The Impact of Diagnosing Teacher-Made Erroneous Solutions, With the Aid of On-Line Prompts and Feedback, on Students' Diagnostic Skills

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Abstract

An on-line activity was designed to improve students' diagnostic performance in physics problem solving (i.e. their ability to explain mistakes in terms of the misuse of principles applied in an erroneous problem solution). The activity engaged students in diagnosing teacher-made erroneous problem solutions, with the aid of principle-based prompts and feedback. We examined the impact of the on-line activity on students' performance in a more natural F2F setting where students self-diagnose their solutions aided by worked-out examples. Students' learning from the self-diagnosis task was assessed in terms of their performance on transfer problems. We compared students' learning from the self-diagnosis task before and after they experienced the on-line activity. The participants were 11th grade students from the Arab sector in Israel studying the topic of geometrical optics.

A detailed analysis of the progression of six students indicated that the on-line activity did not have a significant impact on their diagnostic skills in the more natural setting. This may have been due to the nature of the students' problem solutions, which were brief, with minimal justifications and rarely explicated the physics principles underlying their solutions. Thus students did not have much to respond to in their self-diagnoses.

Keywords: Problem Solving, Self-diagnosis, Self-Repair, diagnosing erroneous solution.

Introduction

Research conducted in the context of "self-diagnosis tasks" in which students are required to identify and explain their mistakes in writing as part of the activity of reviewing their own solutions has shown self-diagnostic performance to be generally poor. In a study carried out in a US college setting (Yerushalmi et al. 2012) fewer than half of the students in an introductory physics course could pinpoint their failure to invoke a required principle, and only one in ten could recognize where they had misapplied the principles. In a study carried out in Arab speaking Israeli high schools (Safadi and Yerushalmi, 2013), when asked to diagnose their solution in light of a worked-out example, the students' self-diagnosis did not entail *self-repair* (Chi, 2000); namely, they rarely acknowledged and attempted to resolve underlying conflicts between their mental model and the scientifically accepted one. Students commonly regarded the instructor's solution as an ultimate template, and viewed surface deviations of their solution from the sample solution as weaknesses.

An on-line activity was designed to improve students' diagnostic performance, and in particular their engagement in processes of self-repair (Yerushalmi et al. 2012). The activity builds on research showing that deliberate exposure to erroneous solutions, where students are asked to diagnose (i.e., identify, explain and correct the mistake), and are provided with feedback on their diagnostic performance, can help them revise misinterpretations of related concepts (Reif & Scott, 1999, Durkin & Rittle-Johnson, 2012). The activity also draws on research showing that including principle-based prompts are effective in inducing principle-based self-explanations (Atkinson et al. 2003).

The on-line activity involved physics students in diagnosing teacher-made erroneous problem solutions, while scaffolding the process with feedback in the form of expert's diagnoses, and principle-based prompts while diagnosing and processing the feedback. Analysis of pairs of students' discourse while performing the activity showed that they engaged in *self-repair* by distinguishing naive from expert interpretations of the scientific ideas involved, and focusing on the features of the concept needed to interpret it accurately. We hypothesized that the inclination to *self-repair* in the on-line activity would transfer to more natural settings where students self-diagnose their solutions with worked-out examples, but without principle-based feedback.

To examine this hypothesis we studied the effect of the on-line activity via the double transfer methodology suggested by Schwartz & Martin (2004). This methodology differs from the traditional examination of the impact of a treatment by means of a direct transfer task. Instead, after the treatment students are asked to study a learning resource and then do a transfer task. This makes it possible to assess the effect of the treatment on their approach to learning. Here, we examined the effect of the on-line activities via an experimental procedure (see table 1) that consisted of pre-test, treatment (two rounds of the on-line activity), post-test. The pre-test and post-test involved studying a learning resource – instructor's worked-out example – offered within a self-diagnosis task, followed by transfer problems.

Table 1. Experimental design

Sequence			topic	Schedule
Pre-test	Double transfer (2 problems)	After presenting a sub-topic, students solve a quiz (source problem) and then self-diagnose their solution aided by worked-out examples	Light and sight	2 lessons
		Students solve transfer problem isomorphic to the source problems		
Treatment	2 on-line activities (2 problems in each) in pairs	Diagnosing two erroneous solutions to two physics problems	Image formation converging lens: 1) virtual images 2) real images	2 lessons
		Mirroring expert's diagnosis & Comparing it to student's diagnosis		
Post-test	Standard transfer	Students solve 2 transfer problems, isomorphic to treatment problems	Mechanical waves: transmission of a pulse across a boundary	$2\frac{1}{2}$ lessons
	Double transfer	Same as in pre-test		

Experiment Setup

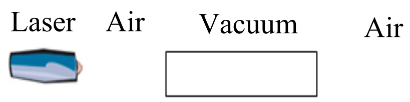
Sample

The participants were11th grade students recruited from an advanced physics class (N=19) in a private school in the Arab sector in Israel, studying the topics of geometrical optics and introduction to mechanical waves. The teacher had 22 years of experience and a Ph.D. in science teaching. It was his first experience with the activity and he was provided with individual guidance how to administer it. The analysis focused on six students, selected to portray the variety of learning progressions throughout the activity.

Pre and post tests

The pre and post-test implemented the double transfer methodology. Students solved a pre-source problem on a quiz, reflected on their solution with the aid of a worked-out example (figure 1), and later solved transfer problems isomorphic to the source problem. The problem was qualitative and set in realistic context. The solution required the principal ideas shown in figure 1.

Problem: The system shown in the figure contains a laser and a vacuum glass tube surrounded by the air in the room. The laser is directed towards the vacuum tube, while all other lights in the room are turned off. What would an observer standing beside the tube see? Explain.



Worked-out example: An observer standing to the side of the tube can detect the laser light in the air, as some of the laser light strikes and is reflected by the dust particles in the air (principal idea b). Some of the reflected light will move through space and reach the observer's eyes (principal idea c), allowing him/her to see the dust particles scattering the light, and detect the existence of the laser light. When the laser light travels through the vacuum tube the observer won't be able to detect its existence, as it does not contain particles that can change the direction of the light (principal idea b), and it will continue propagating in straight line (principal idea a).

Principal ideas: a) light travels in empty space in straight line; b) when light strikes an object a portion of the light can be reflected off the object in a different direction than the incident light; c)an observer is able to see an object when the light from the object moves through space and reaches the observer's eyes. It probed for naïve ideas such as not representing the directionality of the light towards the eye as a condition for sight.

Figure 1. The pre-source problem and worked-out example

The pre-transfer problem (see figure 2) was isomorphic to the pre-source problem. As self-diagnosis did not take place in the transfer step, the worked-out example shown in figure 2 served merely as reference to assess students' performance.

<u>Problem:</u> Please look at the picture portraying an astronaut who has landed on the moon.
a. was the picture take in the moon's day or night?
b. notice that the moon's sky is dark, explain why.
<u>Worked-out example:</u> a. the moon's face is lit up thus the picture was taken in the moon's day.
b. the sky of the moon is dark because the moon does not have an atmosphere like the Earth does. When there is no atmosphere, the sunlight travel in straight line (a) until it strike the moon's interface and is reflected (b) from it. Part of the reflected light strike the eye of the observer (c). This is why the moon's interface is perceived as lit. When there is atmosphere, as on Earth, the light is reflected by the particles in the atmosphere (b) so the sky is seen as lit up . When there are no particles to reflect the light, as is the case for the moon, the sky looks dark.

Figure 2. The pre-transfer problem and worked-out example

The two isomorphic problems that served in the post-test are shown in figure 3.

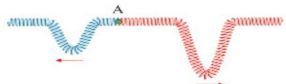
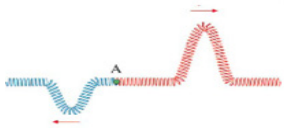
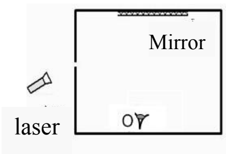
Problem: The following diagram shows two springs – a "light" one and a heavy one. A pulse is introduced on one of the two ends, and when it reaches the boundary point A between the two springs it splits into a transmitted pulse and a reflected pulse, as is shown in the diagram. Which spring is the "light" one– the right one or the left one? Explain your answer. 	source
Problem: The following diagram shows two springs – a "light" one and a heavy one. A pulse is introduced on one of the two ends, and when it reaches the boundary point A between the two springs it splits into a transmitted pulse and a reflected pulse, as is shown in the diagram. Which spring is the "light" one – the right one or the left one? Explain your answer. 	transfer
Principal ideas: a. the speed of a pulse: it is defined as the ratio between $\Delta x = x_2 - x_1$ – The displacement of a specific point on the pulse (such as the crest) from the instance t1 to the instance t2, and between the time interval $\Delta t = t_2 - t_1$ $v = \frac{\Delta x}{\Delta t} = \frac{x2-x1}{t2-t1}$. b. in a light spring a pulse propagates faster than in a heavy spring. 3. an alternative idea.	principles

Figure 3. The post source and transfer problems, principle ideas

Treatment

Figure 4 shows the design of the on-line activity. In the first step students were given a problem and an erroneous solution to the problem. The erroneous solution included both an incorrect prediction, as well as an incorrect justification that revealed a misinterpretation of the involved principal ideas. Students were first asked to determine whether the solution was correct. Second, they were told that the solution was wrong, and were asked to "diagnose" the mistake; that is, (a) copy – paste the wrong part of the statement to a designated slot, and (b) describe which principle or concepts were incorrectly used in the solution, and explain how it differed from the scientifically accepted view. Then students were provided with an expert's diagnosis, and were asked to "mirror" it; i.e., to identify the principle or concept the student solution referred to, and how it conflicts with the accepted scientific view. Finally the students were asked to compare the expert's diagnosis with their own diagnosis and state whether they were convinced by the teacher's explanation. The students worked in pairs and were allowed to access their textbooks during the activity.

1st task: What do you think?



The following sketch describes a dark room with a plane mirror. All the walls are colored black and the room is completely empty, without dust and smoke in its air. A narrow laser beam penetrates to the room via a small opening, as is described in the sketch. Is it possible to see the mirror from point O where the eye is located?

Sami made the following statement: *"It is possible to see the mirror as it is lit by the light beam penetrating to the room"*

What do you think of Sami's statement?

- It is correct
- It sounds reasonable, but I am not sure
- I am not sure
- It does not sound reasonable, but I am not sure
- It is wrong

2nd task: Diagnosis

Sami's statement contains a widespread mistake,
Copy- paste the part that you think is mistaken in Danny's statement

____

Describe which principle or concept Sami got wrong, and explain in what sense his view differs from the scientifically accepted view

____

3rd task: Mirror

Here is a teacher's diagnosis of Sami's mistake:

"Sami wrote: "It is possible to see the mirror as it is lit by the light beam penetrating to the room". Sami used the word "lit" in an erroneous manner, as if it is possible to see any object that the light lit. In other words, Sami thought that it is sufficient that a light beam hits a mirror to see it. Actually, to see the mirror the light beam hitting the mirror should be reflected towards the observer's eyes. To find the direction in which light rays are reflected from a plane mirror, one have to use the reflection law, according to which a ray is reflected to the other side of the normal on the incident point where the reflection angle is equal to the incident angel Since the eye is not located along the reflected beam it does not see the mirror. Sami's mistake stems from his experience in rooms involving light sources that emit wide beams, particles that spread light in all directions, and other objects reflecting light in all the directions. This way the room is perceived as it is "full" of light. In the case described in the sketch there are neither such sources nor such particles and objects. Therefore, the light beam does not scatter before it hits the mirror."

According to the teacher: which concept/principle did Sami get wrong?

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According to the teacher: how does Sami's mistake contradict the scientifically accepted view?

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4th task: Comparison of the teacher's and student's diagnosis

Here is yours and the teacher's diagnosis, explaining the concept/principle where Sami erred and the contradiction with the accepted scientific view:

Teacher's diagnosis	Your diagnosis
Which concept/ principle did Danny get wrong? *The condition for sight: to see an object it should emit light that penetrates to the eyes.* How does Danny's mistake differ/ contradict the accepted scientific view: *Sami thought that to see an object it is sufficient that light hits it. Yet, according to the scientific understanding, to see an object light should be reflected from the object and reaches the eye. Light is reflected from soft plane – mirror – according to the reflection law. But Sami did not refer to this law as he ignored the reflected ray.*	*Student's diagnosis*

Are you convinced by the teacher's diagnosis of Danny's mistake?	Please elaborate
☐ Yes, this is how I explained it	
☐ Yes, but my explanation is not as clear	☐ I didn't articulate the concept /principle Dan misused ☐ I didn't articulate how Danny's view differs n the accepted entific view
☐ Yes, my explanation was wrong	My mistake was ______________
☐ No, the teacher's diagnosis is wrong, my explanation is correct	The teacher's diagnosis is wrong because: ______________
☐ I am still concerned	I am concerned about: ______________

Figure 4. The steps of the activity (based on Yerushalmi, Puterkovsky & Bagno (2012))

Analysis tools

We evaluated changes in students' ability to study a learning resource by the procedure described in figure 5.

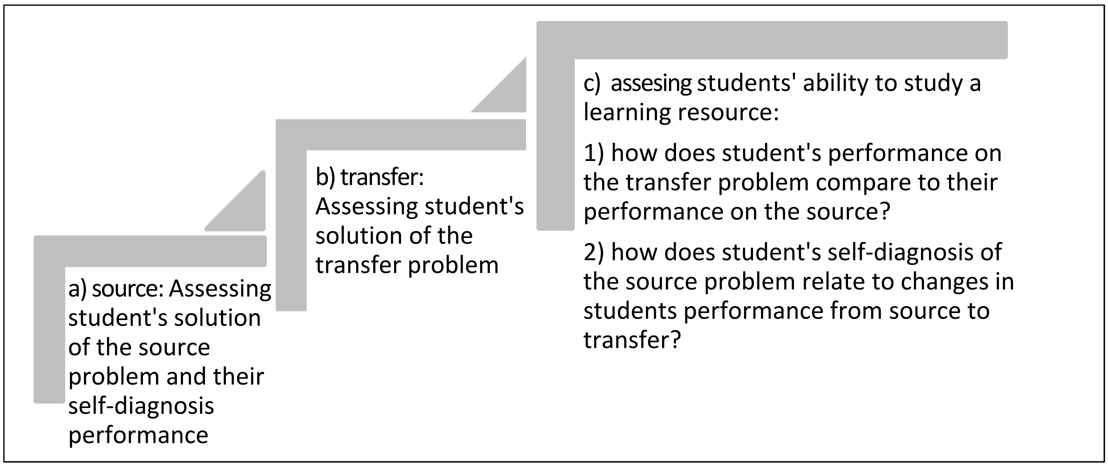

Figure 5. Analysis procedure.

The categories of the rubric used to assess students' solutions integrated both a "top-down" and a "bottom-up" approach: It included the principal ideas required to solve the problem (portrayed in a worked-out example), as well as naïve ideas that were identified while reading the students' answers. The categories used to assess the self-diagnosis were identified "bottom-up" as referring either to the clarity of communication or to the contents (how specific ideas were invoked or applied, and the solution correctness in general).

Sample analysis

The analysis procedure as applied to student #1 both in the pre and the post is described below:

Step a- assessing the solution and self-diagnosis of the pre-source-problem:

Figure 6 portrays the solution of the 1st student and table 2 shows the analysis of her work. As mentioned above the rubric portrayed in table 2 involved both "top-down" categories (based on the principles ideas shown in figure 1) as well as "bottom-up" categories (for assessing the solution and the self-diagnosing). While she got the prediction correct, she did not articulate the scientific principles required to justify it. We interpret her statement "*The laser line does not penetrate the tube as the tube is empty*" to imply that she believes light cannot travel in a vacuum. Her self-diagnosis is brief and does not acknowledge any deficiencies in her solution.

Student 1's solution:	**Student 1's self-diagnosis:**
The laser line does not penetrate the tube as the tube is empty, we see it in the air clearly because of the dust particles and air particles, but in the bottle there is no air, that is, a vacuum, so it won't penetrate into it. After it the straight line of the laser will continue, but it won't be seen in the bottle.	*What I wrote is correct*

Figure 6. Student 1 solution and self-diagnosis to the pre-source problem

Table 2. The analysis rubric for student 1's – pre-source problem

Student 1 pre-source			Source: Ideas invoked + correctness of application			Self-diagnosis		
			Invoked explicitly	Invoked Implied	Not invoked	Content: Specific	Content: General	Comm
Justification principles	Principal ideas-figure1	1)		*The laser line does not penetrate the tube*			*What I wrote is correct*	
		2)		*we see it in the air clearly* ***because of the dust particles***				
		3)		***we see it*** *in the air clearly because of the dust particles*				
	Naïve ideas		*The laser line does not penetrate the tube as the tube is empty*					
Prediction			*we see it in the air clearly… but it won't be seen in the bottle*					

Legend for the analysis of the solution: Prediction: light gray – correct, dark gray - incorrect
Justification: light gray - relevant principal idea invoked and applied correctly
dark gray- relevant principal idea applied erroneously, or irrelevant principle or naïve idea was applied
Legend for the analysis of the self-diagnosis: light gray – adequate; dark gray - not adequate
Content specific: self-diagnosis considers adequately/not adequately how specific ideas are invoked/ applied
Content general: self-diagnosis considers adequately/not adequately correctness in general
Comm: self-diagnosis considers adequately/not adequately communication features

Step b – Assessing the solution of the pre-transfer-problem:

Figure 7 depicts the student's solution and table 3 shows the analysis of his work via a similar rubric to that used in the solution for the pre-source-problem.

Student 1 solution:
a) the picture was taken during the moon's day; b) because space is a vacuum, namely, there are no particles of air or other things, the picture was taken in daylight. On Earth indeed there are dust particles, the moon is lit up and the air is empty, and this is why we don't see light

Table 3. The analysis rubric for student 1's – pre-transfer problem

Student 1 pre-transfer			Transfer: Ideas invoked + correctness of application		
			Invoked explicitly	Invoked implied	Not invoked
Justification principles	Principal ideas-figure1	1)			X
		2)		*because space is a vacuum, namely, no particles of air or other things*	
		3)		*this is why we don't see light*	
	Naïve ideas				
Prediction			*the picture was taken in day light… this is why we don't see light*		

Step c – Assessing the ability to study a learning resource - pre:

When comparing student 1's performance on the source and transfer problems we found numerous similarities. In both she made the correct prediction but did not articulate the principal ideas required to justify the prediction. When considering her self-diagnosis we realize that although she provided a vague self-diagnosis, she had overcome the naïve idea presented in her solution to the source problem by the time that she solved the transfer problem. We conclude that merely reading the worked-out example enabled her to self-repair her ideas, even though the written self-diagnosis did not manifest this process.

Post, steps a-c: A similar analysis procedure (not shown due to space limits) considered the post source and transfer problems (figure 3).

Pre-post comparison:

Table 4 portrays the student's problem solving performance on all problems.

Table 4. The student's problem solving performance on all problems

				Source: Ideas invoked + correctness of application			Self-diagnosis		
				Invoked explicitly	Invoked Implied	Not invoked	Content: Specific	Content: General	Comm
Pre-source	Justification principles	Principal ideas	1)						
			2)						
			3)						
		Naïve ideas							
	Predict								
Pre-transfer	Justification principles	Principal ideas	1)						
			2)						
			3)						
		Naïve ideas							
	Predict								
Post-source	Justification principles	Principal ideas	1)						
			2)						
		Naïve ideas							
	Predict								
Post-transfer	Justification principles	Principal ideas	1)						
			2)						
		Naïve ideas							
	Predict								

Legend: Same as in table 2

The student performance on the source and transfer problems in the posttest was quite similar to the pretest. In both she got the prediction correct but did not invoke explicitly the scientific principles required for justifying the prediction. She did provide justification in the post-transfer; however this was based on naïve ideas. Her self-diagnosis improved: in the pre she realized only a general difference between her solution and that of the instructor, while in the post she acknowledged also her poor communication as compared to the style of the explanation in the worked-out example.

In the pre-test the student's problem solution improved from source to transfer in her ability to invoke the physics ideas required to solve the problem. However, the improvement could not be related to the student's self-diagnosis performance which did not acknowledge any deficiencies in her solution. In the post-test the situation was somewhat different. On the self-diagnosis the student acknowledged her poor reasoning. She improved in this respect as she presented her reasoning for the transfer problem, whereas she did not do so for the source problem. However, she did not improve in her ability to invoke the physics ideas required to solve the problem. Thus, the on-line activity apparently did not have a significant effect on the student's ability to learn from a learning resource in the form of a self-diagnosis task.

Findings: analysis of six students

The analysis of all six students revealed various progressions from pre-source to pre-transfer and later from post-source to post-transfer; however there was a disturbing commonality: the students' problem solutions were very brief, with rare referral to physics principles. Like Student 1, they provided very few justifications, if at all, and as a result the students did not have much to respond to in their self-diagnosis.

In the pre self-diagnosis, three out of the five students who provided self-diagnosis referred only to one category. In the post self-diagnosis students referred to at least two categories. Similarly to students 1, while there was an improvement in students' self-diagnosis, no accompanying improvement was revealed in students' performance on the transfer problems.

Discussion

The analysis described above shows that students' self-diagnosis after the treatment is similar to that of students' who did not receive any treatment, who were found to rarely acknowledge and attempt to resolve conflicts between their solution and that of the instructor (Safadi and Yerushalmi, 2013). A possible explanation for these poor results might be the characteristics of the students' solutions, emphasizing the final answer and providing little justification, if at all. Even worse, most principal ideas required to solve the problem were not articulated in an explicit manner that one could later refer to. Thus, the solutions did not provide material for diagnosis and as a result the students' self-diagnosis did not allow them to improve their problem-solving performance. The "teacher-made" erroneous solution in the on-line activity did provide material for diagnosis as it included both an incorrect prediction and an incorrect justification. However, as this was not the case in the self-diagnosis task, the on-line activities did not improve students' self-diagnosis performance.

Implications

The analysis of students' performance on the pre and post-tests indicated that the on-line activity did not have a significant impact on students' diagnostic skills in the more natural setting, where students self-diagnose their own solutions with worked-out examples. To remedy this shortcoming a culture should be promoted where students provide detailed justifications in their solutions. This direction is consistent with the results of the 2012 PISA survey (OECD, (2013a)), indicating a very large gap in scientific literacy between students in the Arab sector in Israel and the OECD average (both in paper-based tests as well as computer-based assessment).

Alternatively, we suggest examining the effect of the on-line activity by replacing students' own solutions that served in the diagnosis task with teacher-made erroneous solutions that provide justifications and make clear how the physics principles were erroneously applied.

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