WORKED EXAMPLES

Educators can use worked examples to support novices to develop their programming practice

Worked examples demonstrate an 'expert' solution to a problem. They are used in many subjects to support novices, who use the examples as blueprints for solving new but related problems. They can be used in many areas of computing and are particularly useful for supporting programming practice. Learners who encounter worked examples in conjunction with practice problems are more likely to develop and assimilate strategies for solving similar problems.[1] Here, we'll discuss how worked examples can reduce cognitive load, the different types of worked examples, and how to design and integrate them into your lessons.

SUMMARY

Worked examples can:
- Help reduce extraneous cognitive load
- Aid learners in assimilating new knowledge into their existing understanding
- Be especially useful for novices during the early stages of learning

Good worked examples:
- Include sub-goal labelling to highlight structure and common programming 'patterns'
- Present relevant information in an integrated manner
- Combine multiple modes of delivery, such as visual and aural explanations
- May only be partial and require learners to complete them as part of exploration

In a learning sequence:
- Combine worked examples with similar practice problems
- Alternate worked examples and practice problems to keep the example in mind
- Use at least two examples for each concept or 'pattern' explored
- Fade the use of worked examples over time
- Focus on examples that emphasise program structure over surface details

Illustrating process:
- Educators should explicitly model their approach to solving a problem
- Process-oriented worked examples emphasise how a solution was reached
- Product-oriented worked examples provide a possible solution

Reducing cognitive load

Worked examples help reduce the extraneous cognitive load placed on a learner's working memory by providing a model solution for a problem, which the learner can read, understand, and adapt to solve similar problems.

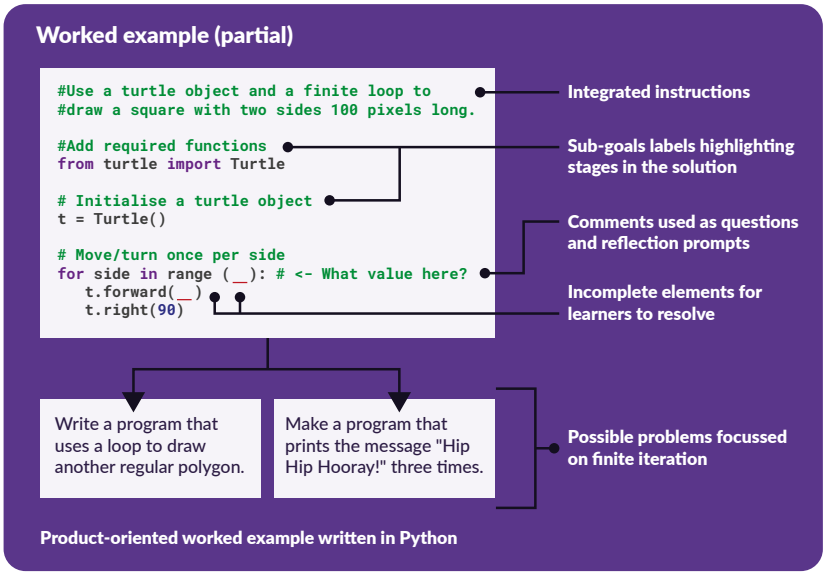
When a learner is given a partial or complete solution, they do not need to recall as much from their long-term memory.[2] If a concept is included in the solution, the learner can quickly retrieve and apply their existing understanding relating to that concept. Partially complete problems help focus learners on particular concepts, because learners only need to focus on the missing aspects.

In focusing learners' attention on structural elements of problems, worked examples support students to organise their new knowledge into 'schemas' (clusters of connected ideas) within long-term memory[3] (see page 20).

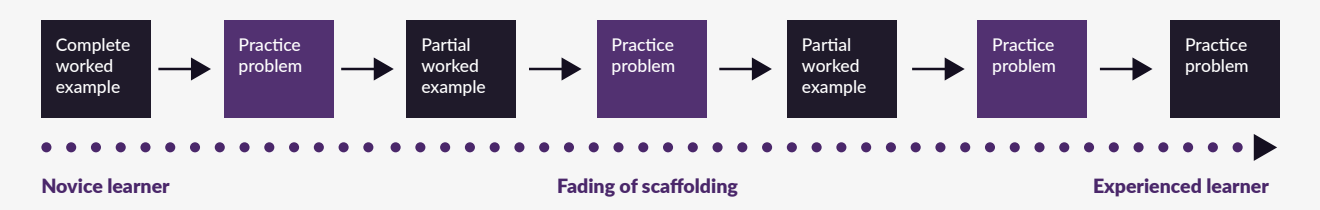
Product versus process

There are typically two types of worked examples found in literature. Both support the learner by modelling solutions to problems:

- **Process-oriented examples** model the steps taken to reach a particular solution. They may be written down (for example,



A product-oriented worked example written in Python



Educators should use worked examples while a concept is new, then fade this support over time

helloworld.cc/poewritten), demonstrated by an expert, or captured on video (for example, **helloworld.cc/poevideo**).

- **Product-oriented examples** model one possible solution and allow learners to examine and apply the solution to a new context.

There is evidence that complete novices benefit more from process-oriented worked examples, as they provide rationale for each aspect of the solution. Learners with some experience will then benefit more from product-oriented examples, from which they can infer the rationale.[4]

Designing worked examples

When designing worked examples, educators should consider the following effects that may affect learners' cognitive load and ability to follow an example.

The split attention effect occurs when information about a problem or example is presented separately. To follow the example or solve the problem, learners must first combine the separate sources of information in working memory. If possible, educators should integrate all of the information into one clear representation.

Similarly, the redundancy effect occurs when information is duplicated within a problem unnecessarily, or other redundant information is included. Learners may still process this information as they try to understand the problem, which results in an unnecessary cognitive burden.

Take advantage of the multimodal effect by presenting key information both visually and aurally, as the brain will process these separately. Studies have shown that presenting the same information — and more specifically, worked examples — in another mode, either simultaneously or sequentially, can support learners in their comprehension, and therefore, their ability to solve future problems.

It is broadly accepted that novices (in many fields) tend to focus on the context of a problem and the surface details, rather than the underlying structure and common elements to solutions. Educators can use sub-goal labelling to identify the important components or steps in a solution and highlight them to learners. To do this, educators could use explanatory comments or annotations, visual labels or highlights, or white space to group related instructions into 'chunks'.[1]

The learning sequence

Educators should also consider how to combine worked examples with practice problems and other worked examples.

It is important to consider variety: presenting the same concept or programming pattern across multiple examples and problems within varied contexts. This variety helps learners to focus on structural connections between the solutions and therefore focus on the general concept, rather than the surface details of the problem.

Research suggests that the more worked examples learners experience, the more they benefit, and that educators should expose learners to at least two worked examples for each concept or pattern. Some studies also suggest that learners should be presented with example and practice pairs[5], which require them to understand an example, then apply it in practice. Alternatively, learners could review one example problem, then complete several practice problems, which would require them to hold the example in their working memory for longer.

Worked examples are highly beneficial for novices, because they support them to build patterns for programs and procedures. However, as learners develop their expertise, they benefit more from solving new problems than from working from examples. Educators should use worked examples while a concept is new and gradually fade this support.[3] In doing so, they can support learners in developing a useful collection of common programming patterns which they can apply, adapt and build on. (HW)

REFERENCES

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