

Physics Learning in the Context of Scaffolded Diagnostic Tasks (II): Preliminary Results

Chandralekha Singh[†], Edit Yerushalmi^{*}, Bat Sheva Eylon^{*}

[†]*Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA 15213, USA*

^{*}*Department of Science Teaching, Weizmann Institute of Science; Rehovot, Israel*

Abstract. In a companion paper we presented self-diagnosis tasks in which students are explicitly required to self diagnose their problem solutions after being given some feedback. In this paper we suggest a rubric to evaluate diagnosis and exemplify its use in two case studies. We present preliminary results regarding how students' performance on the self-diagnosis tasks relates to their performance in solving problems and to their progress during the course. In preliminary analysis, we find that the correlation between students' self-diagnosis grades and their performance in the mid-semester quiz was very low (0.16), the correlation between the grades in the mid-semester quiz and the final exam grades was also low (0.21) while the correlation between the self-diagnosis grades in the mid-semester quiz and the final exam grades was reasonably high (0.68). We suggest that these results can be explained by the hypothesis that the self-diagnosis grades measure the slope of students' learning curve.

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

PACS: 01.40.gb, 01.40.HA

INTRODUCTION

In the companion paper, we laid out an experimental setup designed to explore physics learning in the context of scaffolded diagnostic tasks. We want to investigate whether scaffolded self-diagnosis is helpful in students' learning, what happens in the self-diagnosis that may be helpful in students' learning, and how can we improve the scaffolding. We described three interventions differing in the nature of scaffolding provided.

In this paper we develop a rubric to evaluate diagnosis and exemplify its use in two case studies. We present preliminary results regarding how students' performance on self-diagnosis tasks relates to their performance in solving problems. At this stage we consider the three interventions together to identify general trends that go beyond the particular scaffolding provided.

We focus on the study we conducted in the US in the introductory algebra based course for pre-meds, with 240 students, one instructor and two teaching assistants. We report on the preliminary analysis of seventeen students' self diagnosis of a mid-semester quiz that was given in the recitation in week 6 of a 15 week semester. There were roughly equal number of students from each intervention group.

WHAT IS A GOOD DIAGNOSIS?

The characterization of a good diagnosis is based on defining what is a good solution. Aligned with the cognitive apprenticeship approach in which a principal component is the externalization of an expert strategy to problem solving (PS), we focus the evaluation of students' solution and diagnosis both on the application of physics principles/concepts, as well as on the application of systematic PS approach.

We developed a rubric (shown in table 1) that spans possible deficiencies in these two categories. Similar rubrics adapted to lab assessment [1] and PS assessment [2] can be found in the literature. For example, for the problem shown in the companion paper, appropriate principles that need to be invoked include conservation of mechanical energy and Newton's second law. Yet many students did not invoke them. Moreover, many invoked inappropriate principles such as kinematics equations in uniform acceleration motion, or equilibrium application of Newton's second law. Useful description for this problem would include, e.g., drawing a free body diagram, an acceleration vector, and coordinate axes, defining the reference level for the potential energy, etc. An explicit strategy would include defining an appropriate target quantity (i.e.,

normal force that the scale exerts upon the girl), defining appropriate intermediate variables and explicitly stating in words and/or in a generic mathematical form the principles used to find these variables. Common deficiencies in this category would be laying out surplus equations, writing derived equations related to special cases, with no reference to the principles they are derived from, and ignoring intermediate or final results that make no sense.

TABLE 1: Summary of Diagnostic Components:

Diagnostic components	
Application of Physics principles/concepts	<ol style="list-style-type: none"> appropriate principles that were not invoked inappropriate principles that were invoked principles invoked yet applied incorrectly
Application of systematic PS approach	<ol style="list-style-type: none"> Useful description (re-stating the problem in terms of knowns and unknowns, useful variables, drawing, etc.) Explicit strategy to solve the problem (explicitly defining the physics concepts or principles that will be used to find intermediate variables) Explicit checking of the final answer

A good self-diagnosis should reflect the student's realization of these deficiencies. In particular it should allow the students to learn the lesson from these deficiencies thus preventing them from doing similar mistakes in the future. To achieve this goal students need: 1) to identify where deficiencies have occurred; 2) to explain or/and correct the deficiencies; and 3) to acknowledge the nature of the deficiencies (physics, math,...). With these considerations in mind we evaluated students' self-diagnosis.

Yes, what she heard about the roller coaster was true. At B, she will weigh 75 kg.

The first error I made was calculating the velocity at B. I used the kinematics equation instead of using PE and KE to find velocity. I had a velocity of 14 m/s instead of 20 m/s. (Actually, nevermind. I had that right, the $\sqrt{200}$ m/s \approx 14 m/s. I drew the diagram correctly but used the wrong equation. I didn't use $N_B - mg = -m a_c$. Instead I used the PE and a_c . I see how the correct equation is used to find the answer, because the force due to gravity - centripetal force equals the normal force.

FIGURE 1. Cathy: solution & self-diagnosis.

In Figure 1 and Figure 2 we present two case studies of solutions of diagnoses differing in quality.

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 car along with information on the track (the illustration scale is not accurate). The operator of the ride informs her that the full 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 5 m 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 55 kg. In the roller coaster car the girl sits on the scale. Do you think that the story she had heard about the reading of the scale clinging on the roller coaster is true? According to your calculation, what will the scale show at point B?

1. Yes, I think that the story the girl heard about the reading of the scale clinging on the roller coaster is true.

2. Given:

- $v_A = 0$
- $m_c = 120 \text{ kg} + 55 \text{ kg} = 175 \text{ kg}$
- $F_f = 0$
- $h_A = 15 \text{ m}$
- $h_B = 5 \text{ m}$
- $r = 30 \text{ m}$
- $m_g = 55 \text{ kg}$

Calculations:

- $PE_A = mgh = (175 \text{ kg})(9.8 \text{ m/s}^2)(15 \text{ m}) = 25725 \text{ J}$
- $PE_B = (175 \text{ kg})(9.8 \text{ m/s}^2)(5 \text{ m}) = 8575 \text{ J}$
- $TE = PE + KE = 25725 \text{ J}$
- $25725 \text{ J} = PE_B + KE_B$
- $25725 \text{ J} = 8575 \text{ J} + KE_B$
- $KE_B = 17150 \text{ J}$
- $KE_B = \frac{1}{2} m v_B^2$
- $17150 \text{ J} = \frac{1}{2} (175 \text{ kg}) v_B^2$
- $v_B = 14 \text{ m/s}$
- $F = m a$
- $F_N + mg = m a$
- $F_N = m a - m g$
- $F_N = (175 \text{ kg})(6.54 \text{ m/s}^2) - (5 \cdot 175)$
- $F_N = 1142 \text{ N} - 875 \text{ N} = 267 \text{ N}$
- $T = \frac{2\pi r}{T}$
- $T = \frac{2\pi(30 \text{ m})}{14 \text{ m/s}}$
- $T = 13.46 \text{ s}$
- $a_c = \frac{2\pi v}{T}$
- $a_c = \frac{2\pi(14 \text{ m/s})}{13.46 \text{ s}}$
- $a_c = 6.54 \text{ m/s}^2$

General evaluation:

	Performance level	? Explain what is missing
Problem description	Full / Partial / Missing	
Solution construction	Full / Partial / Missing	
Check answer	Full / Partial / Missing	did not show evidence/explication of verification of units

Diagnosis of the mistakes:

Mistake #	:Mark X if mistake is in			Explain mistake	In ft
	Physics	Math	Other		
1	✓			made (mg) and (ma) positive, when they should have both been negative	

FIGURE 2. Beth: solution & self-diagnosis.

Cathy (all names are pseudonyms), for example, carried out a relatively good self-diagnosis on a

relatively poor solution (see figure 1). Cathy belonged to the 2nd intervention group in which students were provided with a correct solution that the instructor handed out during the self-diagnosis activity. These students were asked to circle mistakes in their photocopied solutions and write what they did wrong in each circled part.

Cathy drew a free body diagram (FBD) but it appears that she was thinking of equilibrium application of Newton's 2nd law, taking centripetal force as a physical force. Moreover, the FBD was a surplus information in her solution as she did not use the FBD for anything else. She invoked a derived equation to find the final speed at point B. She used equation $mgh = mv^2/r$ that has energy on one side of the equation and force on the other side, and as she did not carry out dimensional analysis she did not realize this equation is dimensionally incorrect.

Surprisingly, in her self diagnosis she focused on the principles to be used, realized all the principles she misused, and which principles should be used instead. For example, she realized she was using the equation of kinematics to find v_B , rather than the conservation of mechanical energy. She also realized the strength in her approach to the problem solution. For example she realized she had a relatively good FBD that she did not use.

Beth's solution on the other hand, is an example of a little better solution, yet poor diagnosis. Beth belonged to the 3rd intervention group in which the instructor discussed the correct solution with the students and they were required to fill in a self diagnosis rubric

Her solution has FBD, although she did not draw the axes. She invoked both the conservation of mechanical energy as well as Newton's second law, although she confused the signs and used a wrong mass to calculate the normal force.

She also invoked the expression for the period of revolution T in uniform circular motion, a legitimate principle that is not appropriate in the specific problem, as well as a non-legitimate expression for the acceleration "a" in uniform circular motion as $a_c = 2\pi v/T$, resulting together in a correct equation. Her presentation is organized, but she did not check whether her results make sense.

In contrast, her diagnosis is poor. Beth was in the intervention group that was instructed to diagnose using a rubric. In the first part of the rubric, students were required to mark their performance level for "problem description" and "solution construction". "Problem description" stands for representing the problem in Physics terms (drawing a sketch, determining target variables, etc.), and "solution construction" stands for presenting a set of sub

problems differing in intermediate variables as well as physics principles used to find them. Beth marked both of those categories as "full", not realizing she treated the circular motion as uniform one without justifying why it may work at point B. While she noticed her sign confusion, and even classified it as a physics mistake, she did not explain why this is wrong and which principles/concepts she had applied inappropriately.

TABLE 2. Partial rubric for evaluating a solution:

	Positive	Negative	+	-
Invoking principles	<u>Appropriate principles/concepts</u> 1. Conservation of mechanical energy; 2...	<u>Non appropriate principles/concepts</u> a. Kinematics equations in uniform acceleration motion; b... <u>Non-legitimate principles/concepts</u>		
Application	1. Setting KE to zero when the girl+cart are released; 2....	a. The centripetal force is one of the physical forces ...		
Plan	Appropriate target (i.e., F_N) and intermediate (v_B , a_c) quantities chosen; 2...	a. surplus equations or intermediate variables are written down; b...		
Presentation	1. Invokes a FBD; 2...	b. not stating in words or a generic form the principles used to solve sub-problems		

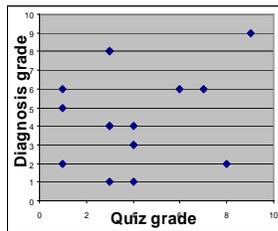
TABLE 3. Partial rubric for evaluating self-diagnosis

Things the students realized regarding his/her solution		
Invoking principles	Realizes that s/he was missing one of the following principles in solving the problem, e.g.: 1. Conservation of mechanical energy; 2... Realizes that s/he was using one of the following inappropriate principles in solving the problem, and explaining why this was inappropriate, e.g.: a. Kinematics equations in uniform acceleration motion; b.	
Application	Realizes principle/concept mis applied, e.g. a) The centripetal force is not one of the physical forces; b) i. Realizing principles/concepts that were not applied correctly, ii. why the way they were applied was wrong or iii. how they could have been applied correctly e. g. iv. categorizes correctly to Physics/math/other error	
Plan	Realizes s/he was missing or providing inappropriate in the following way.: a. surplus equations or intermediate variables are written down b. Inappropriate intermediate variables chosen	
Presentation	Realizes that s/he was missing one of the following 1. FBD; 2. explicitly stating in words or a generic form the principles used to solve this sub-problems	

To transform the above qualitative analysis to a quantitative one and determine a grade for the quiz solution and for the self diagnosis, we constructed a problem specific rubric (Table 2,3). Table 2 lists some specific examples for each of the items in table 1. We marked each item that appeared in the solution of a student in a positive or negative column depending upon their suitability. The analysis was done by two researchers (EY & CS) and any disagreements were discussed and resolved. Based on this analysis, the solutions of all the 17 students were compared to each other and assigned a relative grade.

The above grading procedure using the rubric revealed that the above two examples (Cathy and Beth) reflect a more general pattern, namely, the level of performance on the mid-semester quiz was not a good predictor for the level of self-diagnosis. We note that it is true that if a student had solved the problem correctly, self-diagnosis of mistakes would not be required. However, none of the students we have graded so far were able to solve the context rich problem discussed here correctly. The multi-part problem was sufficiently challenging that all of these students made some mistakes.

Figure 3 shows a plot of the mid-semester quiz grades (1-10 scale) vs. self diagnosis grades (1-10 scale) for 17 students. The correlation coefficient between quiz and self diagnosis grades was very low (0.16).



$$\rho = \frac{COV(X,Y)}{\sigma_y \cdot \sigma_x} = 0.16$$

FIGURE 3. Mid-semester quiz vs. self diagnosis grades.

One can now ask which of these two indicators, the solution or the self diagnosis, correlates better with student's final exam grades?

Our preliminary results suggest that the self-diagnosis grade for the mid-semester quiz was a better predictor of the final exam grades than the grade of the quiz solution itself (see figure 4). The correlation coefficient between the mid-semester quiz grades and the final exam grades (1-40 scale) was very low $\rho = 0.21$ and between self diagnosis and final grades was very high: $\rho = 0.68$.

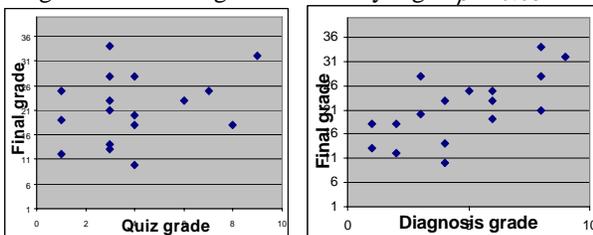


FIGURE 4. Left: Quiz vs. final exam grades. Right: Self diagnosis vs. final exam grades (N=17).

Moreover, comparison of the students we have analyzed in different intervention groups, shows that those students who received an example solution (i.e., received a paper copy of the solution or watched the TA discuss and write the solution outline on the blackboard) were better able to self-diagnose than those who only used the textbook and their notes.

POSSIBLE IMPLICATIONS

We hypothesize that the performance on the self-diagnosis tasks is an indicator of the slope of the learning curve of the students, namely, how well they will progress during the course. Hence, students who performed well on the self-diagnosis tasks are more likely to show superior performance towards the end of the course regardless of their performance at the beginning as measured by their grades in the mid-semester quiz. On the other hand, students with low performance on the self-diagnosis tasks may not progress significantly during the course and may not perform very well at the end of the course even if their performance on the mid-semester quiz was better than many others. An alternative interpretation of our preliminary finding is that the mid-semester quiz was too difficult and thus did not differentiate well between students' of different ability level.

Note that even the presumably "good diagnosis" of Cathy was not that "good". Although she mentioned which principles she did not invoke, she did not explain how she misapplied the ones she did use. However, the preliminary finding that those students who had a superior self-diagnosis performance according to our rubric had significantly better grades at the end of the course than those with poor self-diagnosis performance is encouraging. Scaffolded self-diagnosis activities should be used more often for teaching and learning.

ACKNOWLEDGMENTS

We wish to express our gratitude to the teachers who participated in the study: Korina Polinger, Philip Rojnikovski, Shoshana Ozeri, Jeremy Levy, Patrick Irvin, Shanti Wendler. This study was supported by ISF grant 1283/05 (EY, BE) and NSF grant DUE-0442087 (CS).

REFERENCES

1. E. Etkina, A. Van Heuvelen, S. White-Brahmia, D. T. Brookes, M.J. Gentile, S. Murthy, D. Rosengrant and A. Warren, Phys. Rev. ST Phys. Educ. Res. 2, 020103 (2006)
2. J. Doktor, K. Heller, P. Heller, T. Thaden-Koch and J. Li, "Robust Assessment Instrument for Student Problem Solving", Abstract, AAPT Summer Meeting, July 2007