Worked Examples

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The learning outcomes of STEM courses frequently require students to perform mathematical computations or apply specific rules to solve problems. The rules may be physical laws, chemical reaction mechanisms, the syntax of programming languages, or financial accounting formulas.

Including worked examples in the lesson is important for showing students how to apply these seemingly abstract concepts to solve concrete problems. Worked examples, rather than exploratory-based instruction, are especially beneficial for novice learners (Kalyuga, 2021). However, the opposite seems to be the case for high-knowledge learners, who benefit more from open-ended questions than worked examples (Kalyuga, 2021).

Lesson Plan

A typical lesson plan begins with the statement and explanation of the relevant mathematical equations or rules. Then, an example question paired with the worked solution is presented to explain how to apply the equations or rules to solve the problem (Renkl, 2021).

There are variations to this lesson plan. When there are multiple question-solution pairs in a single lesson, the easier questions are presented before the more difficult questions. Questions of higher complexity may be subdivided into smaller, manageable steps (Renkl, 2021).

Additionally, consider including examples with alternative solution strategies to allow students to compare distinct techniques for problem solving (Renkl, 2021). The worked solution may also point out incorrect solutions to show students what *not* to do (Renkl, 2021).

Practice Questions Versus Worked Examples

Application-based learning outcomes mean that practice questions, also called exercise questions, are essential learning resources alongside worked examples. The difference between a worked example and a practice question is that a worked example is included as a part of the lesson, while a practice question is an activity that students have the option to complete. The importance of practice questions is highlighted in a study about linear algebra, where practice questions were superior for learning than explicit instruction (Brunstein et al., 2009).

Similar to worked examples, practice questions should have worked solutions rather than just listing the final answer so that students can check their work if they cannot arrive at the correct solution. Moreover, the practice questions, which are ungraded, should mirror the difficulty of the questions on graded assessments.

There is no exact number of practice questions that students need to complete in order to meet a learning outcome. However, a course should have enough practice questions so that students have sufficient opportunities to familiarize with the concepts and demonstrate their problem-solving ability on graded assessments.

Practice questions may be included after each question-solution pair in the lesson or as a set of practice questions that students complete after reading through the lesson. Either format appears effective for learning (van Harsel et al., 2019).

Resources

For a sample layout of online lessons with worked examples, consider Paul's Online Notes for undergraduate calculus courses. There are lessons with one example or multiple examples. A problem set with worked solutions appears on a separate webpage that is hyperlinked to each lesson.

- Lesson with one example (https://tutorial.math.lamar.edu/classes/calciii/CylindricalCoords.aspx) and problem set (https://tutorial.math.lamar.edu/Problems/CalcIII/CylindricalCoords.aspx).
- Lesson with multiple examples (https://tutorial.math.lamar.edu/classes/calciii/DirectionalDeriv.aspx) and problem set (https://tutorial.math.lamar.edu/Problems/CalcIII/CylindricalCoords.aspx)

Having to conceptualize questions as well as write the full solutions presents a considerable amount of work for the course developer. Fortunately, several resources are available. Examples and practice questions from OpenStax (https://openstax.org/subjects) online textbooks, CLP Calculus Textbooks (https://personal.math.ubc.ca/~CLP/index.html), and LibreTexts (https://commons.libretexts.org/?_gl=1*qy7gzr*_ga*MTA5NjI4NDE3MC4xNzA4NDA2NzYw*_ga_37C1BN2F1D*MTcxNzk3NzM4Ni4xLjAuMTcxNzk3NzM4Ni4wLjAuMA..) can be adapted for making new courses. The question bank on WeBWorK can be used to make problem sets for practice and for graded assessments.

Summary

- For application-based learning outcomes, especially in STEM, include worked examples in the lesson and provide practice questions with worked solutions.

References

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