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Improved Teaching of Science and Engineering Using Deliberate Practice of Problem-Solving Decisions

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Abstract

The ability to solve complex realistic problems is the most important requirement for being a good scientist or engineer. Here we present a theoretical design for improving the effectiveness and efficiency in teaching technical problem solving at the post-secondary level. The approach brings together theoretical ideas and empirical results from (a) evidence-based instructional practices, (b) development of expertise through deliberate practice, and (c) a decision-based framework for complex problem solving. This design involves explicit practice and feedback on making the set of decisions that define the problem-solving process of skilled scientists and engineers. We provide a template for instruction based on this design. This design also provides a way to assess problem-solving skills that is more accurate than traditional examinations.

Keywords: problem-solving decisions, STEM teaching, deliberate practice

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Introduction and Background

The most important skill that science and engineering ("S & E") students need to learn from post-secondary education is how to solve "real-world" problems. The value of skilled scientists and engineers in the modern world is their ability to solve novel complex problems with no obvious solution and involving many different factors, not all of which are known. Examples of such problems are developing and applying the science and technology needed to adapt to climate change; reducing the impact of prevalent and future diseases; or developing a cheap, flexible, low power mobile phone display. The problems ("school problems") that dominate S & E instruction, however, only teach students to solve familiar problems that can be solved by following standard procedures when all the necessary information is given. Despite the importance of mastering complex real-world problem solving, there are no proven methods for teaching and measuring such problem-solving skills, and there are many demonstrations that traditional instruction with traditional school problems is ineffective at teaching these skills. In this paper, we propose a theoretical approach to teach these essential problem-solving skills in S & E courses by combining advances from (a) evidence-based S & E instructional practices, (b) acquisition of expertise through deliberate practice, and (c) characterization of technical problem solving in terms of specific decisions.

Evidence-Based Instructional Practices

In recent decades there has been extensive research comparing the effectiveness of different forms of instruction in higher education. The most extensive and compelling results have come from "discipline-based education research," which studies the learning of specific topics in science and engineering (Singer et al., 2012). Particular instructional approaches, often called "active learning" have been shown to be highly effective, much more effective than traditional didactic lecture, for teaching concepts in introductory physics and other science subjects (for a review of this extensive field, see Singer et al., 2012). These forms of instruction vary in the details but generally involve students spending class time answering questions that require application of the basic concepts to be learned. The students discuss their answers and get feedback on them from both their peers and the instructor. This approach has shown enhanced performance of students on "concept tests" that probe the relevant conceptual mastery