ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #38406

Developing Deliberate Practice for Learning Engineering Dynamics by Analyzing Students' Mental Models

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Abstract

Practice plays a critical role in learning engineering dynamics. Typical practice in a dynamics course involves solving textbook problems. These problems can impose great cognitive load on underprepared students because they have not mastered constituent knowledge and skills required for solving whole problems. For these students, learning can be improved by being engaged in deliberate practice. Deliberate practice refers to a type of practice aimed at improving specific constituent knowledge or skills. Compared to solving whole problems requiring the simultaneous use of multiple constituent skills, deliberate practice is usually focused on one component skill at a time, which results in less cognitive load and more specificity. Contemporary theories of expertise development have highlighted the influence of deliberate practice (DP) on achieving exceptional performance in sports, music, and various professional fields. Concurrently, there is an emerging method for improving learning efficiency of novices by combining deliberate practice with cognitive load theory (CLT), a cognitive-architecture-based theory for instructional design.

Mechanics is a foundation for most branches of engineering. It serves to develop problem-solving skills and consolidate understanding of other subjects, such as applied mathematics and physics. Mechanics has been a challenging subject. Students need to understand governing principles to gain conceptual knowledge and acquire procedural knowledge to apply these principles to solve problems. Due to the difficulty in developing conceptual and procedural knowledge, mechanics courses are among those that receive high DFW rates (percentage of students receiving a grade of D or F or Withdrawing from a course), and students are more likely to leave engineering after taking mechanics courses. Deliberate practice can help novices develop good representations of the knowledge needed to produce superior problem solving performance. The goal of the present study is to develop deliberate practice techniques to improve learning effectiveness and to reduce cognitive load.

Our pilot study results revealed that the student mental effort scores were negatively correlated with their knowledge test scores with $r = -.29$ ($p < .05$) after using deliberate practice strategies. This supports the claim that deliberate practice can improve student learning while reducing cognitive load. In addition, the higher the students' knowledge test scores, the lower their mental effort was when taking the tests. In other words, the students who used deliberate practice strategies had better learning results with less cognitive load. To design deliberate practice, we often need to analyze students' persistent problems caused by faulty mental models, also referred to as an intuitive mental model, and misconceptions. In this study, we continue to conduct an in-depth diagnostic process to identify students' common mistakes and associated intuitive mental models. We then use the results to develop deliberate practice problems aimed at changing students' cognitive strategies and mental models.

Introduction

To teach problem solving in engineering mechanics, we use examples to demonstrate how to systematically solve problems. Students, however, often rely on guesswork or their memorization of similar problems to solve new problems. The systematic problem-solving strategies we use are built upon cognitive strategies and mental models we have developed over a number of years [1-4]. Students, on the other hand, have only a few disconnected conceptual and structural models of the subject, which fails to result in solving problems systematically [5]. More often, their problem-solving processes are driven by their misconceptions or intuitive mental models [5]. A typical example of intuitive mental models is that students often perceive different magnitudes of impact forces applied on two objects of different masses in impact. Since these intuitive mental models result in wrong mental representation and are hard to change, we need to develop strategies specifically for correcting those mental models in addition to presenting correct cognitive strategies and mental models [6-7].

In this paper, we share how we analyze students' intuitive mental models in learning the principle of work and energy and how we use the results to develop materials to enhance learning. We will first introduce the theoretical frameworks our study uses: Cognitive Load Theory (CLT) and Deliberate Practice (DP), followed by a brief description of the Four Component Instructional Design (4C/ID), the instructional design model we use to develop practice problems. Then we will show how we analyze the intuitive models and apply 4C/ID to help student develop correct mental models and improve learning. This paper serves as a brief introduction to our study. Examples and results will be included in the poster.

Theoretical Frameworks: Cognitive Load Theory and Deliberate Practice

Over the past three decades, CLT has generated a series of instructional principles based on human cognitive learning processes [8]. These principles aim to optimize learning by keeping the amount of learning induced information within the limits of working memory. If the learner's working memory is overloaded, learning will be hindered. Learning difficult subjects, due to the subjects' intrinsic complexity, imposes high cognitive load. CLT provides useful instructional guidelines for teaching subjects with high intrinsic cognitive load without exceeding limited working memory capacity. In [9], we have shown how we segmented and sequenced learning tasks to reduce the load while improving students' level of expertise which in turn increased the functional capacity of working memory through chunking.

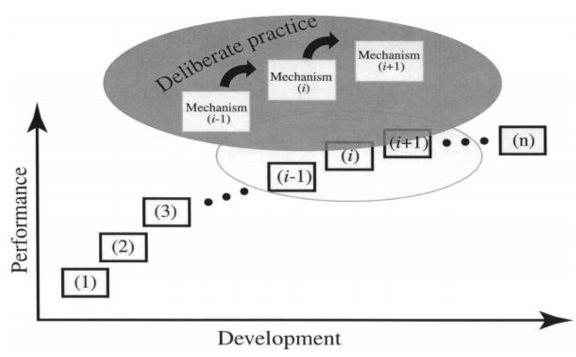

Figure 1 A Schematic Illustration of Deliberate Practice [10]

Deliberate practice (DP) emerged in several studies on the acquisition of expertise about the same time that CLT was introduced. DP is a particular type of practice with the deliberate intention of developing a specific skill that is beyond the learner's current ability. As shown in Figure 1, DP includes mechanisms for monitoring and guiding continuous improvement of specific aspects of performance [10]. Ericsson et al. [11] found that exceptional performance was caused by practice strategy rather than innate ability. However, most research has focused on the influence of DP on expertise development and much less is known about its influence on early learning with novices.

Studies have shown improved learning by applying CLT to DP strategies in medical education ([12-14]). The merit of this integration is apparent because deliberate practice developed based on CLT could fully exploits the limits and strengths of human learning processes to achieve continuous improvement. To continue our study in [9], we apply CLT to design deliberate practice which aims to correct students' intuitive mental models.

Instructional Design Model: 4C/ID

The Four Component/Instruction Design (4C/ID) model, to our best knowledge, is the only systematic instructional design model that has integrated CLT and DP [4, 15-17]. Based on a broad body of research on teaching and training of complex skills, this instructional design model has evolved over more than twenty-five years. The four components refer to four basic interrelated learning elements: learning tasks, supportive information for non-routine learning tasks, procedural information for routine learning tasks, and part-task practice for achieving automaticity of constituent skills to complete learning tasks [4].

4C/ID consists of ten design steps detailing the design guidelines for the four components. The first three steps aim at choosing appropriate learning tasks, developing performance assessments, and creating a proper sequence of learning tasks to maximize learning efficiency. Since learning tasks can be generally divided into non-routine and routine tasks, the next six steps are dedicated to design support and information to facilitate learning without overloading working memory. The last step is to help learners to achieve the required level of fluency to complete certain learning tasks.

Due to the intrinsic difficulty of engineering dynamics, we adopt 4C/ID to develop practice problems to facilitate learning. In this paper, we will show how to apply 4C/ID to design practice problems to address students' intuitive mental models in learning the principle of work and energy to demonstrate the effectiveness of this instructional design method.

Applying 4C/ID in Teaching the Principle of Work and Energy

The principle of work and energy is introduced in Physics I which is taken in the first or second semester by most engineering students. Later, in Statics, the prerequisite to engineering dynamics, students do not encounter any problems related to work or energy. Most students retain little knowledge about work and energy. It is very common that, at the beginning of the semester when students take dynamics, less than 10% students can represent work done by conservative forces and gravitational and elastic potential energy in the example shown in Figure 2. Most mistakes lie in the sign of the work done by the weight and representing the work done by the spring or the elastic potential energy. When interpreting the principle of work and energy, most students are not aware that the energy here refers to kinetic energy.

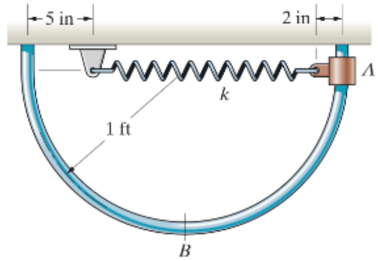

Figure 2 Example in Prior Knowledge Assessment

With this level of knowledge deficiency, students cannot learn effectively by solving whole problems which impose high cognitive load. We need to analyze students' intuitive mental models and then develop practice problems to help them build and consolidate the correct mental models.

To probe students' mental models, a series of simple-to-complex problems were developed to assess students' mastery of constituent skills (see Figure 3). Simple problems focus on one constituent skill (e.g., finding the work done by the weight or determine the kinetic energy of a rigid body). Problems with increasing complexity aim to evaluate students' capability of coordinating the constituent skills.

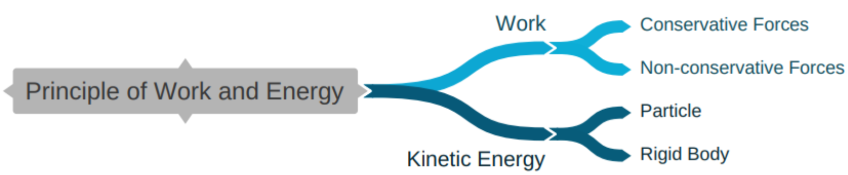

Figure 3 Constituent Skills Required for Applying the Principle of Work and Energy

After we identified students' intuitive mental models, we then applied 4C/ID to develop practice problems. To help students correct their intuitive mental models, we designed supportive information to be presented side by side with problems to provide guidance. For example, students often make mistakes in determining the work done by the weight of a rigid body. They typically forget to use the change in the height of the center of gravity to calculate the work. During the initial practice stage we developed, students are asked to identify the height of the center of gravity before determining the work done by the weight.

In addition to developing supportive information, we also developed part-task practice aimed at helping students acquire and consolidate required constituent skills. For example, students often have trouble determining the work done by a spring or elastic potential energy if the problem involves relatively complicated geometry. Practice problems with a variety of configurations could help them practice this skill. Part-task practice not only helps reduce the mental load on students' working memory, it could also improve learning efficiency. Given a half an hour of practice, students focus on one particular constituent skill instead of attempting to solve a whole problem. It is very likely students could achieve mastery because the specificity of such practice could focus students' attention on developing required cognitive strategies and mental models for this particular constituent skill. Depending on students' prior knowledge, part-task practice problems and a practice schedule can be developed to help students achieve automaticity of each constituent skill before they integrate all skills together to solve whole problems.

Conclusion

In this paper, we have briefly shown how we analyze students' mental models in learning the principle of work and energy and then how to apply 4C/ID to facilitate learning. More examples and assessment results will be presented in the poster.

Acknowledgement

This study is supported by the National Science Foundation under Grant Nos. 1927284 and 1927290.

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