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Scaffolding through Question Prompts to Avoid Pernicious Einstellung (Set) Effect

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Abstract – The Einstellung Effect occurs when the first solution that comes to mind, often triggered by improper initial intuition, prevents a correct solution from being found. The Einstellung effect has been a frequent stumbling block for students when learning dynamics due to their conceptual misunderstanding. Although the phenomenon has been studied in cognitive psychology, it has not been seen in the engineering education literature. This paper will investigate how scaffolding through proper question prompts could avoid this phenomenon. Examples and assessment results will be provided to demonstrate the effectiveness.

By sharing our practice on the Einstellung effect prevention, we intend to inform engineering educators of the fruitful results from cognitive sciences. We can further evaluate the theories in engineering education setting as many of them were developed for other disciplines in a laboratory setting. Those results could serve as stepping stones for us to tackle challenges in engineering education.

Background

Einstellung means "set" in German and the Einstellung effect is referred to the brain's tendency to adopt the most familiar solution (set) to a problem and ignore alternatives. Such mechanization in problem solving was first investigated through the well-known water jar experiment conducted in 1940 [1] . Several problems solvable by a complex procedure (a set) were presented to participants. Then an easy problem which can be solved by a relatively simple approach was given. Because of the set effect, some participates inclined to use the same complex procedure to solve the problem while those who were not exposed to the complex procedure could solve the problem with a better strategy. Consequent studies have shown that the Einstellung effect was relevant to methods of teaching because it occurred more often in the participants from a school using "drill methods" than in a school making more use of "progressive methods" [2] .

The Einstellung effect occurs very often among engineering students when they encounter a new problem which seems solvable by the procedure they have used for drill problems. Since methods of teaching have influence on this phenomenon, we could adopt appropriate instruction strategies to alleviate the Einstellung effect and improve students' flexibility in problem solving.

Compared to "drill" methods which are used quite often in engineering education, progressive methods are learner centered and promote learning by discovery techniques rather than following rigid procedures. Inquiry-based instruction is one of progressive methods. Instead of presenting students with a predefined problem solving process, instructors pose a series of questions to guide students to develop their problem solving strategies and discover the essential principles in solving problems. Through such exploration, students will be able to improve their critical thinking and decision making as they focus on problems rather than procedures.

Most common strategy in teaching Dynamics is to let students drill problems. Students will gain familiarity with different problem types and corresponding strategies through practices. But such familiarity may easily result in mechanization in problems solving or the Einstellung effect. When students encounter a new problem, they may incline to solve the problem with the strategies they have used through drills. On the other hand, if students simply work on drill problems without paying attention to essential differences between problem types, they may develop some faulty assumptions about how to solve problems. Such misconceptions will hinder students' learning.

Mechanics instructors may have observed this phenomenon quite often as students carry many misconceptions and bad habits of problem solving when learning mechanics. We have to take quite a bit efforts on clearing these misconceptions and correcting the problem solving strategies. Such Einstellung effect is even more pernicious as it will result in a wrong solution. If we continue to use drill methods to teach, students might not be able to learn as they may continue to apply their misconceptions and irrational problem solving approaches when they drill. Then the Einstellung effect will be strengthened. Therefore, we need to adopt different strategies to alleviate it.

As the study in [2] has discovered that progressive methods will be more appropriate in alleviating the Einstellung effect, we have started to investigate the effectiveness of inquiry-based method on mitigating the Einstellung effect. Since we have noticed that students incline to solve dynamics problems by plugging and chugging without rational questioning the choice of equations, we provide scaffolding through question prompts to direct their attention to rationalize problem solving strategies rather than adopt a rigid procedure and land on equations without logical reasoning.

In this paper, we will share our practice of using scaffolding in Dynamics to avoid the Einstellung effect and improve students' learning. The paper is organized as follows. We first use three examples to illustrate how we design the question prompts for scaffolding and how they could alleviate the Einstellung effect in learning straight-line motions, free-body diagrams, and rigid-body kinematics. Then we will discuss the results by comparing students' learning outcomes, followed by thoughts on the design principles of the question prompts for scaffolding.

Design and 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. 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 fifty minutes for each meeting or twice with seventy five minutes for each meeting every week.

The assessment of student readiness by using the Mechanics Readiness Test [3] and the Dynamics Concept Inventory 1.0 [4] have indicated that students lack math foundations and key concepts that are required for learning dynamics. Many students relied on their guesswork rather than a systematic problem solving process to solve physics or statics problems. This situation motivated us to adopt effective instructional design strategies which address such deficiencies.

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 [5]. Scaffolding could provide instructions and support to guide students through this structured problem solving strategy and help them change some bad habits when developing solutions. Without such guidance, the Einstellung effect may easily lead to the common pitfalls. We use question prompts to provide scaffolding as these questions will help students develop deep understanding of the governing principles rather than memorize the problem solving procedure. By answering these questions, students will be able to justify their problem solving strategies and gain confidence in solving new problems.

We will use three sets of questions prompts for teaching different topics as examples to illustrate how prompt questions could help alleviate the Einstellung effect.

Straight-line Motion

Straight-line motion is the first topic covered in Dynamics. This topic is not new to students as they have learned some knowledge and problem solving skills in Physics I. Most problems they have learned in Physics, however, are based on the assumption that acceleration is a constant. Therefore, students get used to using kinematics equations (e.g., $v = v_0 + at$ or $s = s_0 + v_0 t + 1/2\, at^2$) to analyze straight-line motions without paying attention to different variations of acceleration (e.g., $a = f(s)$ or $a = f(v)$). Such Einstellung effect obviously will prevent students from solving problems properly.

Because of the relationships between the kinematics properties (i.e., $v = ds/dt$ and $a = dv/dt$), only one of the kinematics properties (i.e., s, v, or a) is needed as a function and the rest of kinematics properties can be obtained through derivatives or integrals with separation of variables or the chain rule. For example, if velocity is given as a function of time (i.e., $v = f(t)$), then the position at instant t_1 can be obtained by using separation of variables as in $\int_{t_0}^{t_1} v dt = \int_{s_0}^{s_1} ds$ where t_0, t_1, and s_0 are given. However, if velocity is given as a function of position (i.e., $v = f(s)$), the position s_1 should be found by grouping $v(s)$ with ds as in $\int_{t_0}^{t_1} dt = \int_{s_0}^{s_1} \frac{1}{v(s)} ds$.

When students learn Dynamics, they usually don't begin the problem solving process by categorizing problems first so they might not notice the difference in the arguments of the velocity. Then they may simply try to use the equation for the first case to solve for the latter case as they get used to selecting an equation without knowing whether the equation is appropriate.

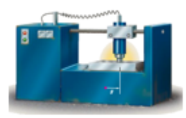
Proper problem prompts could alleviate such Einstellung effect by directing students' attention to identify the given conditions and categorize problems instead of simply plugging and chugging. The following questions are used to guide students through solving straight-line motion problems:

- Which kinematics property is given as a function?
- What is the argument of the function?
- Which tool should be used to solve the problem?
- What kinematics information is provided for which specific instants?

For most straight-line problems, the first question is very easy to answer as the function is usually given explicitly. The only exception occurs when acceleration is a constant (e.g., free fall). The second and third questions will direct students' attention to the argument of the function and apply the fundamental tools (i.e., derivatives and integrals) on the function properly. The last question will help them identify unknowns when set up equations.

Here is an example of an assignment with the prompts for solving a straight-line motion problem. In the example, the process is referred to the given kinematics function and the instants are referred to instants at which kinematics properties are given. By answering the first question, students will know for sure that integrals will be used to solve the problem as the acceleration is given. The second question will prevent students from applying separation of variables as in $\int_{t_0}^{t_1} adt = \int_{v_0}^{v_1} dv$ because a is a function of v instead of t. They will more easily think of applying separation of variables in the other way given by $\int_{t_0}^{t_1} dt = \int_{v_0}^{v_1} \frac{1}{a} dv$. The fourth question will help them identify whether they have set up enough equations for unknowns.

13.41 An engineer designing a system to control a router for a machining process models the system so that the router's acceleration (in in/s^2) during an interval of time is given by $a = -0.4v$, where v is the velocity of the router in in/s. When $t = 0$, the position is $s = 0$ and the velocity is $v = 2$ in/s. What is the position at t = 3 s?



Choose a coordinate system and represent it in the figure.

Given:

Find:

Strategy:

i. Briefly describe the motion.

ii.

a. The process:

b. Instants:

c. Tool (if you need to use integration, indicate whether you need to use the chain rule or separation of variables):

iii. Set up the equation. Show what unknowns are and whether you have enough equations for the unknowns.

Figure 1 Assignment Example of Straight-line Motion

Free-body Diagram

Although students have learned how to draw free-body diagrams in both Physics and Statics, many students still rely on guesswork, which greatly hinders their learning. Such deficiency is usually caused by their lack of understanding of the meaning of "free" in free-body diagrams. Many students do not relate the free-body diagram to forces exerted by the surroundings of the body of interest. Instead of analyzing how each surrounding exerts forces, they often guess forces when draw a free-body diagram. The Einstellung effect induced by their habits will prevent them from creating a correct free-body diagram which is critical in solving dynamics problems. When guided by proper questions, students will be able to recognize the interaction between the body and the surroundings and then identify forces easily.

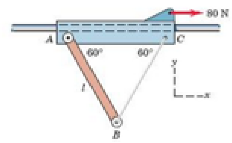
The following question prompts are designed to help students develop a clear thought process when drawing free-body diagrams:

- What is the body of interest?
- Which surroundings is the body in contact with?
- Does each surrounding exert a force normal and/or parallel to the surface of contact?

Instead of guessing forces, students will use these questions to discover external forces and develop better understanding of the cause-and-effect relationship between forces and motions.

Here is an example of an assignment on drawing free-body diagrams.

A frame AC and a uniform slender bar AB slide along a smooth horizontal rod under the action of the force as shown. BC is a wire and the x-y plane is vertical. Draw the free-body diagram of the frame AC and the bar, respectively.



- Circle all surroundings of the bar,
- draw forces exerted at each surrounding, and
- then add the weight to complete the FBD of the bar.

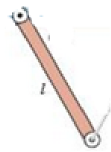


Figure 2 Assignment Example of Drawing Free-body Diagrams.

Rigid-body kinematics

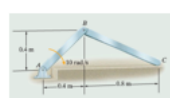
Although rigid-body kinematics can be solved by propagating relative circular motions (i.e., $\vec{v}_{A/B} = \vec{\omega} \times \vec{r}_{A/B}$ and $\vec{a}_{A/B} = \vec{a}_{A/Bn} + \vec{a}_{A/Bt} = \vec{\omega} \times (\vec{\omega} \times \vec{r}_{A/B}) + \vec{\alpha} \times \vec{r}_{A/B}$)), students sometimes do not know where to begin the problem solving process because of the complexity of a given kinematics chain. We could also use question prompts to get students started. The following question prompts are used to help students solve planar rigid body kinematics problems without sliding contacts:

- How many links in the rigid body?
- Which two points on each link will be chosen to apply the velocity and/or the acceleration equations (i.e., $\vec{v}_A = \vec{v}_B + \vec{v}_{A/B}$ and $\vec{a}_A = \vec{a}_B + \vec{a}_{A/B}$)?
- Have you set up enough equations for unknowns?

These questions not only easily get students started, but also direct their attention to the essential principles of rigid body kinematics in motion propagation.

Here is an example of an assignment on rigid body kinematics.

17.33 Consider the instant when bar AB is vertical and rotating in the clockwise direction at 10 rad/s. Draw a sketch showing the positions of the two bars at that instant. Determine the angular velocity of bar BC and the velocity of point C.



Sketch the links with the stated orientation.

Describe the motion for each link:

How many links?

Which two points would you choose for each link?

Given:
(Represent the relative position vector for each link)

(Represent the rest of Givens)

Find:

Strategy:
- Apply the velocity equation to each link to set up equations. You need to show you have set up enough equations for unknowns.

Figure 3 Assignment Example of Rigid Body Kinematics

We have shown three examples of question prompts used in teaching different topics in Dynamics. These question prompts are designed to be in the zone of proximal development, a transition zone between what a learner can do without help and what she can do with help [6] . Since most concepts in Dynamics are not new to students, the learning challenges are usually caused by the Einstellung effect, or students' inherent misconceptions or bad habits of problem solving. Using question prompts will prevent students from landing a solution without justification.

Results and Discussions

The data used for comparison were gathered from the classes taught by the author in the Fall 2013 and Fall 2015, respectively. The two classes received the same average grade (31%) in the Dynamics Concept Inventory as the pre-assessment and both classes were taught by the same instruction methods. The only significant difference was that the class in Fall 2013 was given traditional assignments without scaffolding while the other class was provided with scaffolding through question prompts as shown in Figs. 1-3. Table 1 compares the correctness rate of problems with the similar difficult level on the final exams between the two classes. For each topic, one problem worth the same points was chosen and students' grades for each problem were collected for comparison. We can see clear improvements in scores of all problems.

Table 1 Comparison of correctness rate between two classes.

Semester	Straight-line Motion	Free-body Diagram	Rigid-body Kinematics
Fall 2013	58%	65%	70%
Fall 2015	83%	78%	92%

Rigorously speaking, the result cannot lead to the conclusion that scaffolding through question prompts could alleviate the Einstellung effect as the data were not collected from the strictly controlled learning environment. Other factors (e.g., the student background, the assignment workload etc.) were not included to analyze the correlation. Further research should be conducted to develop a rigorous experiment to compare learning performances between the treatment group and control group. Because of the success rate during the implementation, we would like to inform engineering educators of the fruitful results from cognitive sciences, share our practice through this paper to initiate discussions and seek collaboration to collect data for further investigation. We can further evaluate the theories of cognitive sciences in engineering education setting as many of them were developed for other disciplines in a laboratory setting. Those results could serve as stepping stones for us to tackle challenges in engineering education.

Conclusions

In this paper, we have shared our practice of applying question prompts to avoid the Einstellung effect and help students develop effective problem solving strategies. Our initial results have shown that these prompts could direct students' attention to governing principles instead of guessing equations. Future research should collect more data to explore how scaffolding through question prompts affects students' learning. Future work should also investigate the design of question prompts and the effect on learners with different background. As the ultimate goal of scaffolding is to achieve independent learning, research should be conducted to find out when scaffolding can be removed.

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