

Physics Learning In The Context Of Scaffolded Diagnostic Tasks (I): The Experimental Setup

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Abstract. For problem solving to serve as an effective learning opportunity, it should involve deliberate reflection, e.g., planning and evaluating the solver's progress toward a solution, as well as self-diagnosing former steps while elaborating on conceptual understanding. While expert problem solvers employ deliberate reflection, the novices (many introductory physics students) fail to take full advantage of problem solving as a learning opportunity. In this paper we will focus on self-diagnosis as an instructional strategy to engage students in reflective problem solving. In self-diagnosis tasks students are explicitly required to carry out self diagnosis activities after being given some feedback on the solution. In this and a companion paper, we will present research exploring the following questions: How well do students self-diagnose, if at all, their solutions? What are the learning outcomes of these activities? Can one improve the act of self-diagnosis and the resulting learning outcomes by scaffolding the activity?

Keywords: problem solving, reflection, alternative assessment, self-diagnosis.

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INTRODUCTION

One feature that characterizes experts problem solvers is continuous evaluation of their progress [1]. They monitor their progress towards a solution asking themselves implicit reflective questions such as: "What am I doing?", "Why am I doing it?", and "How does this help me?" [2]. Experts are recognized also by a strategic approach: first carrying out a qualitative analysis of the situation and then developing a plan to solve the problem on the basis of this analysis [3]. While self monitoring is directed mainly towards arriving at a solution, it might also involve self-diagnosis directed towards elaboration of the solver's conceptual understanding, knowledge organization and strategic approach.

In the context of problem solving it is beneficial to foster diagnostic self explanations. It has been shown that the activity of self-explanation leads to significant learning gains [4] and can be enhanced through interventions that require students to present their explanations [5], and encourage students to give justifications via peer interaction or human computer interaction.

In physics education, one common instructional strategy to enhance an expert-like problem solving approach that allows learning from problem solving is

that of cognitive apprenticeship [6]. This approach incorporates three elements:

(1) modeling, (2) coaching, and (3) scaffolding and fading. In this approach, "modeling" means providing examples to demonstrate and exemplify the skills that students should learn. "Coaching" means providing students opportunity, and practice, with guidance and feedback so that they learn the necessary skills. "Scaffolding and fading" refers to decreasing the support and feedback consistent with students' needs to help them develop gradual self-reliance.

In the context of problem solving, this approach is often used with motivating realistic problems that need an expert-like approach mimicking the culture of expert practice. Students often work collaboratively [7] or with a computer [8] where they must externalize and explain their thinking while they solve a problem. In many of these interventions, students receive modeling of a problem-solving strategy [9,10] that externalizes the implicit problem solving strategies used by experts, and they are required to use it. Common steps amongst different strategies include asking students to: (1) Describe the problem, (2) Plan and construct a solution, (3) Check and evaluate their solution. These strategies have been shown to improve students' problem solving skills (planning and evaluating rather than searching for the appropriate

equation without reflection) as well as their understanding of physics concepts [11].

One challenge these approaches often face is that the assessment is traditional, focused on product rather than the process, thus undermining the intended outcomes. The negative impacts of traditional assessment include over-emphasis on grades, and under-emphasis on feedback to promote learning. Thus, traditional assessment approaches are lacking in formative assessment. Black and Wiliam [12] suggest that for formative assessment to be productive, students should be trained in self assessment so that they can understand the main purposes of their learning and thereby grasp what they need to do to succeed. Thus, tests and homework can be invaluable guides to learning, but they must be clear and relevant to learning goals. The feedback should give guidance on how to improve, and students must be given opportunity and help to work on the improvement.

Following these guidelines we constructed a self-assessment task in which students are required to present a diagnosis (namely, identifying where they went wrong, and explaining the nature of the mistakes) as part of the activity of reviewing their quiz solutions. We shall call these tasks “self-diagnosis tasks”. Indeed, an integral activity in physics problem solving should be reviewing the solution that the learner has composed in order to improve it or learn from it. For instance, this activity can occur after comparing a final result of a problem solution to the back of the book answer, as well as when students get their graded work back. The notion that comparing solutions composed by the learners to a worked out example is conducive to learning is actually common amongst physics instructors.

In traditional situations in which students review their solutions, self-diagnosis is not guaranteed to occur. Students may or may not self-diagnose the solution, or it might occur only implicitly. In contrast, in self-diagnosis tasks, students are required explicitly to diagnose their solutions.

SELF-DIAGNOSIS TASKS

Self-diagnosis tasks can be distinguished by:

1. Instructions on how to carry out the diagnosis, e.g. level of detail laying out for students the possible deficiencies in their approach towards the solution and in its implementation.
2. Resources available to the students while diagnosing their solutions (e.g. information provided about the correct problem solution, notebooks and textbook).
3. Feedback: Provision of customized feedback (diagnostic information about the solution).

We report an in-class study focused on three types of interventions that require students explicitly to self-diagnose their solutions, yet differ in the instructions and resources students receive (see Table 1).

In all interventions students first solved realistic, motivating quiz problems (an example is shown in Figure 1). These kinds of problems are sometimes referred to in the literature as "context rich problems"[9] that have a context and motivation connected to reality, have no explicit cues (e.g. “apparent weight”), require more than one step to solve and may contain more than the information needed (e.g. the car's mass). Context Rich Problems require students to analyze the problem statement, determine which principles of physics are useful and what approximations are needed (e.g. smooth track), and plan and reflect upon the sub-problems constructed to solve the problem.

A friend told a girl that he had heard that if you sit on a scale while riding a roller coaster, the dial on the scale changes all the time. The girl decides to check the story and takes a bathroom scale to the amusement park. There she receives an illustration (see below), depicting the riding track of a roller coaster along with information on the track (the illustration scale is not accurate). The operator of the ride informs her that the rail track is smooth, the mass of the car is 120 kg, and that the car sets in motion from a rest position at the height of 15 m. He adds that point B is at 5m height and that close to point B the track is part of a circle with a radius of 30 m. Before leaving the house, the girl stepped on the scale which indicated 55kg. In the rollercoaster car the girl sits on the scale. Do you think that the story she had heard about the reading of the scale changing on the roller coaster is true? According to your calculation, what will the scale show at point B?

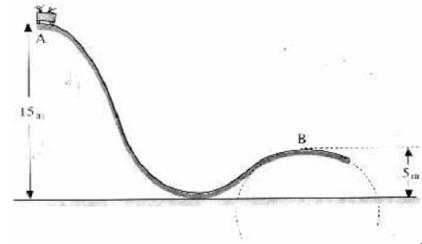


FIGURE 1. Context rich problem.

In some intervention groups, the problem statement included guidelines for how students should present their problem solutions, while in others instructors merely discussed with students these guidelines early in the semester (cf. Fig. 2).

In all intervention groups, in the recitation following the quiz, the instructor gave his students a photocopy of their solution, and asked them to diagnose mistakes in their last week's quiz solution. Students were credited 50% of quiz grade for the

diagnosis. The instructor also motivated them by saying that self diagnosis will help them learn.

Problem description: Represent the problem in Physics terms: Draw a Sketch, List known and unknown quantities, target variable

Solution construction: Present the solution as a set of sub problems, In each sub problem write down:
 The unknown quantity you are looking for
 The physics principles you'll use to find it
 The process to extract the unknown

Check answer: Write down how you checked whether your final answer is reasonable

FIGURE 2. Guidelines for presenting problem solution.

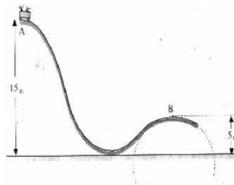
In the 1st intervention group students received minimal guidance, namely, they were asked to circle their photocopied solutions and say what they did

Solution

1. Description of the problem

Knowns:

- The height of release: $h_A=15m$
- Speed of the car at point A: $v_A=0$
- The height at point B: $h_B=5m$
- The radius at point B: $R_B=30m$
- The mass of the car: $M=120\text{ kg}$
- The mass of the girl: $m=55\text{kg}$
- Target quantity: $N_B = \text{Normal force at point B.}$
- Assumptions: the friction with the track is negligible



2. Constructing the solution

Plan:

During the motion of the girl along the curved track, the magnitude of her velocity as well as the radial acceleration changes from point to point. If the radial acceleration changes, we infer that the net force acting in the radial direction on the girl changes as well. The net force on the girl is the sum of 2 forces acting on her: the force of gravity and the normal force. To calculate the normal force at point B we can use Newton's 2nd Law $\Sigma \vec{F} = m \cdot \vec{a}$; however we will need to know the acceleration at this point. To calculate the centripetal acceleration at B, $a_r = v_B^2/R$ we need to know the speed at point B.

We will calculate the velocity of the girl at point B using the law of conservation of mechanical energy between point of departure A and point B (the mechanical energy is conserved since the only force that does work is the force of gravity which is a conservative force. The normal force does no work because it is perpendicular to the velocity at every point on the curve).

Sub-problem 1: calculating the velocity at point B

We'll set ground as the reference for potential energy and compare the total mechanical energies of the girl and car at points A and B: $E_A = E_B$

wrong in that part, aided by their notes and books only, without being provided the solution.

In the 2nd intervention group the students were also provided with a correct solution that the instructor handed out during the self-diagnosis activity (cf. Fig. 3). This solution followed the guidelines for presenting a problem solution (cf. Fig. 2).

In the 3rd intervention group the instructor discussed the correct solution with the students and they were required to fill in a self diagnosis rubric (cf. Fig. 4). The rubric was designed to direct students' attention at two possible types of deficiencies: deficiencies in approaching the problem in a systematic manner ("general evaluation" part) and deficiencies in the physics applied.

Besides the intervention groups, we also had a control group in which the instructor discussed with the students the solution for the problem, but they were not required to engage in a self-diagnosis task.

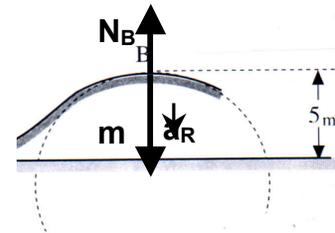
Since the speed is zero at point A the kinetic energy is zero at that point. Therefore we get: $PE_A = KE_B + PE_B$

$$\Rightarrow (m + M)gh_A = (m + M)gh + \frac{1}{2}(m + M)v_B^2$$

$$\Rightarrow gh_A = gh_B + \frac{v_B^2}{2}$$

We can calculate the speed at B in the following way:
 $v_B^2 = 2gh_A - 2gh_B = 2(10\text{ m/s}^2)(15\text{ m} - 5\text{ m}) = 200\text{ m}^2/\text{s}^2$

Sub problem 2: calculating the normal force at B



Using Newton 2nd law

$$\Sigma \vec{F} = m\vec{a}_r$$

$$N_B - mg = -ma_r$$

$$N_B - mg = -m v_B^2 / R_B$$

$$N_B = mg - m v_B^2 / R_B$$

$$\Rightarrow N_B = (55\text{ kg})(10\text{ m/s}^2) - (55\text{ kg})(200(\text{m/s})^2 / (30\text{ m}))$$

$$\Rightarrow N_B = 183.33\text{ N}$$

Final result: when the car crosses Point B at the track, the scale indicates 183.3 N

3. Reasonability check of the final result:

- limiting cases of the parametric solution

$$N_B = mg - m v_B^2 / R_B :$$

At rest ($v=0$): $N = mg$,

On horizontal surface ($R \rightarrow \text{infinity}$): $N = mg$

FIGURE 3. Sample solution aligned with guidelines.

General evaluation	Performance level	Explain what is missing?
Problem description	Full Partial Missing	<ul style="list-style-type: none"> In sketch Known /unknowns
Solution construction	Full Partial Missing	<ul style="list-style-type: none"> Sub problem's unknown Principles used
Check answer	Full Partial Missing	<ul style="list-style-type: none"> Possible checks for reasonability

Circle and number mistakes you find in the solution. Fill in the following rubric

Mistake #	Mark x if mistake is in:			Explain mistake
	Physics	Math	Other	
1				
...				

FIGURE 4. self diagnosis rubric

TABLE 1. Summary of Different Interventions

Control	Rubric + TA outline	Sample solution	Notes + text books
Student solve a quiz problem			
Instructor discusses the correct solution with the students	Instructor outline the correct solution with the students	Instructor provides written sample solution	
NO self - diagnosis	Students are asked to circle mistakes in their photocopied solutions and fill in a self diagnosis rubric.	Students are asked to circle mistakes in their photocopied solutions and explain what they did wrong	Students are asked to circle mistakes in their photocopied solutions and explain what they did wrong
Grading solution	Grading the solution and the diagnosis		

The following table summarizes the various sequences in our study.

TABLE 2. Sequences in the Study:

Pretest	Pre problems, similar in complexity but not isomorphic to Intervention problems.
Intervention	Initial Training Problem-Solving, Diagnosis, Repeated twice
Posttest	Isomorphic (to Pre + Intervention) and far transfer problems both in midterm and final exams, FCI

The study was carried out at two sites:

1. Israel, 11th grade high school classes (algebra based, studying full year advanced high-school mechanics). 120 students, 3 instructors.
2. US, introductory college level (1 semester, algebra based, pre-meds), 240 students, 1 Instructor, 2 TAs

The above setup allowed us to explore questions such as: What kind of mistakes are students able to diagnose? How do students' solutions compare to their diagnosis? Do students' final exam grades correlate with their solutions or their diagnosis performed in the middle of the semester? How do students in different treatment groups compare in their ability to diagnose their mistakes?

Answering these questions would allow us to determine whether self-diagnosis is indeed helpful for students' learning. If it does help, how does it advance students' learning, and how could one modify the scaffolding to improve the outcomes? These questions will be the focus of the companion paper.

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