, such as "Why was this strategy used?" and "What was the principle applied here?" Self-explanation strategies promote deeper thinking by requiring students to explain the rationale of the solution to themselves and its relation to the core concepts. For additional information on self-explanation strategies, see the Resources section.

2. Students might memorize solutions without deepening their understanding.

It is important to vary the surface features of example tasks or problems to prevent rote memorization of solutions. This can be achieved by presenting multiple worked examples that appear dissimilar on the surface, but are representations of the same concept (see Figures 1 & 2). When exposed to contrasting problems that address the same core concept, students can more easily identify the commonalities that unify all the example problems, the deeper structure, and will be less likely to memorize solutions based on surface features (Renkl, 2014a and Paas & van Merrienboer, 1994).

3. Worked examples may not prepare students to approach tasks or solve problems independently.

When students are introduced to a new task, worked examples are more effective than having students problem solve. However, as they deepen in understanding how to perform the task or solve the problem, it is beneficial to encourage them to attempt the tasks independently to develop proficiency and automaticity (Renkl, 2014b). Instructors can do this by alternating worked examples and problems to solve in an increasingly more complex task sequence. Additionally, instructors can reduce the support provided in worked examples, such as having students solve more parts of the example and providing fewer worked-out steps. Faded support is helpful in transitioning from studying worked examples to problem solving (Renkl & Atkinson, 2003), particularly if tasks and problems are complex and challenging.

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Resources

- For best practices for how to design effective worked examples see:
  - Renkl, A. (2014a). Learning from worked examples: How to prepare students for meaningful problem solving. In V. A. Benassi, C. E. Overson, & C. M. Hakala (Eds.), Applying science of learning in education: Infusing psychological science into the curriculum (pp. 118–130). Society for the Teaching of Psychology. HTTP (downloaded PDF freely available)
- For specific considerations when designing worked examples for ill-structured tasks see:
  - Renkl, A. (2023). Using Worked Examples for Ill-Structured Learning Content. In Overson, C. E., Hakala, C. M., Kordonowy, L.L., and Benassi, V. A. & (Eds.), In Their Own Words: What Scholars and Teachers Want You To Know About Why and How To Apply the Science of Learning in Your Academic Setting (pp. 207–224). Society for the Teaching of Psychology. HTTP (downloaded PDF freely available)

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