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Probing students' critical thinking processes by presenting ill-defined physics problems

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Students' reflections on the meaningfulness of physics problem statements and solutions were investigated. The sample consisted of 276 Croatian high school/university students. The students, being at the different learning levels, were all familiar with the physical concepts concerned. Students' critical thinking processes were explored based on their responses to two open-ended ill-defined problems. Further, the teachers' ability to predict the typical students' approach to problem solving was investigated. For this purpose, 48 teachers were administered the closed-ended questionnaire composed of the empirically obtained students' responses to the two ill-defined problems. The results show that ill-defined problems have the potential of eliciting a whole diversity of deep-rooted students' ideas regarding the meaningfulness of problem statements and solutions. Further, the results indicate that the level of students' critical thinking is low regardless of their educational level and curriculum. It seems that traditional teaching does not sufficiently develop critical thinking. The teachers correctly judge the students' ability to consider the meaningfulness of the solution but they significantly overestimate their criticism towards the problem statement. We believe this kind of problems could facilitate the teachers' efforts directed at systematically developing the students' critical thinking processes. Consequently, students' coping with ill-defined problems could help them to improve their real-life competencies, as well as to develop the habit of taking a critical attitude towards the statements and solutions of physics problems.

Keywords: Critical thinking; ill-defined problem; problem statement; students' problem solving.

Hemos investigado las habilidades estudiantiles de revisar la definición de un problema físico y la significatividad de la solución. La muestra constaba de 276 estudiantes de secundaria y universitarios croatas. Los estudiantes, que estaban en niveles diferentes de educación, estaban familiarizados con los conceptos físicos correspondientes. Los procesos del pensamiento crítico de estudiantes eran investigados basándose en su respuesta a dos problemas mal definidos abiertos. También era investigada la habilidad de profesores de prever el enfoque estudiantil típico. Para esta ocasión 48 profesores respondieron a una encuesta de tipo cerrado compuesta de respuestas verdaderas de los estudiantes a dos problemas mal definidos. Los resultados muestran que los problemas mal definidos pretenden estimular a los estudiantes a expresar una gama amplia de sus ideas muy arraigadas sobre la significatividad del planteamiento y la solución del problema. Los resultados indican también el nivel bajo del pensamiento crítico estudiantil, independientemente del nivel de educación y del currículo. La enseñanza tradicional obviamente no desarrolla suficientemente el pensamiento crítico. Los profesores estiman correctamente la habilidad estudiantil de revisar la realidad del resultado, pero por otra parte, sobrestiman considerablemente su criticismo a la hora de definir el problema. Creemos que este tipo de problemas podrían facilitar el esfuerzo de profesores dirigido hacia el desarrollo sistemático de los procesos del pensamiento crítico estudiantil. Por consiguiente, el afrontamiento de estudiantes a los problemas mal definidos podría ayudarles en mejorar sus competencias en la vida real, tanto como desarrollar la costumbre de tomar una postura crítica hacia la definición y la solución de problemas físicos.

Descriptores: Pensamiento; problema físico mal definido; definición del problema; solucionamiento estudiantil del problema.

PACS: 01.40.Fk; 01.40.gb; 01.55.+b

1. Introduction

On September 26, 1983, Stanislav Petrov, a Soviet Union lieutenant colonel was in charge of monitoring satellites over United States [1,2]. Suddenly the screen in front of him turned red and nuclear alarm went off. According to the computerized early warning systems, USA had launched five nuclear missiles towards Soviet Union. These missiles seemed to approach their targets very fast. Therefore, Petrov was required to decide very quickly whether to report this incident to his superiors, in order to get permission for counter-attack. He critically approached the data provided by the high-tech systems. In his opinion a nuclear attack including mere five missiles had no sense. Consequently, he decided not to inform his superiors about the incident. Luckily, it turned out that what the early warning system had interpreted as missiles was nothing more than high-altitude clouds. Today, we know that Stanislav Petrov's critical thinking approach saved the world from nuclear war [1]. In fact, Petrov became famous as "the man who saved the world" and recently he was awarded the Dresden Peace Prize [3]. Obviously, critical thinking constitutes one of the most important real-life competences. In this article, we will introduce some strategies which could facilitate physics teachers' efforts directed at developing students' critical thinking processes.

A criterion commonly used by physics teachers to measure students' mastering the subject, is their success in traditional quantitative problem solving [4] This assumes providing the students explicitly with all the necessary information for problem solving, whereby the problem statement includes no irrelevant data, and there is a unique solution [5]. Solving the problems of this kind typically involves the processes of seeking the appropriate formula and inserting the given values to obtain a numerical solution (so called "plug-and-chug" approach). This way, students practice quick and effective solving of known problems [6]. They can obtain a correct solution and attain high grades in physics even though they don't understand the basic ideas which underlie the physical phenomenon [4, 5].

As a consequence a significant difference in problem solving strategies between experts and novices arises, that is found in the organization and use of knowledge [7,8]. Experts' knowledge is well organized and based on the concepts [9,10]. Their attention is not focused on auxiliary details that are required in the later solving phase, because they first determine the task goals on the basis of qualitative analysis [11,12]. Their evaluation ability allows them to validate the solution with regard to the assumptions and boundary conditions. In this way each solved problem, contributes to deepening experts' knowledge structures which facilitates their dealing with new problem situations [13]. Unlike experts, most students think that solving problems merely means applying certain procedures or algorithms [14]. Since students' knowledge is composed of unrelated facts and equations [15-18], their low-complexity knowledge structures [19] don't enable them to solve more complex real-life problems [20-24]

The choice of the optimal teaching approach that integrates procedural and conceptual aspects of solving physics problems depends on the concrete problem given to the students [25]. Problems that promote the use of effective learning/teaching strategies should inherently require the following solving steps: problem visualization, providing a qualitative description and problem situation analysis, creation of a solving plan before using math, the plan realization and the solution verification, evaluation of the meaningfulness of the solution [26]. In this way the important features of the scientific process, such as decision making and analysis of results are emphasized. For example, Urone [27] thinks that students should be faced with the unreasonable-result problems. In his opinion problems of this kind prompt students to carefully examine the problem concepts and the problem-solving techniques as well. Kariž Merhar [5] believes that students should be given nontraditional problems characterized by unrealistic solutions, inconsistent data, more than one solution, or insignificant data. These kinds of problems are also considered by Erceg *et al.* [28] and Marušić *et al.* [29] who investigated the teaching possibilities of the partially specified physics problems. Use of such problems reduces the probability of obtaining correct answers based on faulty conceptual understanding of the corresponding physical phenomena. Further, problems of this kind promote critical thinking processes, which are usually seen as crucial to physics learning and explicitly stated as goals of physics education in many physics' curricula [30,31]

In fact, critical thinking represents one of the most important aspects of the real life problem solving ability. Scientists have been studying critical thinking skills for about a hundred years, and almost everyone working in the field has produced a list of thinking skills which they see as basic to critical thinking [31-35]. These skills *e.g.* are used for purposes of determining the relevance and validity of information that could be used for structuring and solving problems, as well as finding and evaluating solutions or alternative ways of treating problems [34,36]. In general, skills in critical thinking are essential for students to function within society [37]. The extensive array of available information demands that individuals develop critical thinking skills in order to be able to evaluate the quality of information available in the 21st century [38]. Therefore, teaching higher order cognitive abilities such as critical thinking ability has always been the ultimate goal of education [39]. There are several generally recognized "hallmarks" of teaching for critical thinking [35,40,41], which include: promoting discussion among students as they learn, asking open-ended questions that do not assume the "one right answer", allowing sufficient time for students to reflect on the questions asked or problems posed, and teaching for transfer.

When it comes to teaching physics, there can be no question that critical thinking is a valuable outcome both for the future physical scientist [42] and for those who would enter other fields [34]. Critical thinking could be developed *e.g.* by using tasks that are sufficiently defined as to be solvable, but do not state explicitly which variable or aspect of the problem will constitute or enable a solution [36]. However, the lack of literature indicates a general lack of experience in the field. This paper is intended to make a contribution in this regard. Its aim is reflected in pointing out effective methods that could improve students' approaches to problem solving and make them able to apply their knowledge to real-life situations. This could be done by explicitly encouraging students' critical attitude toward the problem solving task. We examined the extent to which students are able to judge the accuracy of the problem statement and the problems' solvability.

Within the empirical part of the study students were given two ill-defined physics problems. In the first task, after realizing that use of the correct physics leads to an unrealistic result, students were expected to recognize the wrong assumption which had led to the unrealistic result in the first place. In the second task, students were expected to find out that some unnecessary data are given, and the data needed to solve the problem are not given at all. A similar study was carried out by Hari [43] who proposed a new method in which physics students are asked to evaluate different solutions to the problem and decide why a particular solution is the correct one compared to various other approaches leading to the exactly same final answer.

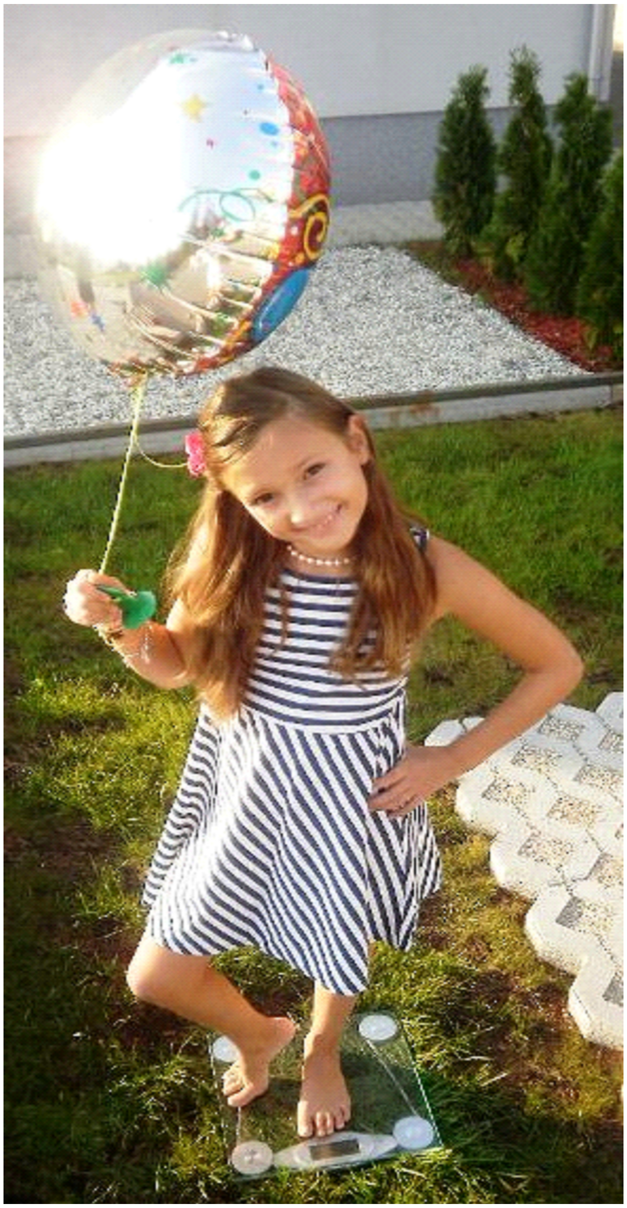

FIGURE 1. The girl with a balloon stands on the scale.

2. Problems

The respondents were presented following problems 1 and 2[i]:

***1.** Wishing to measure body mass, the girl stands on the scale and reads the value of* 30 kg. *If she takes a kids' helium balloon in hand (Fig. 1), the scale shows the lower value.*

***1.1)** What is the mass of the girl with a balloon that reads on the scale if buoyancy of the balloon is* 100 N? *(g* $\approx$ 10 m/s^2)

***1.2)** Are the data in the problem realistic? Why?*

***2.** The physics teacher gave his students the following problem:*

"The tennis player serves a ball (Fig. 2) with the speed 36 m/s. *A third of a second later, a poorly served ball stops suddenly at the net* 12 m *away. What is the stopping acceleration of the ball? (Air resistance is negligible.)"*

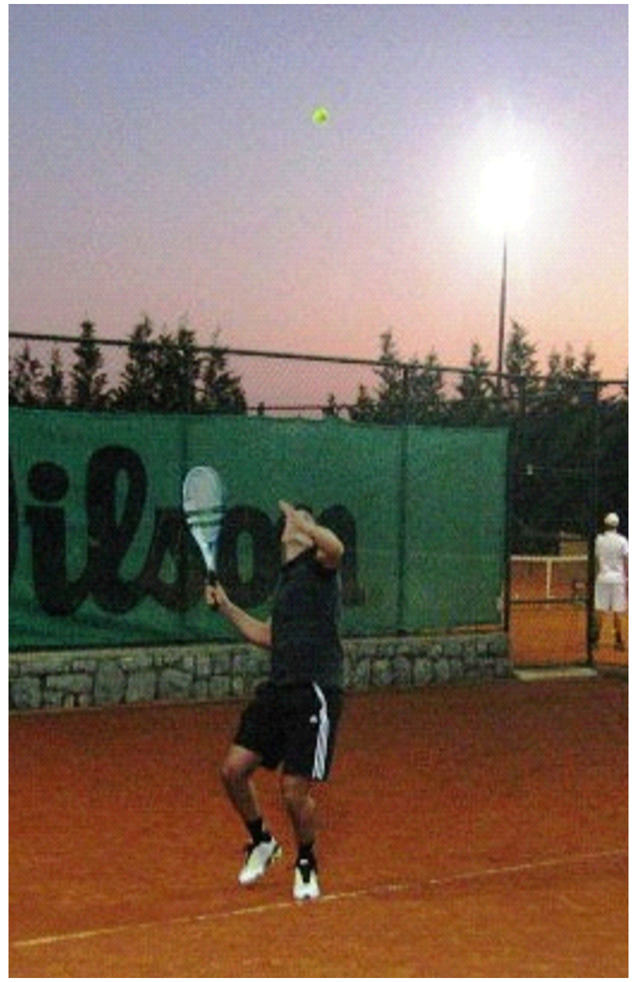

FIGURE 2. The tennis player.

What would you answer to him?

To obtain the correct answer to question 1.1 the correct application of physics concepts and the following solving procedure is needed. The girl on a scale in Fig. 3 is in equilibrium because the two main forces acting on her in opposite directions with equal magnitudes, cancel out. The gravitational force $\boldsymbol{F}_g$ is acting downwards, and the the reaction (normal) force $\boldsymbol{F}_N$ upwards. Buoyancy force on the girl associated with the air pressure gradient is negligible, so the force $\boldsymbol{F}_g$ is balanced by a force $\boldsymbol{F}_N$, *i.e.* $F_N = F_g$. The scale shows the mass of m = 30 kg due to the force that the girl is acting on the scale with the magnitude equal to the magnitude of the normal force:

$$F_N = F_g = mg = 300 \text{ N}.$$

The forces acting on the girl after she took the balloon are shown in Fig. 4. The mass of the balloon is negigible, so that the gravitational force did not change. Now, the two forces are acting upwards. These are the buoyancy force on the balloon $\boldsymbol{F}_B$ exerted by the air and the normal force $\boldsymbol{F'}_N$ which magnitude is now reduced. To calculate the modified mass m', that now reads on the scale, we find the net force

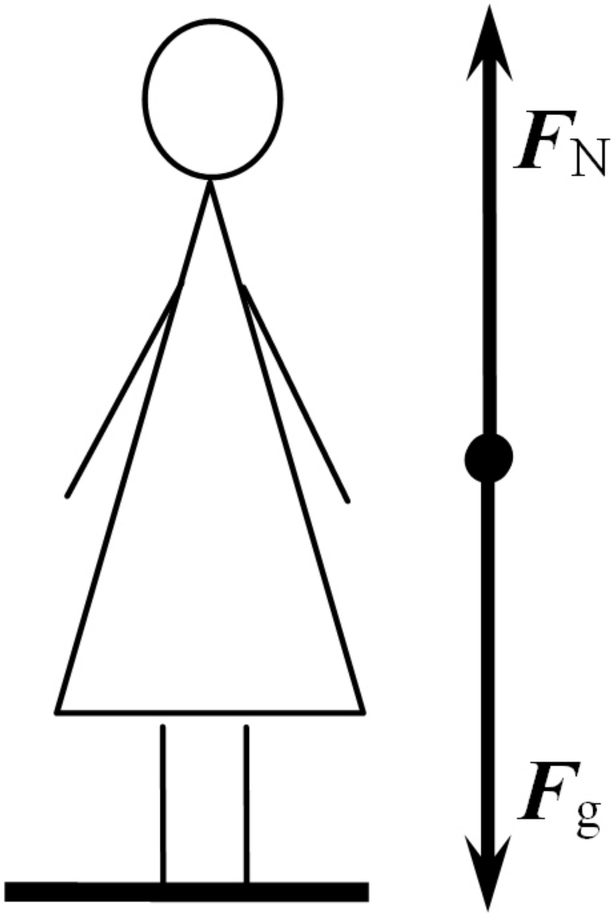

FIGURE 3. Sketch and a free-body diagram of a girl standing on a scale.

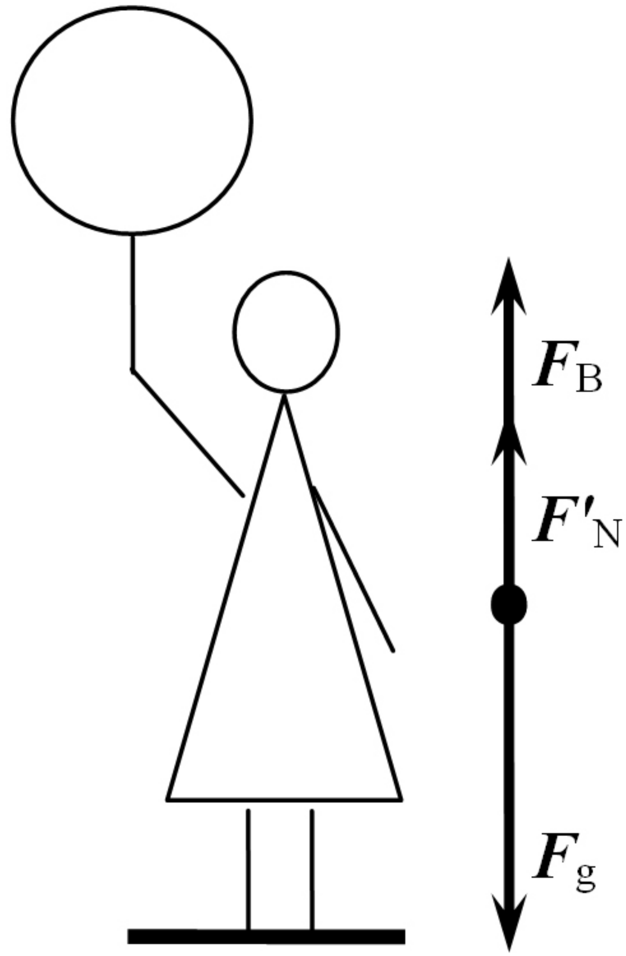

FIGURE 4. Sketch and a free-body diagram of a girl standing on a scale and holding a hellium balloon.

acting on the scale when the girl holds a balloon. This force is equal to the difference between the gravitational force and the buoyancy (see Fig. 4) and is balanced by a normal force

$$F'_N = F_g - F_B = 200 \text{ N},$$

so that the scale reads the modified, mass

$$m' = F'_N/g = 20 \text{ kg}.$$

To answer correctly to question 1.2, students should note that the result, although obtained using the correct physics, is unrealistic. It is not possible that after the girl took a balloon the scale shows the value that is as much as 10 kg less then before. Consequently, one should find out that the problem is not correctly set because the given value of 100 N for the buoyancy force of the kids' hellium baloon is not realistic. The balloon volume should be

$$V = F_B/(\rho_{\text{air}} \cdot g) \approx 10 \text{ m}^3, \tag{1}$$

which is obviously too much for a kids' balloon.

Since physical reasoning is based on a judgment of the significance of particular interactions, it is important to discuss why in the first case we neglect the buoyancy force and in the second case not. While solving the problem situation, one should keep in mind the buoyancy force is exerting not only on the balloon, but also on the girl giving an additional contribution to the upward force

$$\rho_{\text{air}} \cdot g \cdot V_{\text{girl}} = \rho_{\text{air}} \cdot g \cdot (m/\rho_{\text{girl}}) = F_g \cdot (\rho_{\text{air}}/\rho_{\text{girl}}).$$

Since the air density is about one thousand times less than the density of a human body, from the above expression it turns out that the buoyancy force is only about one thousandth that of the gravitational force and thus can be neglected.

Here, it is worth noting the importance of neglecting the irrelevant contribution in physics. We are seeking for the explanation of the main effect, the one responsible for the observed phenomenon. Other effects should be neglected and included in consideration only if we study the effects they produce.

In our case, the equilibrium of the scale is explained by considering the forces acting on the girl before and after she took the balloon. At first we neglect the air buoyancy on the human body, not measurable on a body scale. Even if we would have a highly accurate body scale, *e.g.* with 10 g res-

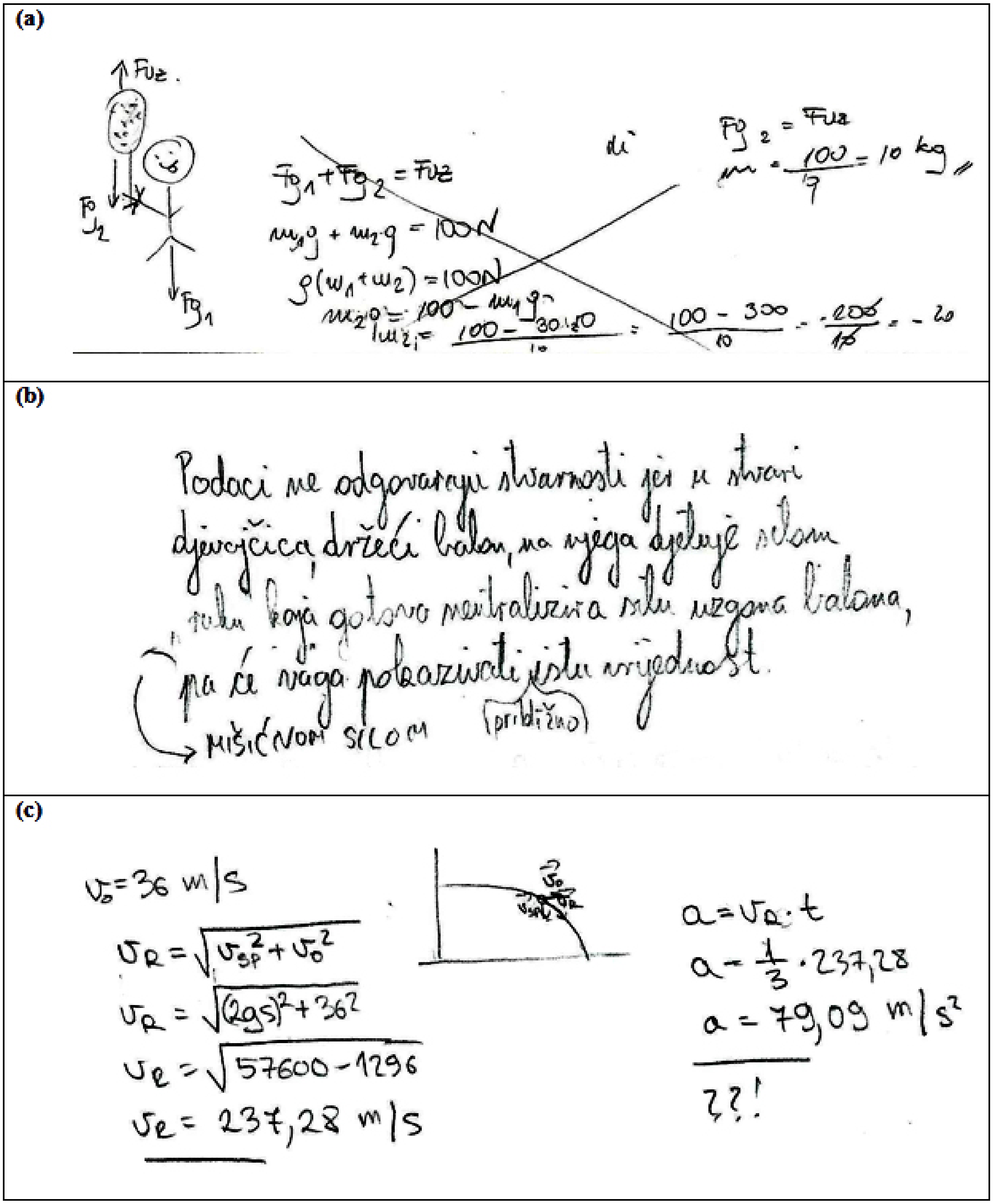

FIGURE 5. Scans of selected student solutions: **(a)** for question 1.1 **(b)** for question 1.2 and **(c)** for question 2.

olution, we would not be able to measure buoyancy because this would require removal of the air and use of the special space suit.

Now, a question arises why in the second part of the task we consider the effect of the buoyancy force on the balloon that is equally small or even smaller than the buoyancy force on the girl which we have neglected. The explanation is as follows. We first consider the main forces acting on the girl in equilibrium. After she takes a balloon, a new, changed equilibrium is set up. This change is what we are interested in the second part of the task. As the change is due to the appearance of the buoyancy force of the balloon it can be explained only if we take this force into account, although in reality being very small. So, initially we should neglect buoyancy, but not in the second part of the task, because buoyancy is the main phenomena we observe.

In task 2, the necessary data needed to calculate the acceleration of tennis ball, such as stopping time or stopping distance, are not given. Therefore, the correct answer should be that the ball stops at the net suddenly so that the deceleration is large, but there is not enough data to calculate its value.

3. Research and results

3.1. Investigation of students

The sample consisted of 72 Science Gymnasium (SG) students and Information-Technology Gymnasium (ITG) students and 139 General Gymnasium (GG) students from Rijeka and Zagreb, 24 Vocational School (VS) students from Rijeka, 41 Physics Teacher (PT) students from Rijeka and Zagreb Universities. The students were selected using the non-random convenience sampling technique [44]. They were at different learning levels but they all had already been taught about physical concepts needed to understand the given problems.

Note that gymnasium is a four-year secondary school in Croatia for students aged 15-19, similar to English grammar schools or U.S. high schools. Having a program that gives a general background, gymnasium is intended to prepare students for the university so that most of the students continue their education at universities. It is completed by a state level final exam called 'matura', which is an entrance qualification for further education. There are several types of specialized gymnasiums that differ with respect to the extent to which different subjects are taught at a higher level. In SG, the focus is on natural sciences and mathematics and in ITG more attention is paid to informatics and technical sciences. Unlike gymnasiums, the vocational schools are intended to prepare students for a certain job. They last for 3-5 years. Finally, the physics teacher students study the five-year university program at the faculty/department of science. They graduate with masters' degree in science education and gain a qualification for teaching elementary and high-school physics. Besides physics, they usually study an additional subject: mathematics, chemistry or information technology. Students were presented problems 1 and 2 in the form of the open-ended questions. This enabled them to express their thoughts and answers by their own words. The students' responses were classified into three different groups with respect to the answers to the three different questions and evaluated by assigning one of the three values: correct answer, incorrect answer and no response. The results of this analysis are shown in Table I.

Figure 6 shows the distribution of the answers to the questions from tasks 1 and 2 which is given in a form of column charts. The results are presented separately for each of the four different groups of students: SG&ITG, GG, VS, PT students. Each column corresponds to one of the questions listed in Table I. The numbers below the columns denote the corresponding question. Each column is divided into three shaded segments, whereby the heights of the segments are proportional to the percentage of the obtained correct answers, incorrect answers, and no responses respectively.

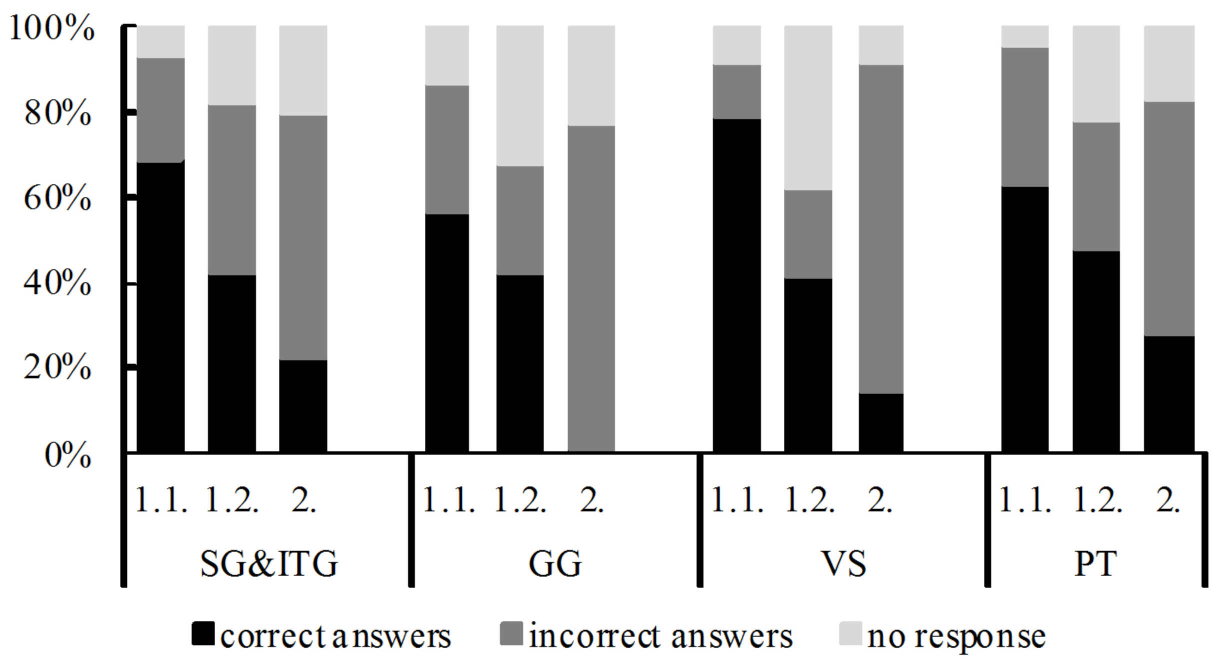

FIGURE 6. Distribution of the students' answers to the questions from the tasks 1 and 2 for science gymnasium and information-technology gymnasium (SG&ITG), general gymnasium (GG), vocational school (VS), and physics teacher (PT) students.

TABLE I. Classification and percentage distribution of the students' responses to problems 1 and 2.

Questions and responses	Percentages
1. Wishing to measure body mass, the girl stands on the scale and reads the value of 30 kg. If she takes a kids' helium balloon in hand (Fig. 1), the scale shows the lower value.	
1.1. What is the mass of the girl with a balloon that reads on the scale if buoyancy of the balloon is 100 N? ($g \approx 10$ m/s^2)	
Correct answer: m = 20kg	**62%**
Incorrect answers:	**28 %**
m = 10 kg (14%) (see Fig. 5a)	
m = 200 N (3.64 %)	
m = 27 kg (1.96 %)	
Other values. (8.4 %)	
No response	**10 %**
1.2. Are the data in the problem realistic? Why?	
Correct answer:	**43 %**
No. The given value for the buoyancy of a kids' balloon is too large. It cannot much affect the weight measured on the scale.	
Incorrect answers:	**29 %**
No. If the girl takes a balloon and stands on the scale, the scale will show the value equal to or greater the mass of the girl. (11.6 %) For example:	
-The girl should hold a balloon tightly, so that her muscles would be tensed and her mass increased.	
-No. While holding a balloon, the girl acts on it with a muscular force. This force almost balances the buoyancy force on the balloon, so that the scale will show approximately the same value (see Fig. 5b)	
Answers assessing the possibility for the given girl and balloon masses to appear in reality. (8.12 %) For example:	
-No, because the girl mass of 10 kg *is too small.*	
-No, because this would mean the balloon mass is 10 kg, *which is impossible.*	
Answers discussing g and containing erroneous mathematical expressions. (3.77 %) For example:	
-No, because we do not know where the girl is, and g is not constant equal to 10 m/s^2 *but varies with the geographic location.*	
-Yes, because $F_B = \rho_v gh$, *so that* h = 1 m	
Other answers. (5.51 %) For example:	
-Yes, because the buoyancy force is opposite to the gravitational force.	
-If so, the girl would slowly begin to levitate.	
-No, because the volumes of the bodies are not the same.	
No response	**28 %**
2. The physics teacher gave his students the following problem:	
"The tennis player serves a ball with the speed 36 m/s. A third of a second later, a poorly served ball stops suddenly at the net 12 m away. What is the stopping acceleration of the ball? (Air resistance is negligible.)"	
What would you answer to him?	
Correct answer:	**12 %**
The stopping acceleration is large, but there is not enough data to calculate the value	

Incorrect answers:	**68 %**
Incorrect numerical solutions with or without the calculation procedure.	
(51 %) For example:	
$a = \Delta v$ / Δt, $\Delta v = \Delta s$ / $\Delta t \Rightarrow a$ = 108 m/s^2 or (see Fig. 5c)	
The ball does not have the stopping acceleration (due to a sudden stop or the momentary cessation of the motion). (9.52 %)	
A tennis player served the ball poorly. (2.72 %)	
The stopping acceleration of the ball is equal to the acceleration of the ball during its movement towards the net. (2.04 %)	
Other answers. (2.72 %) For example:	
At the moment of stopping, or after the ball is stopped, the acceleration is equal to the gravitational force, if the ball mass is not negligible.	
No response	**20 %**

In order to investigate whether the correctness of students' responses to the ill-defined problems depends on their educational level, we decided to create and analyze three contingency tables. For each of these tables, we explored the relationship between the "Nature of response variable" and "Educational level" variable. The "Nature of response" variable consisted of two levels - "Correct response" and "Other" (this level has been obtained by collapsing the categories of incorrect responses and no-responses). Within the "Educational level" variable, we distinguished between "high-school students" and "university students". In order to determine whether two variables are independent of one another, we can use the chi-square test [45].

For task 1.1, the following contingency table has been obtained:

TABLE II. The contingency table for task 1.1.

	Nature of response		
Educational level	Correct	Other	Total
High-school	146	89	235
University	26	15	41
Total	172	104	

For purposes of calculating the chi-square test we used the SPSS 17.0 software. The results for task 1.1 showed no statistically significant association between the educational level of the students and whether or not a correct answer would be obtained. χ^2 (1) = 0.025, p = 0.875.

We also created a contingency table for task 1.2 (see Table III).

TABLE III. The contingency table for task 1.2.

	Nature of response		
Educational level	Correct	Other	Total
High-school	99	136	235
University	19	22	41
Total	118	158	

The results of the chi-square test for task 1.2, show that there is no statistically significant association between the educational level of the students and whether or not the wrong assumption within the problem statement is correctly identified, χ^2 (1) = 0.253, p = 0.615.

Finally, we created a contingency table for task 2 (see Table IV).

TABLE IV. The contingency table for task 2.

	Nature of response		
Educational level	Correct	Other	Total
High-school	21	214	235
University	11	30	41
Total	32	244	

By calculating the chi-square statistics for task 2, relatively small expected frequencies were obtained. In such occasions, it is recommended to calculate the Fisher's exact test [45]. The Fisher's exact test for Table IV turned out to be highly statistically significant (p = 0.003). This result indicates that there is a significant association between the educational level of the students and whether or not the deficiency of necessary data in the problem statement is recognized. This seems to represent the fact that, based on the odds-ratio, the odds of students correctly estimating the solvability of the problem is 3.74 times higher if they are university students than if they are high school students.

3.2. Investigation of teachers

In the second part of the study we used a closed-ended questionnaire to examine a group of 48 high-school physics teachers in the Split-Dalmatian County. The questionnaire was formed exclusively from the students' responses (see Table V). The teachers were asked to mark the answers, not what they think is correct, but what they think their students would most likely do.

TABLE V. Closed-ended questionnaire for teachers as formed for problems 1 and 2.

1) Wishing to measure body mass, the girl stands on the scale and reads the value of 30 kg. If she takes a kids' helium balloon in hand (Fig. 1), the scale shows the lower value.
1.1. What is the mass of the girl with a balloon that reads on the scale if buoyancy of the balloon is 100 N? ($g \approx 10$ m/s^2)
a) 10 kg **b)** 20kg **c)** 27 kg **d)** 200 N
1.2. Are the data in the problem realistic? Why?
a) No. If the girl takes a balloon and stands on the scale, the scale will show the value equal to or greater the mass of the girl.
b) The girl weight of 10 kg is not real at all.
c) No, because in this case a helium balloon should have the mass of 10 kg, which is impossible, because the helium is gas known with its extremely small mass.
d) No, because the buoyancy on kids' balloon is much smaller in reality and it can not much affect the mass shown on the scale.
2) The physics teacher gave his students the following problem: "The tennis player serves a ball (Fig. 2) with the speed 36 m/s. A third of a second later, a poorly served ball stops suddenly at the net 12 m away. What is the stopping acceleration of the ball? (Air resistance is negligible.)" What would you answer to him?
a) Acceleration doesn't exist, because the ball stops instantly.
b) a = - 108 m/s^2
c) There is not enough data to calculate the acceleration.
d) The ball has only the acceleration of the gravitiy g.

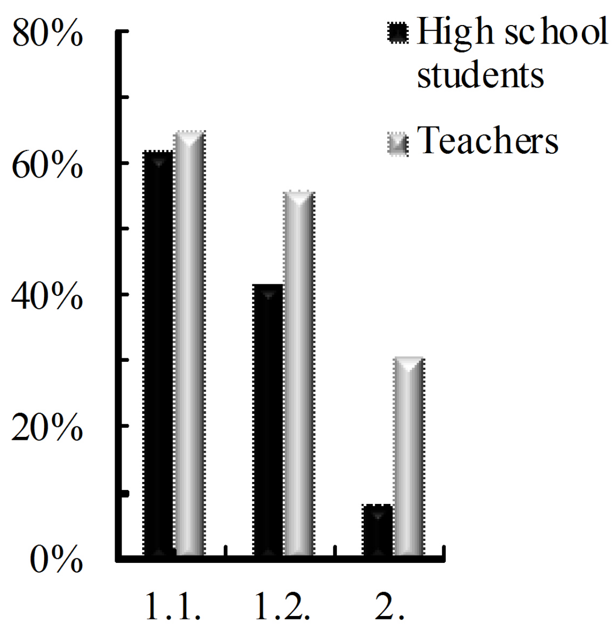

FIGURE 7. Percentages of the expected correct students' answers given by the teachers, and the actual correct students' answers.

The teachers' predictions are shown in Fig. 7, together with the actual percentage of correct students' answers to the questions in problems 1 and 2, for purposes of comparison.

4. Discussion

Most of the respondents (62%) solved the first part of problem 1 (question 1.1) correctly. They accurately calculated the weight of the girl with the helium balloon, although the given buoyancy force was unrealistic (Table I). A relatively small percentage of respondents in each group did not respond. The lowest percentage of 5% refers to the PT students, and the largest percentage of 13% to the GG students. This suggests that the respondents are used to solve similar traditional tasks. The highest percentage of correct answers (79%) and the lowest percentage of incorrect answers (13%) were found for VS students (Fig. 6). This result suggests the VS students are more adept at implementing appropriate procedures or algorithms than others, regardless of their lower educational level as compared to the PT students or less demanding physics curriculum in relation to the gymnasium students. Generally, according to Fig 6, it seems that the extent of exposure to traditional teaching affects neither the development of conceptual understanding nor the development of mathematical skills needed to solve physical problems. This conclusion is supported by the non-significance of the chi-square test for task 1.1.

The question 1.2, required students to reflect on the realism of the given and obtained data. In other words, it was aimed to encourage students' critical attitude towards the problem statement and the corresponding solution. Less than half of the respondents (43%) answered correctly that the given value for the buoyancy is not realistic, because it is too large for a kids' balloon. The percentage of the correct answers is almost the same for all the groups (48% for PT students and 42% for others). The lowest percentage of incorrect answers (21%) and the highest percentage of no-responses (38%) were found for VS students. This reflects the concreteness in their problem approach: they either know or do not know the answer. Alternative explanations could be that they hesitate to provide an answer if they are not confident in its level of accuracy or they favor creating/choosing simple over complex explanatory models (instead of trying to build a complex explanatory model they choose not to respond). They have a better sense for the reality of the situation and for the order of the magnitude of physical quantities than gymnasium students, because their evaluation is mostly based on the practical experience. Irregular percentage distribution of the incorrect answers and no-responses, across other groups, indicate that educational level and curriculum have no significant influence on the development of skills needed for solving nontraditional problems. This conclusion is consistent with the fact that the chi-square test for task 1.2 proved to be non-significant. Generally, the low level of correct responses to task 1.2 across different educational levels could be explained by students' insufficient ability for estimating the order of magnitude for different effects which are included in the phenomenon of interest.

A small percentage of correct responses for the task 2, indicates that the students generally have not developed critical attitude towards the solvability of the problem. They did not notice that some data, needed to calculate the stopping acceleration of the ball, are missing. Even 51% of students obtained incorrect numerical solutions just by putting the given data into the formula without understanding. In fact, they approached the problem as if the ball were experiencing uniform motion and uniformly accelerated motion, at the same time. The PT students had somewhat better results than others with the most correct (28%) and the least incorrect (55%) responses. A relatively small overall percentage (20%) of no-responses probably means that the respondents considered this problem as a traditional one, where a critical review of given data is not requested. This especially applies for VS students who stand out with the lowest percentage of no-responses (8%). Results of the chi-square test for task 2 strongly indicate that the educational level influences students' ability to recognize the solvability of the problem

As seen from the graph in Fig. 7 the teachers overestimate students' abilities to apply mathematics and physics in question 1.1 as well as students' critical attitudes towards the problem statement in question 1.2 and the solvability of the problem in question 2. The lowest percentage difference between the expected and actual correct answers is found for question 1.1, and the largest difference for question 2.

Since the physical description of an observed phenomenon is based on a judgment on the significance of particular effects, we consider the importance of the approximation, as a possibility and a way to neglect irrelevant effects and to consider only the relevant ones.

We think these types of non-traditional problems have a potential to improve physics teaching through a discussion which develops students' critical attitude towards the setup and solvability of problems. Besides, by discovering students' thinking and problem solving strategies, teachers have a better opportunity to adapt their teaching strategies to students' needs. Students and teachers should realize that a proper implementation of physics does not mean only solving physical equations, but also a correct description of nature. If the result is not realistic, the source of the senselessness should be identified. This process is similar to the process carried out in the scientific research where the physical principles and assumptions are reviewed if the theoretical calculations don't match the measured data.

5. Conclusion

We investigated students' critical attitudes towards the statement of physics problems and meaningfulness of the problem solution. The heterogeneous sample consisted of 276 high school and university students from Rijeka and Zagreb and 48 Physics Teachers of Dalmatia, all from Croatia. The students, although being at the different learning levels, were all familiar with the physical concepts concerned. They were presented the two open-ended ill-defined problems that required, respectively: (i) to identify an incorrect assumption, and (ii) to find out that the unnecessary data is given and the data needed to solve the problem is missing. The teachers' ability to predict students' criticism was investigated with help of the closed-ended questionnaire that was composed of the students' responses.

Our results show that the students' critical thinking is not sufficiently developed. As much as 57% of the students either came to an incorrect conclusion regarding the meaningfulness of the problem 1 or did not consider its meaningfulness at all. Further, even 88% believed that the problem 2 was solvable. These results are more or less common to all the groups of the respondents, so that we conclude that the critical thinking skills are low across all educational levels and curricula. The statistically significant relationship between educational level and the skill for recognizing problems' solvability merely means that the corresponding skills are low for PS students, but they are even lower for high-school students. After all, it seems that traditional teaching does not develop sufficiently the abilities to think critically. Comparing the answers that the teachers expect from their students with the actual students' answers, we found that teachers correctly judge students' ability to consider the realism of the result but they significantly overestimate their criticism regarding the problem statement. We also discussed the importance of approximation as a part of critical thinking.

Finally, we think this kind of problems could improve physics teaching with respect to the goal of developing students' real-life competencies. This could improve teachers' awareness of the importance of critical thinking and emphasize the importance of developing students' habits to take a critical attitude towards the statement of the problem and meaningfulness of the solution they obtain.

One of the limitations of this study is reflected in the fact that students' answers on a low number of problems were used as a basis for concluding about the character of students' critical thinking processes. However, the results of this study could be a useful starting point for further studies of students' problem solving behavior. Thereby, it would be especially interesting to design an experiment with the purpose of investigating the effect of teaching with ill-defined problems over a long period of time, on developing the habit of taking a critical attitude toward given problem statements and solutions.

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i. For comparison, the corresponding traditional problems would read: 1. Wanting to measure its mass, the girl is standing on the scale that shows the value of 30 kg. What value the scale will show, if the girl takes kids' helium-filled balloon whith the volume of 3 dm^3? 2. Tennis ball hits the net with the speed of 36 m/s. What is the stopping acceleration of the ball, if the stopping distance is 3 dm?

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