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ARTICLE

Using photographs to elicit student ideas about physics: The case of an unusual liquid-level phenomenon

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Abstract: This work is aimed at exploring some pedagogical opportunities of using photographs in physics instruction. In our study, the photography has been used for eliciting and probing students' ideas regarding the physics of fluids in noninertial frames of reference and under conditions of equilibrium. The study involved a heterogeneous sample of 235 secondary school students, 41 physics students, and 48 physics teachers. They were presented with a photograph of a wine glass filled with liquid whose surface appeared inclined. The students were asked to comment on the reality of the phenomenon captured in the photograph, and the teachers were asked to predict the students' responses. The results showed that about half of the students had a complete or partially complete understanding of the physical ideas and that their practical and conceptual knowledge was not dependent on their education level or curriculum followed. Most of the respondents found the task interesting and relevant. The results indicate that the teachers' expectations regarding students' understanding of physics often significantly depart from reality. We suggest that physics teachers include some photography-based problems and discussions in their classes. This could encourage a broad participation of students with different levels of abilities.

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Résumé : Ce travail vise à explorer les méthodes d'enseignement en physique basé sur la photographie. Nous avons étudié, à l'aide la photographie, la compréhension de la physique des fluides dans des cadres non inertiels de référence et dans des conditions de équilibre. L'étude a porté sur un échantillon hétérogène de 235 lycéens, 41 étudiants en physique et 48 en physique enseignants. Ils ont été présentés avec une photo d'un verre de vin rempli de liquide dont la surface est apparu incliné. Les étudiants ont été invités à se prononcer sur la réalité du phénomène capturé dans la photographie. À l'aide de d'une questionnaire les enseignants ont été invités à prévoir les réponses des élèves. Les résultats ont montré que près de la moitié des étudiants a eu un compléter ou partiellement compréhension complète des idées physiques et que leurs connaissances pratiques et théoriques était ne dépend pas de leur niveau d'éducation ou de programme d'études. La plupart des répondants ont trouvé la tâche intéressante et pertinente. Les résultats indiquent que les enseignants les attentes en ce qui concerne les étudiants la compréhension de la physique souvent de manière significative s'écarter de la réalité. Nous suggérons que les professeurs de physique comprennent certains problèmes et discussions photographie à base de leur programme d'études. Cela pourrait encourager la participation des étudiants qui ont peu de connaissance ou des connaissances relatives physique.

1. Introduction

Since its invention by Daguerre in 1839, photography, as an objective technique of observation, has played an increasingly important role in scientific research. Photography can capture data invisible to the naked eye, or "slow down" events that are too fast to observe. Muybridge's photographs of horses in motion from 1878 solved the long-standing dispute whether all four horse legs are ever off the ground at the same time and Salcher in 1886 captured the image of a bullet flying at supersonic speed [1]. In the 20th century X-ray photography has led to the discovery of the structure of DNA, and charge-coupled device cameras have enabled the capture of images of remote galaxies. Modern scientific techniques, such as functional magnetic resonance imaging and atomic force microscopy, use visual representations that are also based on photography.

We live in the age of visual culture: observation and interpretation of different visual forms are now a part of our everyday life, but when it comes to using photography in physics teaching, we are still in the primary stages [2]. More than two decades ago Mayer and Gallini [3] raised this issue, and Logan and Higinbotham [4] proposed formal teaching of scientific imaging techniques because of the numerous applications of photography in research and industry. Very little has changed since then; teaching physics has remained rather conservative with almost no use being made of modern advances in visualization techniques.

We have observed, however, that for the acquisition and understanding of physical concepts, nonverbal, mainly visual, cognition is of equal importance to verbal cognition [5]. In addition, interpreting a photograph is seen as a critical adjunct to supporting the development of the discipline, which in turn enhances students' motivation and performance in general [6]. Watson and Lom [7] believe the evaluative and creative levels of reasoning that students gain by developing skills in visual communication will help them communicate and evaluate claims more effectively in both academic and nonacademic aspects of their lives.

Photography has not been given enough attention in teaching physics, particularly in terms of visual cognition [8, 9]. This is why we were motivated to involve photography in our research of nontraditional problems. Nontraditional problems [10–14] are characterized by a freedom of parameters, multiple options for a solution and various criteria for their evaluation. For the research

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task, we chose the problem of an inclined water surface, closely related to, but not in accord with, our everyday experience.

Generally, the goal of this paper was to develop and explore nontraditional problems based on photography for better conceptual teaching of physics. This study addressed the following research questions:

(1) Which ideas can be elicited in students by confronting them with the given photography-based problem?
(2) What is the students' attitude towards photography-based problems?
(3) Are physics teacher students more successful when it comes to solving the given physics problem than secondary school students?
(4) How well can teachers predict students' answers to the given problem?

The answers to these questions could provide us with feedback regarding students' ability to relate real-life situations to abstract physical concepts. Further, we could gain some insight into students' attitudes towards nontraditional problems and the information regarding teacher competences could additionally improve the process of designing a more effective system of initial education of prospective physics teachers.

2. Review of relevant literature

There have been many studies about the use of visual representations in science education, in general. For example, Kohl et al. [15] examined students' performance in physics problems presented in different representational formats. They found that multiple representation use is important in successful problem solving and can be taught successfully. Rosengrant et al. [16] also provided insights concerning the importance of multiple representations in student learning, thinking, and problem solving. However, there is a lack of studies that have focused on the use of photographs in science teaching and learning. Neither the research of cognition and learning within psychology [8] nor the studies in science education [9] have brought enough attention to this issue. The pedagogical role of the use of photographs in science classes is still in need of investigation [17].

Photography depicts real-life situations, which is why it differs from drawings and illustrations that only stylize and emphasize the essential information. To discuss physical concepts, students have to distinguish between important and unimportant information in the photograph. On a scale of visual complexity, this spans from the most-abstract-least-detailed to the least-abstract-most-detailed. Photography belongs to the latter [9]. Therefore, learning from photos may create greater difficulties than learning from simplified diagrams [18]. Pozzer-Ardenghi and Roth [19] found that a way out of this problem could be to pay attention to textual explanations, for example, the title or the main text, as well as to the characteristics of the photograph itself (e.g., the appearance of the background and frame). In this way, students are assisted and directed towards the expected interpretation.

Photography may be used in different ways. For example, a photograph of a bicycle wheel in motion showed that the velocity of the rolling wheel at the contact point with the ground is zero [20]. Foong and Lim [21] showed that on the basis of a photograph alone it is possible to correctly estimate the density of a watermelon floating in a pail of water. Eshach [2] asked students to express themselves, both visually and verbally, using their own photographs, which, in their opinion, best described the physical concept of Newton's third law. In this way, he probed their physical understanding of the outside world, and revealed their preconceptions. To encourage discussion in class, Corni [22] proposed the use of unusual images, such as photos with projections of the Sun eclipse on children's bodies in the shade of leafy trees. Bagno et al. [23] believe that photo contests are a good opportunity for active learning in physics. Within these contests students are required to choose independently a phenomenon they find interesting, explain it by using physical concepts and principles, present it to their classmates and finally submit it for evaluation. Lee and Feldman [17] believe that photographs may be a good material for classroom discussion, encouraging students to engage in discussion and providing the opportunity for them to bring their daily experiences to the class. Stamovlasis [24] proposes photography as an interdisciplinary theme that involves chemistry, physics, technology, and art and gives an outline of relations and patterns that connect these fields.

These methods emphasize visual perception. The students also need to play an active role in describing physical situations visually by drawings and diagrams, regardless of whether they work independently by answering questions on a written test, or with the help of the examiner in an individual interview [13, 14].

Liquid-level problems have a long history. In his famous bucket experiment, as described in *Principia*, Newton traced the concavity of the surface of the water in a bucket, as the bucket was set in rotation. He found that the effect is not correlated with relative rotation of the water and bucket. It is correlated only with the rotation of the water, and thus absolute and relative rotation could be distinguished [25]. Liquid-level problems have intrigued not only physicists but also psychologists. Their studies showed that the relationship between experience in the real world and the conceptual representation of that world is not simple [26].

Finally, we could identify only a few studies related to the teachers' competences to estimate their students' abilities. One of rare instances of such research was conducted by Lightman and Sadler [27] who investigated how well teachers can predict the percentage of students expected to get correct answers to the test questions. On the other side, Viiri [28] collected students' answers by means of a questionnaire, presented the same questionnaire to teachers and asked them to record their expectations of students' answers. The study by Mayon and Knutton [29] showed that very few teachers were able to link the natural science contents being lectured to students' everyday life experiences.

3. Methods and research

3.1. Sample

A total of 324 respondents were involved in the study. The nonrandom convenience sampling technique [30] was used. The sample included 72 science gymnasium (SG) students and information technology gymnasium (ITG) students from Rijeka and Zagreb (Croatia), 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, and 48 secondary school physics teachers from Split-Dalmatian County. The teacher sample included all the teachers who participated at the Split-Dalmatian County physics teachers meeting. Respondents' participation in the study was voluntary.

Note that a gymnasium is a type of school providing secondary education in some parts of Europe that is comparable to English grammar schools or U.S. high schools. The subjects taught are mathematics, the natural sciences, the native language, one to three foreign languages (including Latin), geography, information technology, history, history of art, music, philosophy, and logic. Gymnasiums differ regarding the level at which some subjects are taught. For example, special attention is devoted to natural sciences and mathematics in SG and information technology in ITG. The VS prepares students for a particular job.

Here it is worth noting that compulsory education in Croatia lasts for eight years, while secondary education is still optional. Secondary schools are of different types but the basic division is between gymnasiums, which are intended to prepare students for further education and vocational schools (lasting 3–5 years), which offer professional qualifications. The admittance criteria

Fig. 1. A red wine glass filled with a liquid.

are based on the students' primary school results. Gymnasium last for four years and end with the "matura" examination, a state school leaving examination, which is an entrance qualification for further education. Students who attend vocational schools are also allowed to take the matura examination to continue their education.

Physics teacher students study a five-year university program at the faculty of science. They graduate with a masters' degree in science education and are fully qualified to teach elementary and secondary school physics and the other subject they studied, which is usually mathematics, chemistry, or information technology (two-subject course of studies). This does not exclude the possibility of employment in all sectors of modern society that require experts in science and technology.

3.2. Students' task

The students were given an unusual photograph (Fig. 1) of a red wine glass filled with a liquid whose surface was inclined, and were asked to explain whether the situation depicted is possible. They were also asked to express their opinion and impressions about this kind of task. The investigation of students' ideas was carried out by using the problem in open-ended question form [30] to give students a high degree of freedom in expressing their ideas.

Students were presented the following task:

Fig. 1 shows a wine-glass filled with liquid. Please answer the following questions:

- Is it possible that liquid in a glass takes shape as in Fig. 1? Please explain your answer.
- Please comment what you think about this type of physics problem?

They were given up to 15 min to complete their response.

Having in mind that the meaning of a photograph comes also from the relationship between the photographer's view and the perception of the observer [19], we could expect various interpretations of the problem but regardless of that, we expected to gain some insight into students' possibilities of discovering and understanding of the underlying physics.

Students involved in the study were at different educational levels but all of them were supposed to be familiar with the physical concepts needed to solve the problem. The teaching lessons on the behavior of fluids in noninertial systems and the conditions for equilibrium were included in their educational programs. Thereby, the high school students were taught the relevant concepts only within corresponding thematic units in the first grade of high school. On the other side, the university students dealt repeatedly with these topics on a deeper level, in multiple thematic contexts.

The photograph was created as follows. A wine glass with a liquid was attached to a panel using transparent glue. The panel was then tilted with respect to the horizontal surface, at a steep-enough angle so that the glass would have turned over if it had not been glued. This is because the vertical projection of the center of gravity, *CG*, lies outside of the base of support (i.e., beyond the end point *O* of the glass foot; Fig. 2*a*). The camera was tilted to the same angle to remain parallel to the panel.

The examinees were not told how the photograph had actually been taken. Therefore, they could have assumed any physical setup. From our everyday experience, we know that the free surface of a liquid tends to become horizontal. This can be explained in a simple way. Suppose that surface of a liquid is inclined. Under the action of gravity, molecules at the surface will move down the incline until they are placed on the equilibrium position at which the net force is zero. Consider the forces exerting the small liquid volume element ΔV of mass Δm at the surface (Fig. 3). Because of gravity, the weight $\Delta m\boldsymbol{g}$ pulls downwards, and can be balanced only by the upward repulsive reaction, $\boldsymbol{F}_N$, of the molecules beneath the surface. This force is always perpendicular to the surface and is directed upwards only if the surface is horizontal. This is why the equilibrium surface of a liquid in a gravitational field must be horizontal. The students should come up with the conclusion that if the equilibrium surface of the liquid is inclined as in Fig. 2*b*, there should be an additional (inertial) force $-\Delta m\boldsymbol{a}$. As the net force on the volume element ΔV is zero the liquid lies perpendicular to the direction of the vector sum of the weight and the inertial force $\Delta m\boldsymbol{g}' = \Delta m\boldsymbol{g} - \Delta m\boldsymbol{a}$, which must be in equilibrium with $\boldsymbol{F}_N$.

So a realistic assumption was that the glass is inside a noninertial frame of reference, e.g., in a car that uniformly accelerates to the left with acceleration a (Fig. 2*b*). From the figure we can conclude that the mass of the liquid is significantly greater than the mass of the glass. Therefore, we estimate that the center of gravity of the whole object of mass m would be near the center of gravity, *CG*, of the liquid. If we take a closer look at the photo, and draw the force vectors (the weight, $m\boldsymbol{g}$, the inertial force, $-m\boldsymbol{a}$, and the apparent weight, $m\boldsymbol{g}'$) starting from the center of gravity, *CG*, we see that the amount of acceleration is approximately one half the free-fall acceleration $a = g/2 = 5$ m/s². Such acceleration is easily reached when we brake while driving a car, for example. In that case, the situation would also be possible only if the glass is attached to the panel. Otherwise, the glass would turn over, because the apparent weight line passes beyond the endpoint *O* of the foot of the glass.

3.3. Teachers' predictions

The sample used to investigate the teachers' predictions included 48 secondary school physics teachers who were attending the Split-Dalmatian County physics teachers' meeting. They were presented with the problem and they were asked to answer the closed-ended questionnaire [30] that was composed using the answers given by the students. The questionnaire (see Table 1) included most of the students' ideas. The teachers were asked not to

Fig. 2. (Color online.) The forces acting in the frame of reference of a wine glass that could make the surface of a liquid inclined: (*a*) the effect of gravity if the glass is tilted; (*b*) the effect of gravity and inertial force if the glass is uniformly accelerated.

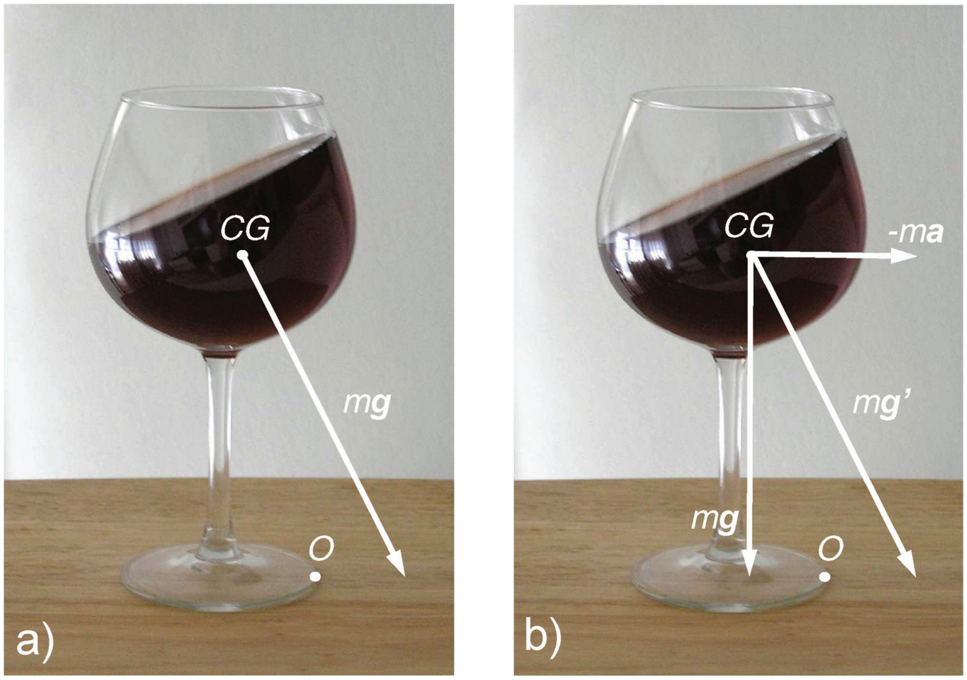
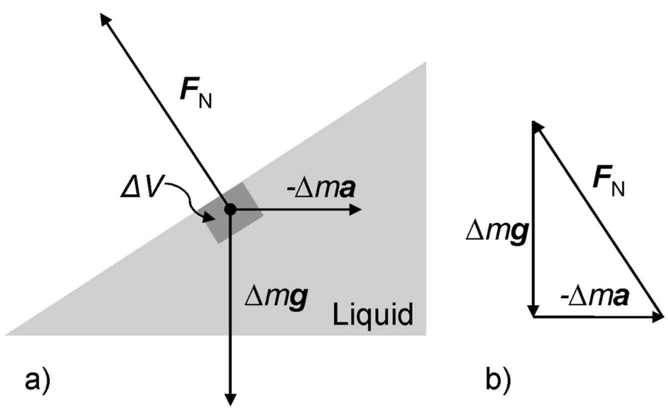


Fig. 3. (*a*) The forces exerting the volume element ΔV at the surface of a uniformly accelerated liquid in the frame of reference of a liquid. (*b*) The liquid is in equilibrium so that the vector sum of the forces (the net force) is zero.



answer what they think is correct, but what they think their students would most likely answer.

3.4. Procedures

The research question 1 required us to explore the nature of student ideas elicited by the given photography-based problem. For purposes of answering this research question, all the students' responses were classified into the following four categories depending on the correctness and comprehensiveness of the solution: complete physical ideas, partially complete ideas, alternative ideas, and no answer. A finite number of typical answers was found for each of the categories. The classification was carried out by the subjective assessment of the examiner, based on many years of teaching experience. The teachers' answers were classified in the same way, to facilitate comparison. In the case that the respondent offered more than one solution, each part of the answer was categorized with the corresponding relative weight factor. For example, the answer: *The situation is possible if the glass is glued to the surface and then tilted, or if the liquid has a structure of a gel*; was classified as one half complete idea and one half alternative idea.

For purposes of exploring the students' attitude towards photography-based problems, the students' answers to the second question from the student survey had to be classified into three categories: positive opinion, negative opinion, and no answer. Thereafter, we calculated a 95% confidence interval for the proportion of students who exhibited positive attitudes towards photograph-based problems. Within the context of research question 2, we also tried to quantify the extent to which photograph-based problems encourage the students to express their own ideas. In our opinion, the ratio of alternative ideas to non-responses could be a useful measure for that purpose. The research question 3 required us to explore how educational level affects the students' ability to solve the given problem. Concretely, we aimed to compare secondary school and physics teacher students with respect to the rate of complete physical ideas. For this purpose we created Table 2, and calculated the Fischer's exact test [31], whereby the statistical analysis was performed using PASW statistics 18. Fisher's exact test can be used to assess the association between two two-level variables. Usually, it is used as an alternative to the chi-square statistics in the case when the frequency of expected counts in some cells of the 2 × 2 contingency table is very low [31]. The rows in our contingency table (see Table 2) are represented by the variable "educational level". This variable has two levels that differentiate between secondary school (level 1) and physics teacher students (level 2). On the other side, the columns of our contingency table are represented by the "nature of response" variable, whereby the two levels of this variable differentiate between complete physical ideas (level 1) and other answers (level 2).

Our null-hypothesis was of the following form: The "nature of the response" variable and the "educational level" variable are not

Table 1. The closed-ended questionnaire based on the students' ideas as prepared for the investigation of teachers' expectations.

Figure 1 shows a wine-glass filled with liquid. Below is the questionnaire based on the students' ideas. Please indicate what you think most of your students would answer. Please mark the TRUE or the FALSE checkbox for each answer.	TRUE	FALSE
The liquid in the glass may take the shape as shown in the picture if:		
1. the glass was shaken and put on the table,	☐	☐
2. a hair dryer is blowing at it,	☐	☐
3. the glass is filled with liquids of different density,	☐	☐
or if:		
4. the panel is inclined,	☐	☐
5. the panel is uniformly accelerated along a straight line,	☐	☐
6. the panel rotates uniformly with the glass being far away from the axis of rotation,	☐	☐
where:		
7. it's not necessary to attach the glass. It is enough to choose a surface with a high coefficient of friction so that the glass does not slip.	☐	☐
8. the glass must be attached to the panel.	☐	☐
9. It's not possible in the real world. This is a photomontage.	☐	☐
10. It's not possible because the liquid always takes a shape of the vessel.	☐	☐

Table 2. Exploring the association between educational level and the ability to solve the problem.

Educational level	Complete physical ideas	Other ideas	Total
Secondary school	18	217	235
Physics teacher students	6	35	41
Total	24	252	276

associated with each other when it comes to the photograph-based problem.

Finally, the research question 4 required us to estimate the extent to which teachers were able to predict students' answers to the given problem. To this end, we decided to compare the expected distribution of student answers to the observed distribution of student answers, whereby the expected distribution was derived from the results of the teacher survey. To accomplish this task, the goodness of fit chi-square statistics [31] has been calculated. The necessary calculations were performed by means of the PASW statistics 18 software. Within the "Chi square" dialog, we deselected the "All categories equal" option and put in the expected proportions of complete ideas, partially complete ideas, and alternative ideas. Students who did not provide answers at all were excluded from the analysis.

The goal of our analysis regarding research question 4, was to assess the null-hypothesis according to which the expected distribution of student answers is the same as the observed distribution.

4. Results

Our investigation showed that 8.7% of the students' answers could be classified as complete physical ideas, i.e., their answers were entirely correct. Among the answers there were 8.2% of those that described a static situation as shown in Fig. 2*a*. Example of a correct answer is: *It is possible if the glass is attached to the panel and panel is tilted*. The remaining 0.5% students described the dynamic situations as seen in Fig. 2*b*. For example: *It is possible if the glass is attached to the panel and uniformly accelerated along a straight line*.

Forty one percent (40.7%) of the students' answers fall into the category of partially complete physical ideas. Those were the answers that lacked the consideration of stable equilibrium, or answers that the situation is not possible due to inability to consider other ideas. Some examples of such answers are: *It is possible if the panel and the camera are inclined* (Fig. 4*a*). *It is possible if the glass is uniformly accelerated along a straight line* (Fig. 4*b*). *It is possible if the panel rotates uniformly and the glass is far from the axis of rotation* (Fig. 4*c*). *The liquid could be so viscous that it keeps its shape for a long time, after the tilted glass is put back to the upright position* (Fig. 4*d*).

Thirty five percent (35.1%) of the students' answers were categorized as alternative ideas. These answers are mainly based on a fantasy inspired by high technology. Here are the two examples: *It is possible if the liquid has properties of a gel* (Fig. 5*a*). *It is possible if the liquid contains iron (ferrofluid) and we put a strong magnet on the right side of the glass* (Fig. 5*b*).

Regarding the first example it should be noted that, although being made mostly from liquid, due to the cross-linked solid network that spans the entire volume of gels they behave like solids, which makes them fundamentally different from liquids. Therefore, it follows that the given photograph could have been made by using a gel, but it is certainly improper to state that "the liquid has properties of a gel". With regard to the second example, it is important to state that ferrofluids are colloidal liquids consisting of ferromagnetic nano-particles suspended in a carrier fluid. They are strongly attracted by a magnet, but in a magnetic field, rather than being flat, their surface follows a pattern of regular peaks and valleys. This rules out the interpretations of the photo representing a ferrofluid placed close to a magnet.

Generally, the answers characterized by alternative ideas and their corresponding percentages are shown in Table 3.

Finally, the lowest share of answers (15.4%) was associated with the category "no answer".

When it comes to the research question 2, it has been shown that a relatively large majority of secondary school students (95% CI [61%, 73%]) exhibits positive attitudes towards photograph-based problems. In most of the student answers that were categorized as "positive attitude", the students judged photography-based problems to be more interesting, more appropriate, and (or) more realistic in comparison to traditional problems. Similar results (95% CI [57%, 85%]) have been obtained for physics teacher students. Taking into account that both confidence intervals include only values above 50%, it follows that a statistically significant majority of high school and university students take a positive attitude towards photography-based problems. Generally, the results regarding the character of students' attitudes towards photography-based problems are shown in Fig. 6. In relation to research question 2, it should be further emphasized that the observed ratio of nonresponses to alternative ideas was 1 : 2.29. This ratio is very similar in the samples of secondary school and physics teacher students.

Fig. 4. Sketches of the (partially) complete students' ideas that explain the inclination of the surface of the liquid in the glass on the panel: (*a*) the panel is tilted; (*b*) the panel is uniformly accelerated; (*c*) the panel rotates uniformly; and (*d*) due to its large viscosity the liquid keeps the given shape for a long time.

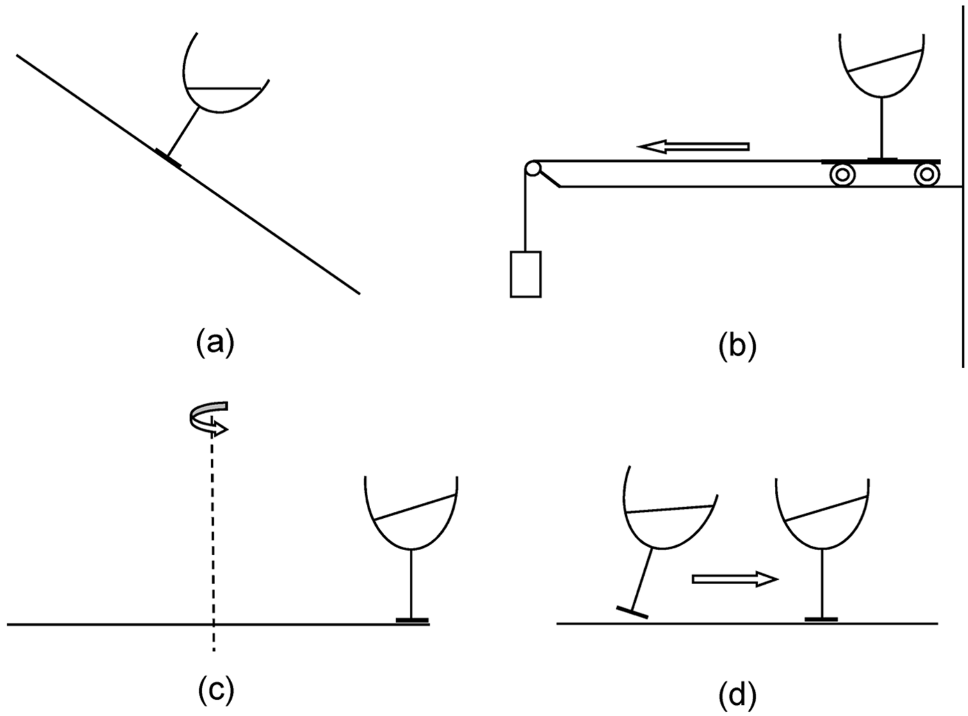
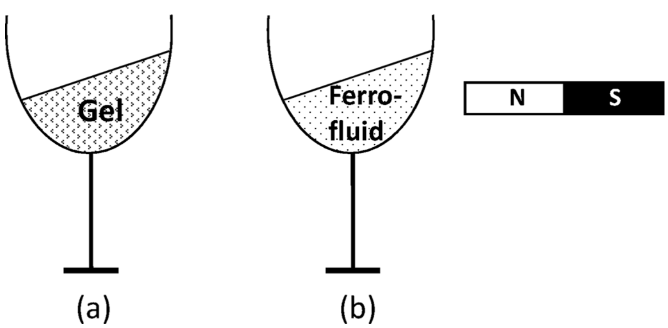


Fig. 5. Sketches of some students' alternative ideas: (*a*) the liquid has properties of a gel; and (*b*) the liquid is ferrofluid attracted by a strong magnet.



For purposes of comparing the association of educational level with students' ability to solve the given photograph-based problem (research question 3), we created a contingency table (see Table 2) and calculated the corresponding Fischer's statistics. The Fisher's exact test was nonsignificant ($p = 0.142$). Thus we had to retain our null-hypothesis according to which there is no association between student's educational level and the ability to provide complete physical ideas within the context of the photography-based problem. Additional information, regarding the relationship between students' answering behavior and their educational level and (or) curriculum exposure, can be obtained from Fig. 7.

Finally, for purposes of answering research question 4, we had to compare the expected and observed distributions of student answers (see Fig. 8). Taking into account the expected proportions across the several response categories (0.22, complete ideas; 0.26, partially complete ideas; and 0.52, alternative ideas), we created a contingency table (see Table 4) and calculated the corresponding chi-square statistics.

The results of the goodness of fit chi-square analysis show that the observed distribution of students' answers across different response categories significantly departs from the expected distribution ($\chi^2(2) = 50.96$, $p < 0.001$).

5. Discussion

As we know, the goal of physics is to give a unique explanation of natural phenomena. To achieve that, different observation techniques are needed and photography is just one of them. Photography emerges as a projection of an event from a four-dimensional space-time to a two-dimensional plane, where a significant amount of information is lost. For this reason, photography is not an unambiguous record of reality. It presents a number of possible events. With the help of physical laws and concepts this ambiguity can be reduced to a minimum of possible events, i.e., possible physical solutions. The low proportion of students who exhibited complete physical ideas when faced with the photograph-based problem suggests that the process of discovering possible and rejecting impossible events is demanding for most students across different educational levels.

Taking into account the relatively low ratio of nonresponses to alternative ideas, it seems that the given problem provides an opportunity for broad student participation, despite its high difficulty level.

The results of Fischer's exact test showed that the students' educational level was not significantly associated with the ability to provide complete physical ideas when it comes to the given physics problem. It is worth noting that the highest percentage of complete physical ideas was found among VS students who also gave the most "no answer" responses. They either know or do not know the answer, which reflects concreteness in their approach to the problem. It seems that vocational education, aimed at teaching procedural knowledge, unlike declarative knowledge, is

Table 3. The answers of different groups of students are grouped into the four main categories and the corresponding percentages are listed. The most frequent answers with the overall percentage for each category are listed too.

Group of students	SG, ITG (*N* = 72)	GG (*N* = 139)	VS (*N* = 24)	PT (*N* = 41)	Overall (*N* = 276)
Answer category					
Complete physical ideas	7.6%	6.2%	16.7%	14.6%	8.7%
It is possible if the glass is attached to the panel and tilted.					8.2%
Partially complete ideas	41.9%	40.8%	25.0%	47.6%	40.7%
It is possible if the glass is tilted.					16.4%
It is not possible because the surface of the liquid lies perpendicularly to gravity.					12.7%
It is possible if the glass accelerates.					5.3%
It is possible if the glass swings.					2.9%
It is possible if the glass is in a circular motion.					1.7%
It is not possible unless the glass is attached, otherwise it would turn over.					1.2%
Alternative ideas	35.9%	37.9%	33.3%	25.6%	35.2%
It is possible if the glass is moved, or swung and put on the table.					8.8%
Answers where the possibility of the situation is related to the action or lack of action of corresponding force or some other external influences.					7.7%
It is possible if the liquid in the glass is shaked, mixed or similar.					7.0%
It is not possible because the liquid takes the shape of the vessel.					5.9%
Answers where the possibility of the situation is related to aggregation state, or other physical properties of a liquid.					4.9%
No answer	14.6%	15.1%	25.0%	12.2%	15.4%

Fig. 6. Relative fractions of the students' opinions on the given task for different secondary schools and university: science gymnasium and information technology gymnasium (SG, ITG; *N* = 72), general gymnasium (GG; *N* = 139), vocational school (VS; *N* = 24), and physics teacher students (PT; *N* = 41).

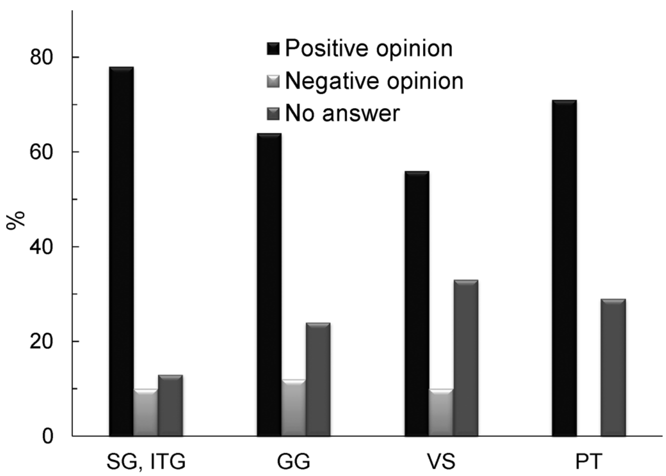
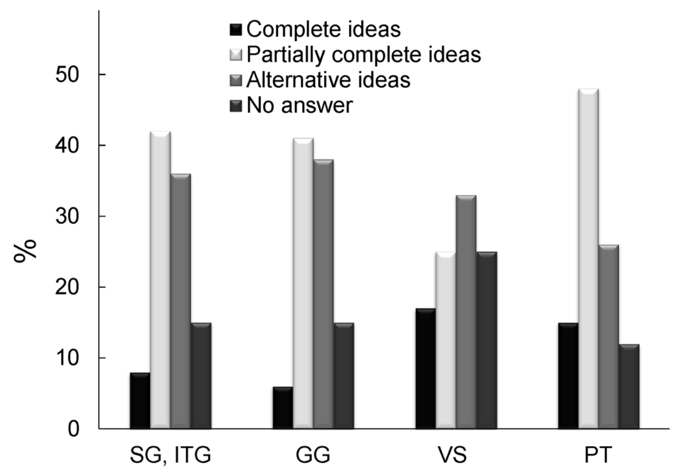


Fig. 7. Relative fractions of the students' answers according to the different categories of the problem-solving approach for different secondary schools and for university: science gymnasium and information technology gymnasium (SG, ITG; *N* = 72), general gymnasium (GG; *N* = 139), vocational school (VS; *N* = 24), and physics teacher students (PT; *N* = 41).



more effective in developing self-awareness and confidence about the possibility to solve physics problems. However, taking into account the small sample size (*N* = 24) of VS students, we should accept the described results with caution.

Furthermore, the answers given by the PT students mostly belong to the category of partially complete physical ideas, regardless of their higher education level. Obviously, there were weaknesses in their knowledge that had not been detected throughout their education. Taking into account the nonsignificance of Fischer's exact test, we can assert that our results challenge the assumption according to which higher education ensures the necessary knowledge of the relevant subjects [32], which is also consistent with our previous results [13]. The largest fraction of alternative ideas was found for GG students. This was not unexpected due to the general nature of their curriculum, designed for broad education. Although the physics curriculum in the GG is the same as in SG, the number of physics classes is reduced. It is encouraging that even 47% secondary school students responded with complete or partially complete physical ideas. They have a predisposition for scientific thinking so that potential for future physicists obviously exists in Croatia, even though only a few students enroll in physics.

When it comes to students' attitudes towards the photograph-based problem, it has been shown that a statistically significant majority of students across all education levels exhibit positive attitudes, describing the problem as interesting, realistic, and applicable. Only 9% students expressed negative opinions. They found the task too complicated, boring, useless, and not desirable for school, adding that physics was already hard enough.

Bearing in mind the results of the research project Relevance of Science Education (ROSE) [33], which showed that most pupils

Fig. 8. A comparison of the relative fractions of answers given by students ($N = 276$) and the expected students' answers predicted by teachers ($N = 48$) for the different answer categories.

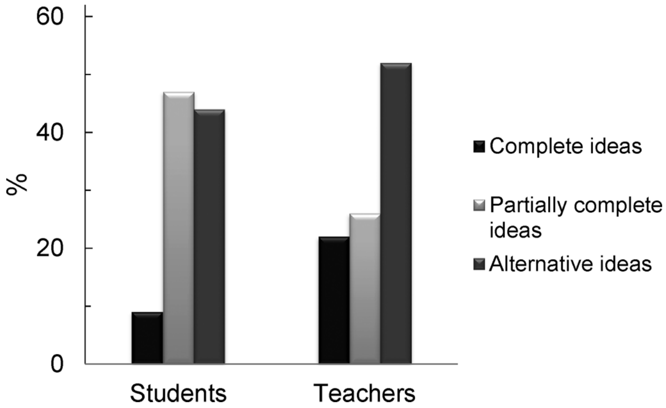


Table 4. Comparing the expected and observed distributions of students' answers.

	Complete ideas	Partially complete ideas	Alternative ideas
Observed	18	93	87
Expected	43.56	51.48	102.96

perceive physics teaching as unpopular, boring, irrelevant, too difficult, not opened for free discussion, and not related to contemporary issues, it seems that the type of problems as proposed in our study possess the potential to contribute to changing students' attitudes towards physics. This feature of photography-based problems qualifies them as highly desirable because according to Sharot and Phelps [34] positive emotions towards the study material are an important prerequisite for effective learning.

Finally, the results of the chi-square analysis suggest that secondary school teachers often are not capable of adequately estimating the abilities of their students. This conclusion is supported by results of similar studies that had been conducted in the Republic of Croatia [11, 12], whereby other types of physics problems had been used. These findings indicate that secondary school physics teachers from Croatia lack the competence to reasonably reflect on their students' abilities, which can lead to ineffective planning of physics instruction. We could also assert that they lack the required expertise for estimating self-effectiveness, or reflecting on the efficacy of their instruction in general. However, in the relevant literature this teacher competence is regarded as highly important [35]. It follows that the results of our study provide useful feedback that could in the future positively affect the planning of initial education of prospective physics teachers on Croatian universities.

6. Suggestions for teaching

We suggest that teachers discuss photography-based problems in their classrooms. The first step should be to find out what is unusual in a photograph, in our case of a wine glass filled with liquid. All students would agree that the free surface of a liquid tends to become horizontal so we should first discuss physical arguments for such behavior of a liquid.

We found that some students' ideas are associated with the latest scientific topics and thus stimulate the discussion of various physical issues at different levels. The students' ideas can be subsequently elaborated by using other forms of visual representations (e.g., simplified diagrams) that have proved to be effective in the development of the relevant concepts [18].

The partially complete physical ideas should be completed, not corrected, as should be the case with the alternative ideas. Apart from the discussion on the equilibrium, many other issues at different levels can be discussed. For example regarding the answer:

It is possible if the panel is inclined and the camera set parallel to it (Fig. 4*a*);

we can ask:

Is it necessary that the glass is attached to the panel, or just the high-enough coefficient of friction is sufficient to prevent the glass from sliding?

The answers:

It is possible if the glass is accelerated uniformly along the straight line (Fig. 4*b*). *It is possible if the panel rotates uniformly and the glass is far from the rotation axis* (Fig. 4*c*);

next questions may follow:

What kind of physical system do we have? Why is the surface not horizontal? Why was it important that the motion is uniformly accelerated? How would the surface of a liquid lie if the glass moved uniformly along a straight line, and how if it was at rest? How would the surface of a liquid look like if the panel rotated and the glass was in the center of the rotation and why? How distant from the axis of rotation should the glass be to enable the liquid to be inclined like in the picture?

In response to the answer:

The liquid might be so viscous to keep its shape for a long time after the glass is turned upright (Fig. 4*d*);

we can discuss the structure of matter and ask:

Is there a viscosity limit above which liquid becomes solid?

These are the answers based on imagination stirred by high technology, and as such they also raise questions for discussion:

Is gel a liquid? (Fig. 5*a*) *What are ferrofluids? Are there magnets so strong that they can attract the ferrofluid and make it lie in the position seen in the photograph* (Fig. 5*b*)?

Those who thought this was a photomontage could come up with that answer without any knowledge of physics, using logical reasoning and practical modern knowledge. However, we can ask them how the image was made and what had to be done (reflections, shadows) to make the image realistic. The questions that could arise in this way may encourage also those students who do not feel confident to discuss physical issues. This is an essential prerequisite for the construction or upgrade of physical concepts, as demonstrated by the results of the ROSE [33].

7. Conclusions and future work

We started from the notion that in addition to verbal cognition, a nonverbal, mainly visual cognition is required for the acquisition of physical concepts. Photography is still rarely used for this purpose.

Based on photography, we elicited and probed students' ideas regarding fluids in noninertial frames of reference and the conditions of equilibrium. The study involved 235 secondary school students, 41 physics-teacher students and 48 physics teachers. The participants were given an unusual photograph of a wine glass filled with a liquid, the surface of which was inclined. They were asked about the reality of the situation captured in the photograph. We used open-ended question form to allow respondents to express their own ideas. Based on their ideas, the teachers were asked by means of a closed-ended questionnaire about what they expected their students would answer.

The results show that the practical and conceptual knowledge of the explored topics do not depend significantly on the education level and curriculum followed. This finding especially raises questions regarding the quality of the content knowledge dimension of physics teacher education in Croatia. However, it is encouraging that almost half of the students exhibited at least partially complete understanding of the physical ideas.

A statistically significant majority of the respondents took a positive attitude towards photography-based problems. Therefore, it seems as if the use of photography possesses a relatively great potential for motivating students to discuss their ideas about physics.

By comparing the physics teachers' predictions with the actual students' answers, we found that the teachers have significantly overestimated the proportion of students' who exhibited complete physical ideas related to the presented problem. It is important to repeatedly emphasize that these results show a lack of awareness of students' abilities in Croatian physics teachers. This finding is supported by results of similar studies [11, 12] and it should be taken into account within the process of reforming the initial education of prospective physics teachers in Croatia.

In this study, we discussed the use of a photography-based problem within the context of only a limited number of introductory physics concepts, but the obtained findings strongly suggest that this type of problem could arouse the interest of most students across different educational levels. Thus, photography-based problems can enrich the repertoire of teaching techniques that can be used for purposes of promoting creativity and interactivity in physics classes. We propose that teachers include some of the non-traditional photography-based problems in their physics classes and use students' ideas and contributions to drive the learning process rather than treating them as distractions. This could enable equal participation of all students, including those that still have not developed the knowledge of physics. Teachers would thus become aware of students' problem-solving strategies, which could result in a better link between the natural science contents being lectured and students' everyday life experiences.

Additional didactical potential of this method has yet to be explored. Thereby, future research could consider in more detail how students' attitudes and beliefs about physics are affected if such problems are involved in lectures. Another task for future work could be a controlled study about the effectiveness of this kind of teaching. To achieve more general conclusions, the study should be repeated with different photography-based problems from other areas of introductory physics. A good idea would be to make an online repository of interesting and puzzling photographs that could be used in the classroom.

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