122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #13588

Develop a Better Way to Practice to Enhance Students' Experience in Learning Dynamics

Dr. Yan Tang, American Society of Mechanical Engineers

Dr. Yan Tang is an assistant professor of mechanical engineering at Embry-Riddle Aeronautical University in Daytona Beach, Fla. Her current research in engineering education focuses on cognitive load theory, deliberate practice, and effective pedagogical practices. Her background is in dynamics and controls.

Dr. Haiyan Bai, University of Central Florida

Haiyan Bai, PhD., is an Associate Professor of Quantitative Research Methodology in the College of Education and Human Performance at the University of Central Florida. Her interests include resampling method, propensity score analysis, research design, measurement and evaluation, and the applications of statistical methods in educational research and behavioral sciences. She is actively involved educational and social science research projects. Dr. Bai has published books and many professional articles in refereed national and international journals. She has won several competitive awards at the University of Central Florida for her excellent teaching and research. Dr. Bai also served on several professional journal editorial boards, such as Journal of Experimental Education, Frontiers in Quantitative Psychology and Measurement, and Journal of Data Analysis and Information Processing. She is also the Fellow of the Academy for Teaching, Learning, and Leadership and the Faculty Fellow at The University of Central Florida.

Develop a Better Way to Practice to Enhance Students' Experience in Learning Dynamics

Abstract – In this paper we will share how we design appropriate practice activities in the undergraduate dynamics course to enhance students' learning experience and improve their problem solving skills.

Solving dynamics problems involves numerous knowledge and skills such as problem formulation, applying concepts of dynamics, and finding numerical solutions etc. Students often find it difficult in learning dynamics because learning these concepts and solving problems have produced exceedingly high cognitive loads for their limited working memory. If learning activities were not designed to integrate characteristics of working memory, long-term memory, or the intricate relations between them, students won't be able to achieve truly learning via effectively using their working memory and gradually accumulating knowledge and skills in long-term memory. Therefore, we need to modify learning materials and design practice activities to match students' cognitive level. This teaching philosophy has been well explained in Cognitive Load Theory (CLT). On the other hand, researchers in psychology have done extensive work and theoretical development regarding elite performers' characteristics. It has been discovered that deliberate practice (DP) plays an important role in shaping expert performance because it leads to refinement and maintenance of the mediating mechanisms such as mental representation, anticipation skills, and control of motor actions etc.

Based on CLT and principles of deliberate practice, we isolate elements of problem solving skills, develop repetitive and successive refined exercises to improve each of the elements, and schedule the sequence of activities to achieve smoother transitions to more complex learning tasks. We will share details of applying deliberate practice in teaching dynamics. Both attitudinal and objective assessment will be used to demonstrate the effectiveness of this teaching practice. The widely adopted Dynamic Concept Inventory (DCI) Version 1.0 will be used in our study as the objective assessment tool.

1. Introduction

Dynamics is one of the most difficult subjects for engineering students. It requires a solid foundation of mathematics, a good understanding of physical systems, and effective problem solving skills. However, some students are not well prepared with respect to these requirements. Therefore, developing effective instruction strategies to help these underprepared students learn has been a central topic within the community of mechanics instructors [1-7].

However, few studies have tried to tackle the learning challenge by addressing the fundamental reason: cognitive overload. Many training professionals have adopted the recommendation to design their instruction around the "magical number of 7 plus or minus 2" to avoid overloading their learners [8]. According to this guideline, our cognitive system can only process 7 ± 2 items at one time. Once we exceed those limits, our thinking and learning processes will be hindered. Solving dynamics problems involves accurate interpretation of what is given and what is to be found, capability of drawing free-body diagrams (FBD), familiarity of Newton-Euler equations and kinematics equations, and skills of solving a system of algebraic equations. Each single step may constitute of 7 ± 2 items depending on students' prior knowledge and how the contents are presented. No wonder why students often experience difficulty when learning dynamics. Based on the rule of 7 ± 2, a school of researchers have developed a comprehensive set of instructional principles called Cognitive Load Theory (CLT) [8]. CLT has seen great success in organizational training, but it seems unfamiliar to engineering educators and has little impact on instructional design. Since CLT is the scientific basis for efficiency in learning, introducing CLT to engineering education will definitely help enhance learning.

Similar to engineering educators' unfamiliarity with CLT, deliberate practice (DP) has not seen wide adoption in engineering education either. Aligned with CLT and redeemed as the cause for expert performance, deliberate practice (DP) is referred to a highly structured activity designed with the specific goal of improving performance [9]. This research has been popularized by the "10,000-hour rule" in the bestseller *Outlier* by Malcolm Gladwell [10]. Different from merely performing a skill a large number of times, DP focuses on breaking down the skill to small chunks and improving the skill chunks during practice paired with immediate coaching feedback. For example, instead of solving 10 different dynamics problems even of the same category, DP is to apply a series of exercises with each set of exercises focusing on one specific weakness such as drawing FBD or applying conservation of energy. Since these focused practices can fully utilize students' working memory without causing cognitive overload, students will be able to acquire specific skills within a short period of time and stay motivated to practice and master more complex skills.

Although DP is mainly investigated on its effectiveness of expertise acquisition, we have seen its successful application on beginners as well. In this paper we will share how we follow the guidelines from CLT to design DP activities in the undergraduate dynamics course to enhance students' learning experience and improve their problem solving skills. The paper is organized as follows. We will first explain CLT and DP in Section 2 Background to layout the foundations for our instructional design. The next section Implementation will present the DP examples we used in teaching particle kinematics, followed by Section 4 Discussions presenting assessment results. Finally, the summaries and conclusions are presented in Section 5.

2. Background

2.1 Cognitive Load Theory

Any instructional design without knowledge of human cognitive process will fail [11]. The structures that constitute the framework of human cognitive architecture can provide essential guidelines for educators to deliver learning materials. CLT is one such theory for instructional design that was explicitly derived from knowledge of human cognitive architecture [11]. CLT provides essential information and tools that are relevant to instruction along with instructional consequences compatible with the architecture. CLT illustrates ways to reduce unproductive form of cognitive load and simultaneously maximize productive sources of cognitive load that result in efficient learning.

Learning relies on two memory systems including working memory and long-term memory and the coordination between them. The relationship between working memory and long-term memory is similar to that of RAM and the hard drive in a computer. While in learning mode, working memory does the processing of new information to form knowledge structures called schemas which will be stored in long-term memory later on [8]. Schemas are memory structures that permit us to treat a large number of information elements as though they are a single element. The difference between experts and novices is that experts have effective schemas to engage greater information in working memory needed to solve complicated problems while novices have not developed schemas to hold more necessary information. The level of expertise derives from number and complexity of schemas stored in long-term memory. Before novices are able to develop effective schemas to process more information, appropriate instructional methods and practice strategies are essential to engage them to achieve gradual improvement.

The limits of working memory were first made explicit by George Miller's seminal paper published in 1956 [12]. The phrase 7 ± 2 refers to limited working memory capacity as well as the duration of information hold in working memory. The limitation implies that the information in working memory needs to be processed repetitively in order to be transferred to long-term memory which has massive capacity for information storage. Problem solving involves harmonic collaboration between working memory and long-term memory as all conscious processing only takes place in working memory which relies on schemas stored in long-term memory. More knowledge and skills stored in long-term memory will result in the greater virtual capacity of working memory.

Limited working memory are subject to three main types of cognitive load including intrinsic load, germane load, and extraneous load [13]. Intrinsic load is the mental work imposed by the complexity of the content. Germane cognitive load is mental work imposed by instructional activities that are beneficial for achieving instructional goals. In contrast to germane load which is relevant to learning goals, extraneous load is mental work imposed by inappropriate instruction strategies and consequently wastes limited working memory and hinders learning.

For a given subject, intrinsic load is determined by the subject complexity and the learner's prior knowledge which is beyond the instructor's control. What the instructor can control is to maximize germane load and minimize extraneous sources of load by segmenting and sequencing content in ways that optimize relevant information in working memory.

2.2 Deliberate Practice

Although breaking contents to chunks compatible with working memory capacity can avoid cognitive overload, the learning goals cannot be achieved without appropriate practices to process transient information in working memory and transfer it to long-term memory to be integrated with existing schemas or develop new schemas. Deliberate practice is one types of practices developed by the psychologist K. Anders Ericsson through his extensive research and theoretical development regarding elite performance [9, 14]. Ericsson concludes that expert performance is the result of deliberate practice rather than innate talent. For many fields, skill improvement may be illustrated by a sequence of states as seen in Figure 1. Deliberate practice can change any complex State i into the directly following complete State i+1. So we could apply principles and guidelines of DP to maximize the impact of times students spent in practice.

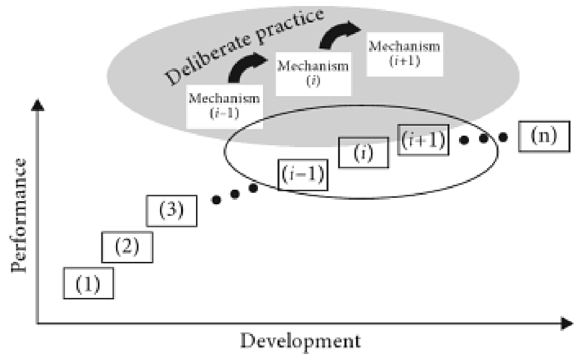


Figure 1 A schematic illustration of the expertise acquisition [15].

The rapid advancement of technology has imposed great challenges on engineering education [16, 17]. Educational researchers have started to relate key findings from studies of development of expertise to engineering education [18]. Deliberate practice has received attention from engineering scholars. The two key processes in deliberate practice include identifying which knowledge and/or skills to be proved and selecting a learning approach resulting in the desired improvements. The need for two types of practice, practice that develops component skills and practice that requires skills to be integrated to address more complex problems, has been discussed [19].

The research findings from CLT and DP have provided guidelines for us to design practices to enhance effective learning experiences.

3. Implementation

ES 204 Dynamics (three credit hours), the second mechanics course following ES 201 Statics, is required for students in aerospace, civil, and mechanical engineering at Embry-Riddle Aeronautical University (ERAU). Each semester, ES 204 is offered in five sessions with approximately 30 students in each session. The textbook we have adopted is titled Engineering Mechanics: Dynamics by Anthony Bedford and Wallace Fowler (5^{th} ed.). Each session meets either three times with one hour for each meeting or twice with one and a quarter hours for each meeting every week. We have started to develop and apply DP activities in one session every semester since the fall 2013 semester.

The assessment of student readiness by using the Mechanics Readiness Test [20] and the Dynamics Concept Inventory 1.0 [21] indicated that students lack math foundations and key concepts that are required for learning dynamics. This situation motivated us to adopt effective instructional design strategies which address such deficiencies. Because of their foundation deeply rooted in human cognitive architecture, CLT and DP have been adopted and investigated through our teaching practices. By following guidelines of CLT, we have developed DP practices intended to improve the systematic problem solving skill and achieve learning goals for dynamics.

Research has indicated that a structured problem solving approach will help students develop a universal problem solving procedure which can be applied in any engineering course or research and development [2] . We have adopted the five-step problem solving procedure, consisting of Given/Find, Strategy, Governing Equations, Numerical Solutions, and Reflection, commonly used in advanced mechanics courses and upper-division engineering courses at ERAU. In Given/Find, students are required to use appropriate variables and notations to represent what is given and what is to be found. By relating given information to relevant principles, tentative strategies along with the associated rationale are presented in Strategy, followed by governing equations. When a system of independent equations for the equal number of unknowns is obtained, Matlab is used to find numerical solutions. Finally, the problem solving is concluded by students' reflection on the problem by verifying the correctness of the solution and discussing the solution's physical meaning.

However, our background survey results showed that few students had used this approach prior to taking Dynamics. It will produce extraneous (irrelevant) cognitive load for students who are not familiar with the approach if they are forced to adopt this approach without any training. By following the guidelines of CLT, we have developed DP activities to focus developing knowledge and skills for each step. When the majority has mastered the knowledge and skills for each step, we then require students to implement the complete procedure.

Since Steps One (Given/Find) and Four (Numerical Solution) are common for all learning modules and do not require content related knowledge, we designed DP activities to help students develop good habits and skills required for formulating Given/Find and familiarize them with using the Symbolic Toolbox in Matlab. During the first two weeks, students were assigned with homework only requiring them to show Given/Find and represent Givens in Matlab. For each problem, students need to conduct self-assessment in Reflection to evaluate whether they meet the criteria for Given/Find: be accurate (use exact values and units), be thorough (include all given information), and be appropriate (use suitable variable names and subscripts to facilitate representation in Matlab). The learning goal of the Matlab part is to develop good habits in naming conventions and code readability.

Since students are only required to work on Steps One and Four by filling in blanks in the assignment sheet, the simplicity and intensity of exercises can result in good learning outcomes. Here is an example of such assignment.

13.1 In Example 13.2, suppose that the vehicle is dropped from a height $h = 6$ m

(a) What is its downward velocity 1 s after it is released?

(b) What is its downward velocity just before it reaches the ground?

Draw the coordinate system on the figure.

Given:

Find:

Use the provided script template to represent Given in Matlab.

Figure 2 A Deliberate Practice Example.

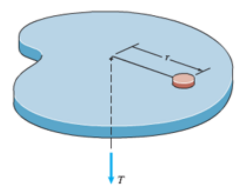
Steps Two (Strategy) and Three (Governing Equations) are related to learning modules. The DP activities were designed by identifying key component knowledge and skills essential for understanding each topic (particle kinematics, particle kinetics, rigid-body kinematics, and rigid-body kinetics). Refer to [22] for more details on the contents and skills for each unit.

When students started a new unit, they were provided with assistance, often referred to as "scaffolding" [18], to learn how to develop appropriate strategies and set up governing equations. For example, when students have learned energy methods for particles, they have trouble in determining whether to use the principle of work and energy or conservation of energy. Instead of asking students to solve several problems, we provided focused practices with a single goal: determine whether to use the principle of work and energy or conservation of energy. Here is an example.

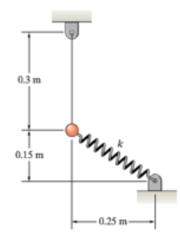
Do NOT solve these problems.

2. At the instant shown, the 160-lb vaulter's center of mass is 8.5 ft above the ground, and the vertical component of his velocity is 4 ft/s. As his pole straightens, it exerts a vertical force on the vaulter of magnitude $180 + 2.8y^2$ where y is the vertical position of his center of mass *relative to its position at the instant shown*. This force is exerted on him from to when he releases the pole. What is the maximum height above the ground reached by the vaulter's center of mass?
Draw the FBD, determine which method to use, and explain why.

3. A1-kg disk slides on a smooth horizontal table and is attached to a string that passes through a hole in the table. A constant force $T = 10$ N is exerted on the string. At the instant shown, $r = 1$ m and the velocity of the disk in terms of polar coordinates is $\vec{v} = 8\vec{e}_\theta$ (m/s). Because this is central-force motion, the product of the radial position r and the transverse component of velocity v_θ is constant. Determine the velocity of the disk in terms of polar coordinates when $r = 2$ m.
Draw the FBD, determine which method to use, and explain why.



4. The mass $m = 1$ kg, the spring constant $k = 200$ N/m, and the unstretched length of the spring is 0.1 m. When the system is released from rest in the position shown, the spring contracts, pulling the mass to the right. Use conservation of energy to determine the magnitude of the velocity of the mass when the string and the spring are parallel.
Draw the FBD, determine which method to use, and explain why.



5. A group of engineering students constructs a sun-powered car and tests it on a circular track with a 1000-ft radius. The car, with a weight of 460 lb including its occupant, starts from rest. The total tangential component of force on the car is $\Sigma F_t = 30 - 0.2s$ lb, where s is the distance (in ft) the car travels along the track from the position where it starts. Determine the magnitude of the *total* horizontal force exerted on the car's tires by the road when it is at the position $s = 120$ ft.

Draw the FBD, determine which method to use, and explain why.

Figure 3 An example of deliberate practice.

Through this exercise, students could focus on selecting the right method without being overloaded by other information such as setting up equations and/or solving equations. When their understanding of the similarities and differences between the principle of work and energy and conservation of energy has been improved, we could move on to the next important skill. Similar assignments were given for each learning module to address specific learning difficulty. For example, when learning the principle of work and energy for rigid bodies, students had trouble representing kinetic energy of rigid bodies. Instead of solving couple of problems completely, students just needed to find kinetic energy of each rigid body at different instants in five to ten different problems, which could take the same time required for solving two complete problems. This strategy also helps maximize germane (relevant) load by exposing students to different contexts to improve their problem solving skills.

In summary, the key to applying DP is to design practices with focused goals and opportunities for repetition to help learners transfer transient information in working memory to form schemas in long-term memory without causing cognitive overload. When students develop knowledge and skills required for each step of the problem solving procedure through DP activities, they will acquire better schemas to hold more information together to solve problems effectively.

4. Discussion

An intact clustered sample of 26 students taking the course participated in this study. The widely adopted Dynamic Concept Inventory (DCI) Version 1.0 [21] with a multiple-choice exam with 29 questions was used to collect student learning outcome data. DCI covers 11 concept areas in rigid body dynamics and several more in particle dynamics.

Paired sample t-test is used to answer our research questions using pre and posttest data comparing group differences of changes after the intervention period. The current data analysis discovered that there was a statistically significant differences between student pre and posttest ($t_{(24)} = 5.08$, $p < .001$) with posttest mean score of 14.44 ($SD = 4.98$) which is 4 points higher than their pretest mean score of 10.44 ($SD = 4.09$, $N = 25$). Considering the small sample issues of large sampling errors, we used the bootstrap procedure for the paired sample t-test, with the bootstrap result as shown in Table 1. From Table 1 we can see that the bootstrap paired sample t-test was still significant with posttest scores significantly higher than the pretest scores ($p = .001 < .05$).

The current results has limitations because we used a small sample which may not be representative to the large population; therefore we need to be cautious to generalize the study results. In addition, in the current stage of the study, we did not control for the covariance which may contribute to the differences between the posttest and pretest scores. We propose to conduct further analysis with more data available in the later data collections.

Table 1. *Bootstrap for Paired Samples Test*

			Bootstrap[a]				
						95% Confidence Interval	
		Mean	Bias	SE	*p* (2-tailed)	Lower	Upper
Pair 1	posttest - pretest	4.000	-.032	.756	.001	2.560	5.480

a. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

5. Conclusion

In this paper, we have shared our practice of applying CLT and DP in designing practice activities to enhance learning. Because of the intensity the DP activities could produce, it could be possible to optimize the usage of students' working memory by maximizing germane load and minimizing extraneous load. As a result, students' learning performance could be improved within a relatively short period of time.

References

[1] Gray, G.L., and Costanzo, F., "A problem-centered approach to dynamics," *American Society for Engineering Education Annual Conference and Exposition*, 2008.

[2] Costanzo, F., and Gray, G.L., "A structured approach to problem solving in statics and dynamics: Assessment and evolution," *American Society for Engineering Education Annual Conference and Exposition*, 2008.

[3] Mikesell, D.R., and Yoder, J.S., "Teaching Dynamics with a Design Project," *American Society for Engineering Education Annual Conference and Exposition*, 2011.

[4] Coller, B., "First look at a video game for teaching dynamics," *American Society for Engineering Education Annual Conference and Exposition*, 2011.

[5] Nissenson, P.M., Seong, J., Chen, C., "Developing web- Assisted learning modules in vector dynamics," *American Society for Engineering Education Annual Conference and Exposition*, 2014.

[6] West, M., and Herman, G.L., "Sustainable reform of introductory dynamics driven by a community of practice," *American Society for Engineering Education Annual Conference and Exposition*, 2014.

[7] Lovell, M.D., and Brophy, S.P., "Transfer effects of challenge-based lessons in an undergraduate dynamics Course," *American Society for Engineering Education Annual Conference and Exposition*, 2014.

[8] Clark, R.C., Nguyen, F., and Sweller, J., "Efficiency in learning: Evidence-based guidelines to manage cognitive load," 2006,

[9] Ericsson, K.A., Krampe, R.T., and Tesch-Römer, C., "The role of deliberate practice in the acquisition of expert performance." *Psychological Review*, Vol. 100, No. 3, 1993, pp. 363.

[10] Gladwell, M., "Outliers: The story of success," Hachette UK, 2008,

[11] John Sweller, Paul Ayres, and Slava Kalyuga, "Cognitive Load Theory," Springer, 2011,

[12] Miller, G.A., "The magical number seven, plus or minus two: some limits on our capacity for processing information." *Psychological Review*, Vol. 63, No. 2, 1956, pp. 81.

[13] Sweller, J., "Cognitive load theory, learning difficulty, and instructional design," *Learning and Instruction*, Vol. 4, No. 4, 1994, pp. 295-312.

[14] Schneider, W., and Shiffrin, R.M., "Controlled and automatic human information processing: I. Detection, search, and attention." *Psychological Review*, Vol. 84, No. 1, 1977, pp. 1.

[15] Starkes, Janet L., and Karl Anders Ericsson. *Expert performance in sports: Advances in research on sport expertise*. Human Kinetics Publishers, 2003.

[16] Jamieson, L.H., and Lohmann, J.R., "Creating a Culture for Scholarly and Systematic Innovation in Engineering Education: Ensuring US engineering has the right people with the right talent for a global society," *American Society of Engineering Educators (ASEE),* 2009

[17] Sheppard, S.D., Macatangay, K., Colby, A., "Educating engineers: Designing for the future of the field," Vol. 2, Jossey-Bass, 2008,

[18] Litzinger, T.A., Lattuca, L.R., Hadgraft, R.G., "Engineering Education and the Development of Expertise," *Journal of Engineering Education,* Vol. 100, No. 1, 2011, pp. 123-150.

[19] Ambrose, S.A., Bridges, M.W., DiPietro, M., "How Learning Works: Seven Research-Based Principles for Smart Teaching: Seven Research-Based Principles for Smart Teaching," John Wiley & Sons, 2010.

[20] Snyder, V., "Mechanics readiness test: Revisited," *Proceedings, ASEE Annual Conference and Exposition,* 1988.

[21] Gray, G.L., Costanzo, F., Evans, D., "The dynamics concept inventory assessment test: A progress report and some results," *American Society for Engineering Education Annual Conference & Exposition,* 2005.

[22] Yan Tang and Doug Holton, "Apply Deliberate Practice in Teaching Dynamics to Reinforce a Systematic Problem Solving Approach," *American Society for Engineering Education – Southeastern Section Conference,* 2015.