Chapter 10
Innovation in Physics Teaching/Learning for the Formative Success in Introductory Physics for Bio Area Degrees: The Case of Fluids

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Abstract Physics course for student in bio area scientific degrees is a multidimensional problem, where the acquisition by students of a functional understanding of physical concepts is the main problem. To face this problem requires a strong revision of topics and of approaches to physics concepts. Physics has to be problematized and offered to students as a useful tool for their future study and job in contexts which are related to the bio area. Design-based research intervention modules were studied in the last two years, taking into account the above-mentioned needs, for degrees at the University of Udine of Agricultural Science and Technology, Biotechnology, Environmental and Nature Sciences and Technology, Oenology, and Science of foods. The courses involved two cohorts (2014/15 and 2015/16), respectively, of 342 and 483 students. Each course covers the classical physics and consists of three modules. Physics of fluids is here selected as topic characterizing in different ways the professional education of student in such degrees. The characteristic of the intervention module on fluids exemplifies the approach followed, testing the effectiveness and documenting the students' learning outcomes.

A positive general trend emerges in the average students' learning outcomes, indicating the effectiveness of the proposal implemented. The more problematic aspects for 10–30% of students are related to the concepts of pressure and the Pascal principle, the bridge from static to dynamic situations. The engagement of students in analyzing those questions that are typically evidenced as learning problems is effective not only in overcoming the single specific aspects but also in facing new situations. The management of math for students is critical as well as the confidence with the validity range of a physical law.

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M. Pietrocola (ed.), *Upgrading Physics Education to Meet the Needs of Society*,
https://doi.org/10.1007/978-3-319-96163-7_10

10.1 Introduction

Physics course for student in scientific degrees in the bio areas is a multidimensional problem, mainly concerning what Lillian McDermott defines a functional understanding of physical concepts (McDermott and Shaffer 1992; McDermott et al. 2006). That is, students must be able to apply the physics concepts in the different contexts of their specific field of study and their professionalism. The main aspects to be faced are:

(A) To redesign the way in which physics is offered so that its role can be recognized in the specific subject matter characterizing the degree: turning the ways in which physics is approached, changing the role of each topical areas, and individuating specific applications of physics in the professional field of the degree (Cummings et al. 2004; Hoskinson et al. 2014; Meredith and Redish 2013; O'Shea et al. 2013)
(B) To offer instruments and methods building a physics competence in different fields (Hoskinson et al. 2013)
(C) To individuate strategies able to produce an active role of students in learning physics and to give them the opportunity for an appropriation of the applied physics methodologies (Hoskinson et al. 2013)
(D) To support student learning in multitasking ways by means of ICT tools, of lab activities, of problem-solving, and of step-by-step evaluation of learning outcomes (Laws 2004; Redish and Hammer 2009; Meredith and Redish 2013)

Design research-based intervention modules (Collins et al. 2004) on physics were studied in the last 2 years, taking into account the abovementioned aspects, for degrees in the University of Udine of C1, Agricultural Science and Technology; C2, Environmental and Nature Sciences and Technology; C3, Oenology; C4, Science of foods; and C5, Biotechnology (Michelini and Stefanel 2016). The courses involved two cohorts (2014/2015 and 2015/2016), respectively, of 342 and 483 students. Each course covers the classical physics and consists of three modules. The physics module for the bio area has a common heart and was differentiated concerning the context-related activities (exercises, applications considered). Physics of fluids is here selected as topic characterizing in different ways the professional education of student in such degrees.

The characteristic of the intervention module on fluids is discussed together with the student learning outcomes.

10.2 Theoretical Background

The innovation in introductory and upper-level STEM education is actually a challenge including both disciplinary and interdisciplinary efforts in established and emerging fields, targeting all institutions of higher education and involving research groups and associations of different subjects (AAAS 2004). Physics education research focused on the innovation of physics course for Undergraduate Science Curriculum identifying, developing, adapting, implementing, disseminating, and assessing of exemplary educational materials (tutorial), processes, and models for active learning (Heron et al. 2004; Laws 2004). These research also became examples for developing new curricula for physics course in other areas as, for instance, the biology one (Donovan et al. 2013), as well as to integrate current science into the physics curriculum ad in general to promote the student learning in interdisciplinary biology and physics classes (AAAS 2011, p. 54; Brewe et al. 2013). The first basic question is how to integrate physics into biology curriculum (or biology into physics curriculum) beyond simple provision of examples from the respective disciplines (CBE 2013). The request of interdisciplinarity opens new research questions concerning starting assumptions about students, content to treat, competencies to focus on, corridors and barriers to constructing an effective course, and condition and resource for effective inter- or transdisciplinary instruction (Redish et al. 2014). Future research aims could be how sophisticated, biologically relevant physics topics can be taught at the introductory level and how biology instruction should be changed such that students are prepared to use physics knowledge and theory to understand biological phenomena. Adding problems emerges from the different perspectives and epistemologies of physicists and biologists. Topics that physicists view as "canonical" and considered important for all students are quite different from topics that biologists view as important for understanding and doing modern biology, as, for instance, random motion, diffusion, microstate thermodynamics, and fluid flow (CBE 2013; Redish et al. 2014).

Physicists usually isolate the object of study to be able to focus on fundamental processes in systems with a (relatively) small number of degrees of freedom. In biology, the systems are always interconnected and not separable. Moreover, essentially everything takes place in a fluid environment—air or water—and the fluid has a critical influence on biological function. For that the dynamic of fluid is essential to include in a physics course for bio area, and other topics can or must be eliminated, as, for example, the projectile motion (as paradigmatic example) or gravity (Meredith and Redish 2013).

In this vast area of concerns, some studies addressed the role for an integrate learning of methodological aspects, such as problem-solving and modelling (Hoskinson et al. 2013, 2014) or crosscutting themes as, for instance, energy (Cooper and Klymkowsky 2013; Svoboda Gouvea et al. 2013; Dreyfus et al. 2014), usually proposed in very different ways, for instance, in physics courses and in biology courses, producing fragmented understanding (Svoboda Gouvea et al. 2013) or contradictory, inconsistent conceptions in the students (Dreyfus et al. 2014). Other scholars studied how physics can be used to explain significant biological processes and phenomena (Bustamante 2004), the possibility to give a formal description to biological phenomena (Redish and Cooke 2013). Although the role of math in biology increases, some research evidenced that students do not have the same perception (Hall et al. 2011, Watkins and Elby 2013). The role of integration in producing capacity to integrate knowledge and modes of thinking in two or more disciplines was also explored in different dimensions (Ivanitskaya et al.

2002; Boix et al. 2007). General criteria are proposed for the evaluation of new learning objectives, integrating physics, and biological thinking (Watkins et al. 2012; Svoboda Gouvea et al. 2013, Thompson et al. 2013). Recently a great effort was made to design new physics courses entirely curved on biology (Cummings et al. 2004; Meredith Redish 2013; O'Shea et al. 2013), adopting innovative curriculum models (Watkins et al. 2012; Manthey and Brewe 2013; Donovan et al. 2013, Thompson et al. 2013) to help students develop reasoning strategies that move beyond traditional disciplinary boundaries.

As discussed by Svoboda Gouvea et al. (2013), almost three are the levels of integration of physics and biology tasks:

1. Features of Level 1 Tasks—Superficial Interaction describes a relatively low-level interaction between disciplines, (as, for instance, the fish buoyancy problem, where biology is just a context where students are requested to reason about the Archimedes law and the buoyant force acting on a fish).
2. Features of Level 2 Tasks—One Discipline Impacts the Other, one discipline impacts or modifies a second in some substantial way (e.g., this might mean applying a technique that is common in physics (e.g., dimensional analysis) or in the case when physics law explain a bio aspects (as pressure to understand the arteriosclerosis formation).
3. Features of Level 3 Tasks—Exploring Connections Between the Disciplines, where the integration occurs, for instance, bringing different conceptual frameworks of each discipline to bear on a problem and explicitly examining why these frameworks differ and where they overlap (as in exemplum analyzing ATP cell role with an energy perspective).

Our work goes in the perspective to give a contribution on teaching physics to bio area in an integrated way according to above level 2–3 tasks. We follow the Redish group suggestions, in particular concerning the need to change radically the approaches, rooting the treatment of physics content in context interesting for bio area, focusing more on fluids and fluid dynamic more than to the mechanics of material points (Meredith and Redish 2013; Cummings et al. 2004; Redish et al. 2014). We stress also the importance to include experimental lab, interactive lectures, and high student engagement (Redish and Hammer 2009). We discuss the general characteristic of our approach, exemplifying it in the case of the module of fluids and presenting student learning outcomes.

10.3 The Research Questions

The present contribution focuses on the following research questions: RQ1—Which contents are more problematic for student learning? RQ2—Which role does play the engagement of students in the analysis of questions typically evidenced as learning problems? RQ3—Which kind of reasoning evidence students facing these questions?

General Characteristics of the Course in Physics for Bio

As indicated before, following Redish approach (Cummings et al. 2004; Meredith and Redish 2013), physics is offered usually starting from context and applications of bio areas. For instance, a contextualized problem-solving introduces the motion issues: "A cheetah hunting an antelope: will the cheetah reach the antelope?". The usual encountered problem becomes a problem-solving starting from the characteristic of the involved animals (the maximum speeds, the typical acceleration, the distance covered with maximum speed). Examples are taken from the environment, wine production, and food preparation, focalizing where physics is important to understand a "bio" phenomenon. For instance, fluid dynamics is treated not only in ideal conditions but also in the water flow in an open and closed duct, in the river flow, in the blood circulation, and in the respiratory apparatus in human body.

A privileged attention is given to the fluid dynamics, compared to those given in the traditional physics courses, where the prevalence is on fluid statics. As concern strategies, we adopt a context-related problematic approach to each topic using sometimes flipped classroom strategies to engage students in finding the general physical behavior that lies at the base of the problem proposed. As concern methods interactive lecture demonstrations are integrated with group work problem-solving activities, analysis of contextualized problems (problem facing situations typical of the science area), seminars, and labwork. Frequent formative learning outcomes evaluations are proposed by means of clickers questionnaires and traditional multiple-choice or open questionnaires and only for C5 students open problems. After each learning outcomes evaluation, an in-depth discussion is carried out with student on learning knots emerged.

Usually each hour of the courses is organized as follows: 45 min of lessons, using blackboard, PP presentation, and demonstrative experiments, and 15 min of clickers or manual clicker-like sections, exercise, and simple applications.

The Module on Physics of Fluids

Table 10.1 reports the schema of the module, indicating the main contents included and the number of hours dedicated.

On the physics point of view, the fluids are introduced as systems flowing, not reacting to transverse forces (static) or F//surface = 0. Their description requires a mesoscopic modelling and a change in the typical quantities used (density and pressure vs. mass and forces in the Newtonian dynamic of material points). The concept of pressure is discussed in three perspectives: as a force distributed on a surface, as (normal) a compression on the surface of the fluid, and as a state property of a fluid. In the third perspective, the Pascal principle emerges as the general law characterizing the specific behavior of fluids in equilibrium or near the equilibrium and distinguishing with respect to the solid systems. Stevin and Archimedes laws are

Table 10.1 Schema of the module on fluid

Hours	Contents
2	Physics of fluids in equilibrium (fluid as a continue system that can flow, pressure concept and Pascal Principle, Stevin and Archimedes laws, density concept and its role in buoyancy)
2	Dynamics of fluids (flux and flux conservation equation, Bernoulli theorem)
2	Real (more realistic) fluids (the concept of viscosity, Stokes' force, Poiseuille equation, capillarity, surface tension)
1	Problem and exercises
2	Lab (experimental study of balls falling inside different liquids—only in the two courses AGNV and STF courses)

discussed in many important applications and examples, as for instance: the communicating vessels; the dam; the measurement of χ in liquids with the piezometer; the Mariana trench and the gradient of pressure with depth in a liquid; the hydraulic torque; the U-tube manometer; the syphon; the Torricelli and other barometers; the heart pressure in human and giraffe; the hydrostatic paradox; the density meter, discussed also as a rigid rotating body, and the alcohol meter; the buoyancy of liquid in liquid; the Archimedes forces in the air as in the candle flame; the Montgolfier; the bulb and the cylinder on the equal arms balance and the vacuum pump; the measurement of the hydrostatic force; the King Hiero legend. The surface tension, introduced as work to enlarge a liquid surface, and the surface phenomena are introduced as important aspects of physics of fluids in living systems, starting from capillarity in the trees as well in the peripheral blood circulation. Laplace formula and Borelli-Jurin law are discussed and applied to explain that phenomenology as well as specific examples as the drop method to measure the tension coefficient, or the emboli formation.

The dynamic of fluids is discussed starting from the phenomenology of real cases (i.e., the water flow in a river, as well as the blood circulation in the body). Continuity equation is stated as the general condition that must be satisfied by a fluid flow. The complex case of turbulence and viscosity motion is discussed qualitatively, as base for a quantitative formal approach with simplifying assumptions, that are valid in specific situations concerning the context of applicability of Poiseuille law and Bernoulli theorem.

As claimed before, and more extensively discussed in a previous work (Michelini and Stefanel 2016), the water flux in a river is a typical introductory context to discuss the dynamics of fluid. The approach starts from the video analysis of the motion of the water in a real river at different distances from the riverside. The parabolic profile of velocity is then discovered analyzing the water flow in a rectangular duct in the physics lab and then modelled assuming that friction forces acting between contiguous layers of flow are moving at different speeds. The viscous forces and the layer models emerge as consequences of experimental observation and not as a priori assumption or abstract hypothesis. The Poiseuille law is also contextualized in the blood flow, where the typical range of validity is well satisfied. The continuity equation and Bernoulli theorem are discussed to interpret the formation of a plaque in an artery stenosis and atherosclerosis on the base of the pressure concept.

The analysis of blood circulation given to us to stress another point characterizing our approach on physics for bio. That analysis, in fact, shows that physics underlying blood circulation is the same as that of other physical systems, as, for instance, that of electric circuits. The analogy between blood circulation and electric current flow is based on an effective correspondence between elements (heart-battery; close blood system-close electric circuits; viscous resistance elements-electric resistors) and concepts (differences of pressure and differences of electric tension as driving factors, continuity equation, and charge conservation). The analysis of the decreasing of the arterial blood pressure from the hearts to the peripheral areas, interesting in itself, becomes a powerful context which activates the analysis of electric circuits on the base of decreasing of the potential along an electric circuit and vice versa.

This kind of approach activates students' model-based reasoning (Nersessian 2002) giving the opportunity to construct competencies on physics concepts contextualized in their own field and an integrated vision of physics models as useful model to describe different phenomenologies both important for bio area and for physics.

10.4 Instruments, Method, and Contexts of Evaluation

To evaluate the effectiveness of our approach and in particular to answer our research questions, we analyzed the questions submitted to the students for their (written) examination. Appendix reports the collection of question concerning fluid here considered. The format reported is that of multiple-choice questions, but in the different courses, the format of the questions contained some little change. In particular, in the course BT1–2 an explanation was explicitly requested and evaluated; in the courses AGNE1 and STF1, students get motivated of the choice done, also when not explicitly requested. In the courses AGNE2 and STF2, questions 1, 2, and 4 were proposed as open questions in intermediate questionnaires proposed during the lessons to the students.

The question proposed are of two types: qualitative questions on fluids in equilibrium concerning knots typically evidenced as learning problems (Loverude et al. 2010), to evaluate the conceptual understanding of students, and quantitative questions aiming to test the functional understanding of basic concepts of fluid dynamics.

The sample here considered consists of two cohorts of students attending the courses in 2014–2015 and 2015–2016 composed, respectively, by 342 and 483 students per each academic year as detailed in Table 10.2. Only the C5 are selected students on the base of a test with the same criteria at national level, producing an admission of 60%. The C1–C4 students are not selected students, only half of them with a modest preparation in physics and the other half with no previous preparation in physics at all.

Table 10.2 Composition of the sample of the two cohorts of students (AY 2014–2015 and AY 2015–2016) in the three courses concerning five degrees

Course	Degree	AY 2014–2015	AY 2015–16
Course 1 AGNE	C1-Agricultural Science and Technology	$N_{AGE1} = 186$	$N_{AGE2} = 261$
	C2-Environmental and Nature Sciences		
	C3-Oenology		
Course 2 STF	C4-Science of foods	$N_{STF1} = 110$	$N_{STF2} = 177$
Course 3 BT	C5-Biotechnology	$N_{BT1} = 46$	$N_{BT2} = 45$

10.5 Methodology of Data Analysis

A quantitative analysis of answers given by students to the multiple-choice questions was performed to extract indication about the general outcomes of our educational approach, especially with the signs of which aspects were better learned and what difficulties persist.

Using the qualitative research criteria, it also carried out an analysis of the student patterns of resolution and of reasoning expressed in the motivation/explanation of the choice of students.

Analysis of Student Learning Outcomes and Reasonings

Table 10.3 resumes data concerning Q1–Q8 items. Concerning Q1 the mean percentage of correct answers is 43% for the two cohorts, 47% for cohort 1 and 35% for cohort 2. The difference is explained by the different modes of administration of the question: closed questions in the first case and open-ended questions for the AGNE2 and SFT2 cohorts. In the few explanations, the prevalent strategy of solution was the dimensional analysis of the equation proposed (70% of student explaining the choice). Students showed difficulties in the individuation of the physical dimensions of χ, in the inversion of the formula that defines the compressibility coefficient χ, and in the passage from DV to Dρ. Therefore, it is not a surprise that the percentage of correct answers collapse to 13% and 24% in the case of AGE2 and STF2.

The percentage of correct answers to question Q2 is 68% for the overall sample, 78% for cohort 1, and 47% for cohort 2. Also in this case, the main difficulties are related to the inversion of the formula used (that defining pressure). Therefore, the better results in Q2 with respect to Q1 seems more related to the numerical format of the question Q2, than to other aspects. (Table 10.3).

Fifty-eight percent of the overall sample gave the expected answer to Q3 (equal pressure at the same level in the two arms of the container), without differences between the two cohorts. Usually students explained the answers referring to the Stevin law (because of “Stevin law”) and/or the fact that “points at equal level have

Table 10.3 Percentage of responses to questions Q1–Q8 (see Appendix).

		BT1	BT2	AGNE1	AGNE2	STF1	STF2	TOT1	TOT2	TOT
		N = 46	N = 45	N = 167	N = 41	N = 108	N = 68	N = 321	N = 154	N = 475
Q1	**A**	**9**	**27**	**53**	**13***	**55**	**24***	**47**	**35**	**43**
	B	35	16	27	7*	22	6*	26	9	21
	C		11	20		15	7*	15	28	19
	NA	57	47		80*	8	63*	11	28	16
Q2	**A**	**67**	**76**	**80**	**27***	**79**	**40***	**78**	**47**	**68**
	B	22	2	17	51*	18	47*	18	35	24
	C	2	9	3	20*	3	12*	3	13	6
	NA	9	13		2*	1	1*	2	5	3
		N = 46	N = 45	N = 158	N = 41		N = 68	N = 204	N = 154	N = 358
Q3	**A**	**70**	**64**	**53**	**61**		**54**	**57**	**59**	**58**
	B	20	20	29	10		28	27	21	24
	C	4	4	18	5		13	15	8	12
	NA	7	11		24		4	1	12	6
		N = 46	N = 45	N = 158	N = 218	N = 99	N = 120	N = 303	N = 383	N = 686
Q4	**A**	**63**	**27**	**47**	**62**	**73**	**57**	**58**	**56**	**57**
	B	4	4	18	9	13	28	14	14	14
	C	4	9	29	22	8	15	18	18	18
	NA	28	60	6	7	6	1	10	11	10
		N = 46	N = 45	N = 120		N = 92	N = 120	N = 258	N = 165	N = 371
Q5	**A**	**37**	**31**	**49**		**77**	**38**	**57**	**35**	**70**
	B	17	2	23		14	18	19	12	23
	C	7	7	24		8		15	3	16
	NA	39	60	3		1	44	9	50	30
		N = 46	N = 45	N = 120		N = 92		N = 258	N = 45	N = 303

(continued)

Table 10.3 (continued)

		BT1	BT2	AGNE1	AGNE2	STF1	STF2	TOT1	TOT2	TOT
		N = 46	N = 45	N = 167	N = 41	N = 108	N = 68	N = 321	N = 154	N = 475
Q6	**A**	**76**	**49**	**73**		**64**		**71**	**49**	**67**
	B	4	9	5		0		3	9	4
	C	2	13	21		35		22	13	21
	NA	17	29	1		1		4	29	8
		N = 46	N = 45	N = 120	N = 41	N = 92	N = 68	N = 258	N = 154	N = 412
Q7	**A**	**67**	**47**	**63**	**26**	**78**	**68**	**69**	**51**	**62**
	B	2	18	29	74	14	32	19	39	26
	C	2	4	7		5		5	1	4
	NA	28	31	2		2		7	9	8
		N = 46		N = 120		N = 99		N = 258		N = 258
Q8	**A**	**43**		**72**		**80**		**70**		**70**
	B	2		8		10		8		8
	C	9		18		9		13		13
	NA	46		2		1		9		9

The answer (A) is the (more) correct one (in bold% of correct answers). (*: submitted as open question). In Q3–Q4–Q5 the percentage of the total sample are related to the number of students equal pressure." Students motivated B answers evidencing three different ways of reasoning: the first is based on the liquid level "above the head" ("...the point K presents a mass of water over it greater than J"); the second stresses the role of the atmospheric pressure on the open arm ("in K, also Po is acting"); and the third starts from the definition of pressure and motivates the different pressures with the different sections of the two arms. The third way of reasoning is based on an arbitrary assumption that the same force is acting on the two arms and the wrong use of proportionality. The same assumption and the correct use of proportionality motivate some C answer. Another motivation for answer C considers what happens if "I open right arm.... → PK > PJ." In this case, the student evidences the idea that the pressure remains the same in opening the right arm.

Questions 4 and 5 regard the analysis of the dynamic of fluids. More than half of students (57%) performed the numerical evaluation requests in question 4. The main strategies of solution are the following: the combination of continuity equation and the Bernoulli principle to perform the computation arriving to the results and a qualitative reasoning, underlying the same laws—S decreases → v increases → P decreases. The answers B and C usually are motivated forcing the manipulation of the same equations to give the expected answer. The majority of students (70%) performed the requested analysis of dependence of parameters in Q5. As in the previous case, the main strategies of solution include an explicit manipulation of the Bernoulli equation and continuity principle. B answers are motivated referring to the Stevin law (P equal at equal h) or to the Pascal principle (P equal in any points). Concerning Q6, 67% of the full sample individuated on the velocity profile the level at which the flow speed is half of that of the superficial layer. The main reasoning is based on the linear relation between v and h. The percentage of answers changes proposing different profiles of velocity (i.e., a quadratic profile), evidencing the needs to go behind the use of the linear proportionality.

In the analysis of the Venturi tube, proposed in Q7, 62% of students correlated correctly the pressure and the level of the liquid in the corresponding column in each section of the tube. A higher percentage was observed for the groups performing clicker/clicker-like sessions. The main reasons for the answer (A) are based on the Bernoulli theorem, reconstructing qualitatively the chain: P decrease, decreasing the section. Other explanations are tautology ("PA > PB because the flow exerts a bigger pressure in A than in B") or descriptive ("the left arm push on the right one").

The velocity behavior of a ball falling in a liquid (question Q8) was individuated by 70% of students. The AGNE and STF students explored the phenomenon in the lab that seems at the base of better results. The main argument is based on the idea that the falling ball reaches a regime/limit speed. The option C is based on the expectation of an exponential trend. Option B is based on the application of a proportional reasoning.

10.6 Results and Conclusion

A study was performed on physics teaching-learning in degrees of the bio area, having as a framework the researches carried out in that field and in particular referring to the approach and results of the studies of the Redish groups. The main characteristic of the courses designed was here presented, focalizing on the module on fluids. The outcomes of students learning here discussed emerged from the analysis of the question presented in appendix and regarding the answers to our research questions.

A positive general trend emerges in the average student learning outcomes, indicating the effectiveness of the proposals. At the same time, we can discuss the more controversial aspects emerged by the analysis. First, the more problematic aspects for 10–30% of students regard the concepts of pressure and the Pascal principle. We observe also that some open knots remain passing from static to dynamic situations, more than considering the dynamic cases itself. For the students of the bio area, there is a critical management of math, as, for instance, in the analysis of the inverse problems and in going over the use of the proportional reasoning. Students of our sample show a weak preparation in math mixed with the epistemological obstacles observed in literature (Watkins and Elby 2013). Moreover, 20–25% gave no answers. This indicates the existence of a possible threshold in the construction of a functional understanding of physical concepts (RQ1).

Concerning RQ2, we have an indication that the engagement of students in analyzing questions typically evidenced as learning problems is effective not only to overcome that specific aspect but also to face dynamical situation. A threshold seems to exist also in this case. In any case a link between qualitatively/conceptual and quantitative questions emerged by data.

In the answers of quantitative questions, the majority of students adopted a (direct) proportional reasoning. This is for many students the only formal source that they adopt. It seems that the proportionality is the construct which builds the formal thinking of these students, and a great effort must be done to go over this construct in itself. Students used a descriptive/qualitative approach as a tool for prediction, more frequently than the interpretative/quantitative way of reasoning. About 20% of the student showed the extension of validity range of a physical law was out its range of validity (RQ3).

Our future research work will address how to increase the level of integration of physics in the areas of biological sciences in our approach, studying in particular how to improve the competencies of the students in the use of formal/mathematical tools.

Appendix: Items Included in the Written Questionnaires

NB: The first answer is considered the (more) correct one. A random order was used submitting the questions to students.

Q1. Water at environment pressure and temperature have a density of $\rho = 1000$ kg m^{-3} and a compressibility of $\chi = 6 \cdot 10^{-10}$ Pa^{-1}. Which expression give the variation $\Delta\rho$ of the density of water when is pressure increase of ΔP?

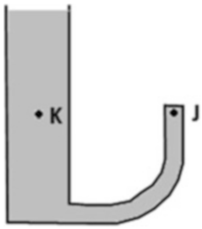
(A) $\Delta\rho = \rho\chi\Delta P$ (B) $\Delta\rho = \rho\chi/\Delta P$ (C) $\Delta\rho = \Delta P\chi/\rho$

Q2. A submarine is located at a depth such that the pressure exerted by the water on its walls is equal to $2.5 \cdot 10^5$ 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 toward the interior of the submarine?

(A) 7.510^3 N (B) 8310^6 N (C) 4510^3N

Q3. (Elaboration from Loverude et al. 2010) A container, such as that shown in the figure, is formed by the left open branch and the right closed branch. Compare the pressures at points J and K. Which relation is correct?

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



Q4. A nonviscous liquid of density $\rho = 1200$ kg·m^{-3} was flowing in a conduit between two circular sections A and B of area $A_B = 0.5\ A_A$. Section B is located at the same level of section A. In A the fluid pressure is $P_A = 60{,}000$ Pa and its speed is $v_A = 0.7$ m/s. What is the pressure of the liquid in B?

(A) 59,118 Pa (B) 60,221 Pa (C) 60,294 Pa

Q5. In a pipeline is flowing a fluid of density ρ. In a section A of the pipeline that is on the level h_A, the pressure is P_A and the speed is v_A. In a 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 of the relationship between the areas of the section A and section B?

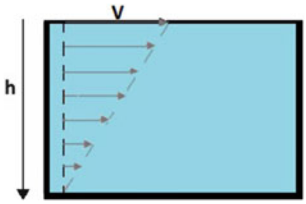
(A) This ratio depends on h/v_A^2.

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

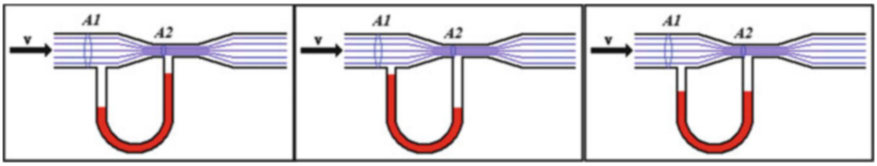
(C) This ratio is independent both from v_A and from h.

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 the figure. At what depth the water speed is half the speed with which it moves the surface layer of the water?

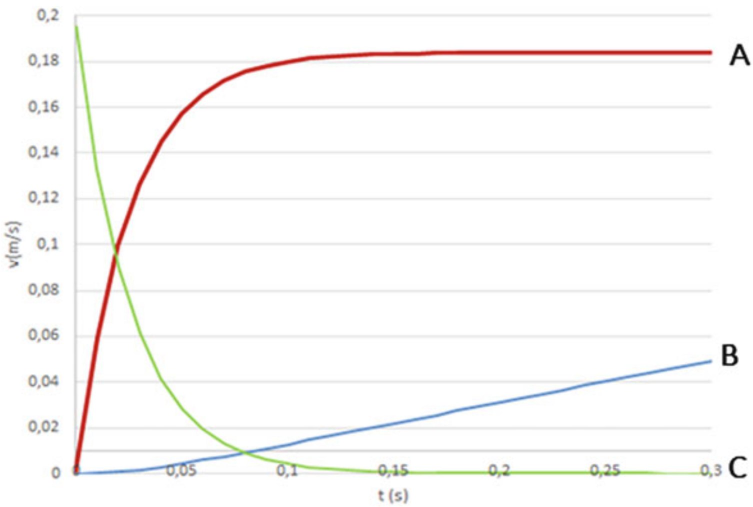
(A) h/2; (B) h; (C) h/4



Q7. A steady flow of water flowing in a conduit. A U-tube, which contains mercury, is inserted between the sections A1 and A2 of the conduit, the diameter of which is a double of the other. What figure best represents the height of the mercury in the two branches of the U-tube?



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



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