Teaching Physics to Non Physicist: Physics for Agricultural, Biotech and Environmental Sciences

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Abstract
Physics is a basic discipline for all sciences and therefore included in the university scientific degrees. The research problems are: to identify topic areas and meaningful contexts for each specific subject area in which the cultural value of physic emerged and is recognized; to use new technologies and lab activities to stimulate an active role of students in the construction of their learning and in the experimentation of the methods of physics. In the undergraduate degrees for Agricultural, Environmental and Nature Sciences, Science of Foods and Biotechnology at the University of Udine a physics course has been implemented, focused on topics such as the physics of fluids and examples taken from the wild, as contexts for introduction and building the concepts of physic. The learning outcomes were evaluated with a written questionnaire on fluids. The analysis of real situations in lab and the clickers sections help students to overcome main difficulties. Problematic areas for ¼ of students remained: Pascal principle; the static-dynamic passage; critical management of math.

Keywords
Physics for life area, university students learning.

Introduction

Physics is a basic discipline for all science subjects and therefore included in all degrees of the scientific area. Nevertheless, both "non-physicist" students, and an increasing number of university professors of the scientific area do not seem to recognize the formative value of physics. This is also a result of errors made in the past. All students were taught physics in the same way, emphasizing the use of ideal models in ideal contexts (the material point, the floor without friction, the ideal gas), without giving sufficient attention to the modelling process and to the role that ideal models can have in the comprehension of everyday life phenomena (Michelini, Santi, Stefanel 2013; Michelini 2010). Moreover, the role that physics plays is different in different areas and therefore also its teaching must be adapted to the context in which it is proposed (Michelini 2010; Hoskinson et al. 2014). At university level, we can identify at least four major areas: physics for students of physics and mathematics degrees; the physics for engineers; the physics for the large and differentiated area of medicine, biology, natural sciences where you can also include other topics as agronomy and food science; the physics for the area of human science, as for instance philosophy, literature, history, art. In this paper, the third area will be considered.

The research problems are: to identify topic areas and meaningful contexts for each specific subject area in which the value of a culture in physics emerges and is recognized (Cummings et al. 2004; Meredith, Redish 2013; O'Shea et al 2013); to use new technologies and lab to stimulate an active role of students in the construction of their learning (Hoskinson et al 2014).

In the context of undergraduate courses for Agricultural Science and Technology, Environmental and Nature Sciences and Technology, Oenology, Biotechnology, at the University of Udine *three parallel physics courses* were implemented, focused on topics such as the physics of fluids and examples taken from the wild, medicine as contexts where the physics concepts can be introduced and built. Lab sections using on-line sensors, clickers sections for the personal involvement of students in the analysis of conceptual knots, problem solving sections for a functional understanding of concepts where proposed to students. The course of physics are framed within a project for didactic innovation in T/L at the University of Udine.

The approach of the different topics starts from real phenomena and experiments to construct simple models based on physics principles. It will be exemplified in the case of the hydrodynamic of a river water, documenting also the learning outcomes.

Research questions
The focus of the present work is on the following research questions:

RQ1 – What role does the engagement of students play in the analysis of questions typically evidenced as learning problems?

RQ2 – When students face these questions, which kind of reasoning they evidence?

RQ3 – What contents are more problematic for students learning?

The structure of the Physics courses for non physicist

The three courses were designed and implemented in parallel during the period February-June 2015, as follow: BT- Physics course for the Biotechnology degree (3 c.t.s. – 30 h): N1= 46 students of the 1st year (teacher MM); AGNE-Physics for Agricultural, Science and Technology of Nature, Oenology degrees (6 c.t.s. – 60 h): N2 = 186 students of the 1st year (teacher AS); FST (6 c.t.s. – 60 h): N3 = 110 students of the 1st year (teacher AS).

The topics treated in all the three courses were: Introduction to physics; Kinematic of motion; Translational dynamic; Work and energy; Oscillation and waves; Thermodynamics and electric and magnetic phenomena; Fluids in equilibrium and fluidodynamics.

In the two courses AGNE and FST some topics were added: optics; 4 experimental lab sections, each of 2 hours; 10 hours of exercises and problems; a more extensive treatment of the thermodynamic module. In the BT course a part was devoted to dynamics of systems.

The peculiar aspects, characterizing all the three courses, are the following:

- The approach to the different topics starts from real phenomena, analysed in relevant contexts for natural, living sciences, where the physical principles find plausibility and areas for their translation /application in physical models.
- Each lesson integrates: A) discussion of contents, adopting the approach described above, PPT presentation, demonstrative experiments, blackboard (45 minutes); B) exercises and problem solving, analysis of simple applications discussed on the topic faced (15 minutes).
- Continuous assessment, in the context of the lessons, and through three intermediate written questionnaires, each of them concerning one of the three modules.

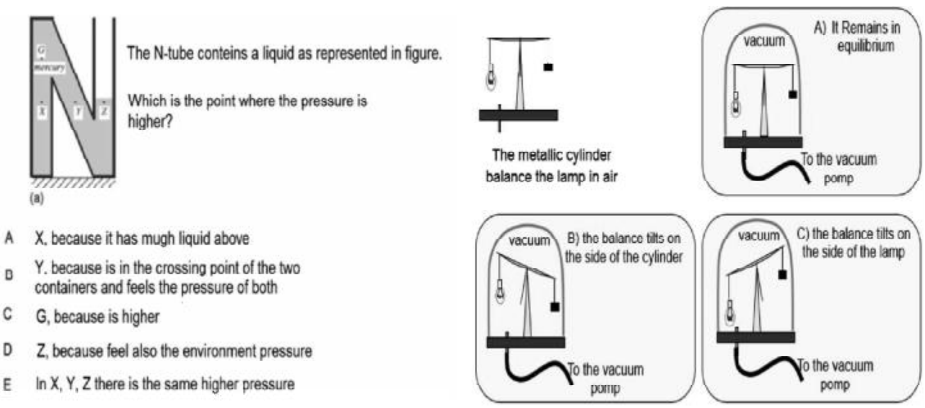

Figure 1. Two examples of clickers questions concerning the Pascal principle (elaborated from Loverude et al. 2010) and the hydrostatic force of air.

Specifically, the module on Fluids was organized as follows: 2 h - Physics of fluids in equilibrium (Fluid as continuous system that can flow, pressure concept and Pascal Principle, Stevin and Archimedes laws, density concept and its role in boyancy); 2 h - Dynamics of fluids (Flux and flux conservation equation, Bernoulli theorem); 2 h - Real fluids (concept of viscosity, Stokes force, Poiselle equation, capillarity, surface tension); 1 h problem and exercises. In the courses AGNE and FST, two hours of experimental lab was added, regarding viscosity studying the balls falling inside different liquids (water, oil, glycerine) and a clicker session (see fig. 1) was included in the lessons.

The third module and the third questionnaire in the course BT was focalized on fluidodynamics. In the other two courses, fluids were included in the first and second modules and the questions were included in all the three intermediate questionnaires.

Each question was proposed to the different groups of students using different forms: multiple choice questions with or without explanation; slightly differentiated implementation; open-ended questions. From the multiple choice questions we can obtain statistical data to compare the effectiveness of the approach in the different groups, to see the role of lab or clicker section (proposed only to AGNE and FST, but not to BT students). From open question and the explanation of the choices we obtained information on the students' reasoning.

In the appendix we report the questions analysed here, as proposed in the form of multiple choice items. We were able to follow the students reasoning because the same questions were proposed to the BT students asking for a motivation of the choice. Moreover some students of AGNE and FST motivated their choice also when not explicitly requested.

The dynamic of the water flow in a "real" river

The discussion of the dynamics of the water in a river included three steps: a) experimental analysis, by means of video analysis, of the motion of the water flow in a river; b) videoanalysis of the water flow in an open duct, made in the laboratory; c) modelling of the phenomenon.

The first step is triggered by the question: *How does the water of a river flow on a flat land?* A first answer can be obtained by a video-analysis of the velocity of the water flow at a defined distance from the border of a real river (i.e the Arno river in Florence city as in fig.2).

It turns out that this speed is constant and uniform, so it does not change over time and does not change at all points that are equidistant from the border. The question arises: *Will the behaviour be the same at each distance*? Repeating the measurement at different distances, it emerged that the speed at the border is very small (or null), it grows progressively towards the centre.

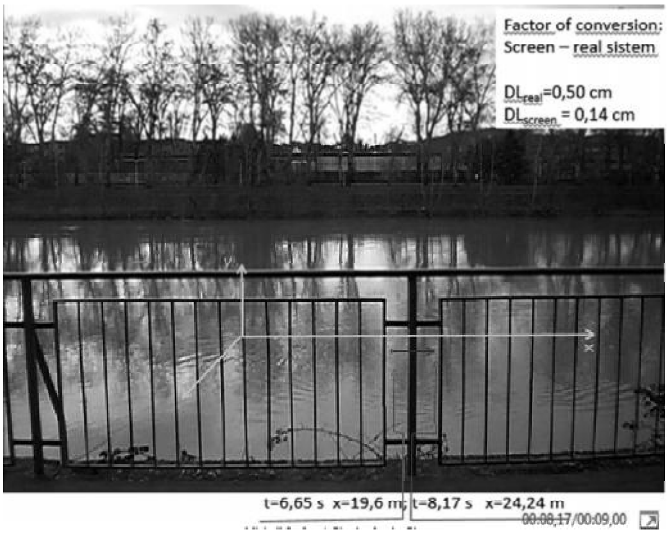

Figure 2. The picture reproduce a frame of the video of flow of the water in the Arno river in Florence. The segments indicated by the arrows are superposed to the images of the wood stick driven by the current. The length of the stick of wood was measured on the riverside and used to obtain the ratio: real length/screen length. The position of the piece of wood is measured with respect to the standing reference frame (in yellow) related to 8,17 s and 6,65 s.

On the base of this measure, at 16 m from the riverside of the Arno, the speed of the water is v_{16}= 3,3±0,1 m/s, constant and uniform. At 0.8 m from the riverside, the speed is also constant and uniform, but his value is $v_{0,8}$= 0,18 ±0,01 m/s.

How does the speed of the water grow from the riverside to the centre of the river? One can assume that this rate will grow linearly from the side to the centre of the flow? To answer these questions, it is not enough to detect the speed of the water at different distances from the side. A more systematic measurements is needed. To simulate the river flow in lab, a simple experiment can be performed using a flat open pipe, where a controlled water flows is produced by a continuous source and the movement of the water is guaranteed by a longitudinal slope of the pipe. In that controlled condition, the analysis was carried out of the role of the parameters involved in the river flow (step b of the path).

If the duct have a rectangular cross section and the flow is sufficiently slow, as it is obtained with a duct only weakly tilted, the water depth is the same over the entire cross section of the flow and also of a good part of the longitudinal section. In this condition, we would expect a velocity profile symmetrical with respect to the medial plane of the flow itself, depending only on the distance from the center of the flow. The depth of the water is not important in determining the velocity profile being the same the influence on the different part of the flow. The water flow can be studied with a videoanalysis of the motion of flour or other bits of coloured powder thrown into the water. A parabolic profile of the velocity emerges by that analysis.

To account this profile, a simple model is implemented, based on the law that defines the viscosity of a fluid (step c) and the experimental results obtained in the previous steps: the river water flows at a constant velocity; the speed is the same for a fixed distance from the riverside, where the speed is approximately 0. It can therefore assume that the flow of water is described as sliding of adjacent layers, assuming the boundary condition v=0 at the borders.

This model is implemented at finite differences in an electronic worksheet. It allows to describe the time evolution of the speed of each layer. The time evolution of the speed of each layer has an exponential trend which tends asymptotically to a constant regime value (fig 3).

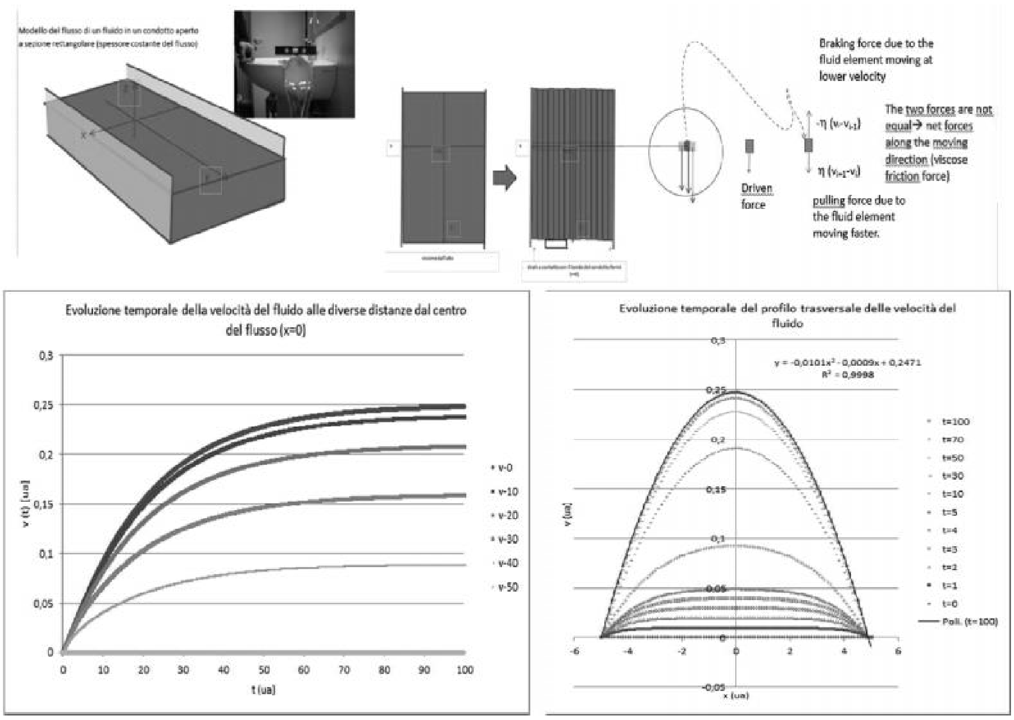

Figure 3. Implementation of the model: The flow of water divided in parallel layers each of them interacting with the adjacent layers, with a force proportional to opposite of the gradient of the velocity. The driven force is constant, due to the inclination of the duct and the action of the base of the duct that is the same being equal to the depth for each x. The graphs represent the time evolution of the velocity of each layer and evolution of the velocity profile of the flow tending to a parabolic profile as evidenced by the fit.

Analysis of students learning

A first evaluation of the course was performed analysing the students' answers to the questions included in the written questionnaires used as formative assessments. We are presenting the analysis of a set of questions concerning fluids. A quantitative analysis of multichoice questions was made, and a qualitative analysis of the motivation/explanation permitted to individuate pattern of resolution and pattern of reasoning. In table 1 there are resumed the questions analysed here and resumed in the appendix.

To the item Q1, 48% of the sample gave the expected answer A), with the BT group markedly lower than the average. The few students explaining their choices evidenced a prevalent strategy, based on the dimensional analysis. The main difficulty in this case was the correct identification of the physical dimensions of the compressibility coefficient χ, although the item text made explicit its units. The few students, who have adopted the strategy of obtaining $\Delta\rho$ from the χ definition formula, met two types of problems: construction of the inverse formula; transformation of the volume change ΔV in density change $\Delta\rho$.

78% of the sample chosen the expected option A) to the item Q2, applying a strategy based on the definition of pressure to evaluate the force acting on the porthole: P = F/S (by definition) →$F=PS = 3\cdot10^5 * 0,1 = 3\cdot10^4$. The main difficulties were related to the definition of pressure, to derive the inverse formula, to calculate in scientific notation.

Table 1. Number and percentage of responses to questions Q1-Q8 (see appendix). In bold correct answers.

		BT (N1 = 46)		AGNE (N2 =167)		STF (N3=108)		TOT (N= 321)	
		n1	%	n2	%	n3	%	n	%
Q1	**A)**	**4**	***9***	**89**	***53***	**59**	***55***	**152**	***48***
	B)	16	*35*	45	*27*	24	*22*	85	*26*
	C)			33	*20*	16	*15*	49	*15*
	Na	26	*57*			9	*8*	35	*11*
Q2	**A)**	**31**	***67***	**133**	***80***	**85**	***79***	**249**	***78***
	B)	10	*22*	29	*17*	19	*18*	58	*18*
	C)	1	*2*	5	*3*	3	*3*	9	*3*
	Na	4	*9*			1	*1*	5	*2*
		BT (N1 = 46)		AGNV (N2 =158)				TOT (N= 204)	
		n1	%	n2	%			n	%
Q3	A)	2	*4*	46	*29*			48	*24*
	B)	9	*20*	28	*18*			37	*18*
	C)	**32**	***70***	**84**	***53***			**116**	***57***
	Na	3	*6*					3	*1*
		BT (N1 = 46)		AGNV (N2 =158)		STF (N3=99)		TOT (N= 303)	
		n1	%	n2	%	n3	%	n	%
Q4	A)	2	*5*	28	*18*	13	*13*	43	*14*
	B)	**29**	***63***	**74**	***47***	**72**	***73***	**175**	***58***
	C)	2	*4*	46	*29*	8	*8*	56	*18*
	Na	13	*28*	10	*6*	6	*6*	29	*10*
		BT (N1 = 46)		AGNV (N2 =120)		STF (N3=92)		TOT (N= 258)	
		n1	%	n2	%	n3	%	n	%
Q5	A)	3	*7*	29	*24*	7	*8*	39	*15*
	B)	8	*17*	28	*23*	13	*14*	49	*19*
	C)	**17**	***37***	**59**	***49***	**71**	***77***	**147**	***57***
	Na	18	*39*	4	*3*	1	*1*	23	*9*
Q6	A)	2	*4*	6	*5*	0	*0*	8	*3*
	B)	**35**	***76***	**88**	***73***	**59**	***64***	**182**	***71***
	C)	1	*2*	25	*21*	32	*35*	58	*22*
	Na	8	*18*	1	*1*	1	*1*	10	*4*
Q7	**A)**	**31**	***68***	**75**	***63***	**72**	***78***	**178**	***69***
	B)	1	*2*	35	*28*	13	*14*	49	*19*
	C)	1	*2*	8	*7*	5	*6*	14	*5*
	Na	13	*28*	2	*2*	2	*2*	17	*7*
Q8	A)	1	*2*	10	*8*	9	*10*	20	*8*
	B)	**20**	***44***	**86**	***72***	**74**	***80***	**180**	***70***
	C)	4	*9*	22	*18*	8	*9*	34	*13*
	Na	21	*45*	2	*2*	1	*1*	24	*9*

Concerning item Q3 (elaboration from Loverude et al. 2010), the expected answer C was given by 57 % of students following a reasoning linking Stevin law and Pascal principle (points at equal level→equal Pressure). The three main reasoning motivating answer B are based on: B1) the liquid level "above the head" ("…the point K presents a mass of water over it greater than J"); B2) the role of the atmospheric pressure ("In K, also Po is acting"); B3) the definition of pressure ("P=F/S, Sj>Sk → Pk>Pj"). The motivation of answer A was based on a sort of "virtual work theorem" ("What happens if I open the left arm of the tube"…the water flows...→Pj>Pk").

The expected answer B to the item Q4 was given by 58%, combining the continuity equation and the Bernoulli theorem (S decreases→v increases → «the pressure decreases»). The resolution paths in the other cases were based on typical short circuits on formalism: A) answer -AaVa=AbVb → Vb=(Aa/Ab)Va → Vb^2=(Aa/Ab)Va^2; B) – answer - AaVa=AbVb → Pb=Pa+1/2 ρ Va^2.

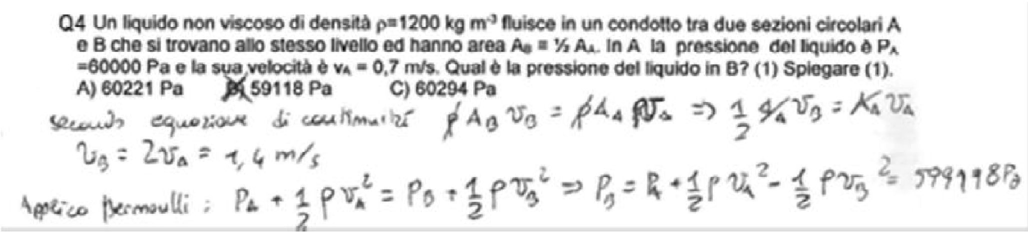

Figure 8. Typical answer B) and motivation to the item Q4.

The percentages of responses for the three groups were quite different for the item Q5, in fact the expected answer C) was given by 37% of BT group, 49% of ANGN group, 77% of STF group, with an average of 57% on the global sample. The main strategy adopted was a combination of the continuity equation and the Bernoulli theorem (S decreases→v increases → «the pressure decreases»). The main difficulties facing the question with this approach have been related to the calculation, which is due to the high percentage of non-responses. The response A was given mainly by who has applied reasoning based on the idea that P is proportional to h. Answer B is instead linked to the idea that P is equal in any place of a fluid.

The answer B) to the item Q6 was given by an average of 71% of the students, based on the reasoning that there is a linear relation between v and h. About 10% gave the answer B) just associating ½v to h/2. This emerged in the implementation of the group AGNV, whose percentage is lower due to this type of feedback.

To the question Q7, 69% gave the expected answer A), with a higher percentage for the group that has carried out systematic clicker/clickers like sessions. The main reasons for the answer A) are: A) qualitative reasoning, based on Bernoulli theorem: P decrease, decreasing the section; B) PA> PB because the flow exerts a bigger pressure in A than in B; C) Explanatory: The left arm push on the right one.

To the question Q8, on average 70% of students gave the answer B), with a significantly higher percentage for groups AGNV and STF who explored the similar phenomena in the laboratory, aspect that show the role of the lab on students learning. The main argument is based on the idea that the falling ball reach a regime/limit speed. The option C is based on the expectation of an exponential trend. Those who chosen the option A) applied a proportional reasoning instead.

I should be stressed that the questions Q1-Q2-Q5-Q8 were related to the conceptual aspects proposed in the clickers section proposed only to the AGNE and STF students. This seems to result from the different percentages of correct answers in BT group with respect the other two groups, as reported in table 1.

Results and conclusions

A course on basic physics was designed and implemented in the undergraduate courses for Agricultural, Environmental and Nature Sciences and Biotechnology at the University of Udine. It focused on topics such as the physics of fluids and examples taken from the wild, as contexts in which the concepts of physics was introduced and built. The approach to physics was inclined towards the typical contexts and typical problems in biological, medical and natural sciences.

In the paper this approach was exemplified in the case of fluid dynamics. The video analysis of the water flow in a real river and then in a duct in the laboratory under controlled conditions provides the elements to construct a simple model based on the law that defines the viscosity of a liquid.

The course has been implemented with three groups of students composed of 46 students of the degree course in Biotechnology, 167 students of the courses Agricultural, Environmental and Nature Sciences, Oenology, and 108 students of the degree in Sciences and Technology of food.

A first evaluation of the course was performed using the items proposed in written questionnaires.

From the results reported and in particular from the qualitative analysis of students reasoning it seem that the engagement of students in analysing questions typically evidenced as learning problems, it is effective not only to overcome the typical learning problems, but also to face dynamical situations as shown by the data related to the correct answers. This require a base content knowledge and to create a link between qualitatively/conceptual and quantitative questions. The different percentage of correct answers in the different groups show the role of the lab sections and of the clickers sections (RQ1).

The principal conceptual path evidence (direct) proportional reasoning, descriptive/qualitative approach as a tool for prediction more frequent than interpretative/quantitative, extension of the role of physical law outside its range of validity (see: use of p=ρgh law, Archimedes law as a base for a viscosity force model) (RQ2).

The particular problematic areas for 20-25% of students were: Pascal Principle; the passage from static to dynamic situations (lack in basic concepts: pressure, Pascal Principle → what is changing in the dynamical situation?); critical management of math, for instance related to the inverse problems. Moreover, it is seen that another 20%-25% of the students have not answered the questions. This seems to suggest the existence of a threshold that must be reached in order to be able to deal with the questions (RQ3).

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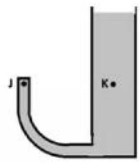
Appendix: Items included in the written questionnaires

Q1. Water at environment pressure and temperature have a density of ρ=1000 kg m^{-3} and a compressibility of χ=6 10^{-10} Pa^{-1}. Which of the expressions gives the variation $\Delta\rho$ of the density of water when the pressure is increased of ΔP?

A) $\Delta\rho = \rho\ \chi\ \Delta P$ B) $\Delta\rho = \rho\ \chi / \Delta P$ C) $\Delta\rho = \Delta P \chi / \rho$

Q2. A submarine is located at a depth such that the pressure exerted by the water on its walls is equal to 2,5 10^5 Pa. The portholes of the submarine have circular flat surface whose area is 0,03 m^2. What is the intensity of the resultant force with which the water pushes a porthole towards the interior of the submarine?

A) 7,5 10^3 N B) 8,3 10^6 N C) 4,5 10^3 N



Q3. A container, such as shown in the figure, is formed by the left, closed branch and the right one open, wider and higher of the left branch. Compare the pressures at points J and K. Which of the relations is correct?

A) $P_J > P_K$ B) $P_J < P_K$ C) $P_J = P_K$

Q4. A non-viscous liquid of density ρ=1200 kg m^{-3} flowing in a conduit between two circular sections A and B of area $A_B = 0{,}5A_A$. Section B is located at the same level as the section A. In A the fluid pressure is P_A =60000 Pa and its speed is v_A = 0,7 m/s. What is the pressure of the liquid in B?

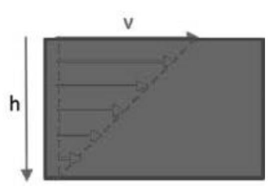
A) 60221 Pa B) 59118 Pa C) 60294 Pa

Q5. In a pipeline a fluid of density ρ is flowing. In a section A of the pipeline which is on the level h_A, the pressure is P_A and the speed is v_A. In the section B of the duct which is located at a level h_A- h, the pressure is P_B=P_A. What can be said about the relationship between the areas of the section A and B

A) This ratio is independent of both v_A and h.

B) This ratio depends on h, but does not depend on v_A.

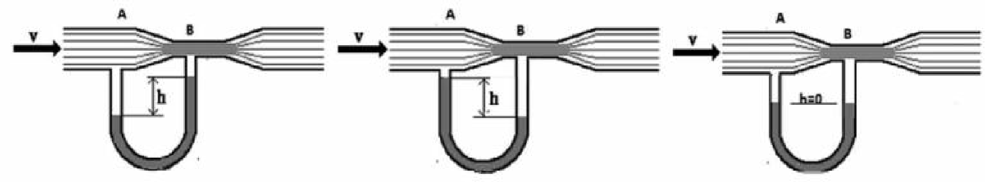
C) This ratio depends on h/v_A^2.



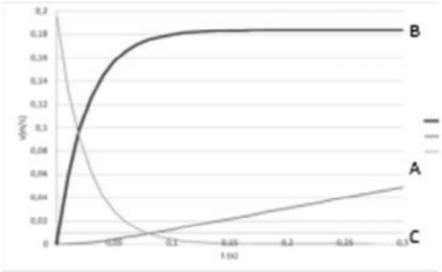
Q6. In an open tube of rectangular cross-section there is a steady flow of water of thickness h. The velocity profile at different depths is shown in figure on the right. At what depth the water speed is half the speed of the surface layer?

A) h; B) h/2; C) h/4

Q7. A steady flow of water flowing in a conduit is presented in the figure. The diameter of conduit in the section A is twice the diameter in the section B. A U-tube, which contains mercury, is inserted between the sections A and B. Which of the figures represents the best the height of the mercury in the two branches of the U-tube?



Q8. A glass ball is located on the surface of the water contained in a long vertical cylinder. From the graphics shown on the right, which one describes the best the time evolution of the speed of the ball, when dropped into the water?



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