"Total force" on bodies immersed in air and water: An error living three centuries in physics textbooks

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ABSTRACT

This article presents numerous examples of an erroneous conception, stating that the "total force" by which a fluid acts on an immersed body is equal to the product of corresponding fluid pressure and the body's surface area. This conception, which started its long life at the beginning of XVIII century, still appears in today's physics textbooks published in different countries for different educational levels. It is formulated either as an "astonishing fact" or should be "discovered" through students' calculations. In the last case, students' knowledge may be unnecessary fragmented. Finally, a few differences between cultures of school and research physics are shortly discussed.

KEYWORDS

Total force on an immersed body, physics textbooks

RÉSUMÉ

Cet article présente de nombreux exemples d'une conception erronée, selon laquelle la «force totale» par lequel un fluide agit sur un corps immergé est égale au produit de la pression de fluide correspondant et de la surface du corps. Cette conception, qui a commencé sa longue vie au début du XVIIIe siècle, apparaît encore dans les manuels scolaires de physique d'aujourd'hui publiés dans différents pays pour les différents niveaux d'enseignement. Elle est formulée, soit comme un fait *«étonnant» ou devrait être «découverte» par le biais des calculs des élèves. Dans ce dernier cas, les connaissances des élèves pourraient devenir inutilement fragmentées. Enfin, quelques différences entre la culture de l'école et la culture de la recherche en physique sont brièvement discutées.*

Mots-Clés

Force totalesur un corps immergé, manuels scolaires de physique

Introduction

In the last tree decades, many studies have been carried out to know more how students and teachers think about phenomena explored by science and how they comprehend almost every single concept used in elementary science. A recent bibliography (Duit, 2009) about students' and teachers' alternative conceptions relevant for science education has almost 8,500 entries.

In physics education research, the focus was mainly on different conceptual difficulties students face in introductory college physics (McDermott & Redish, 1999) and on design and classroom testing of effective teaching strategies which help students overcome these difficulties which strongly interfere with their physics learning (Thacker, 2003).

Although textbooks play an important role in science teaching and learning, scientific accuracy and cognitive adequacy of their contents were explored and analyzed much less frequently than alternative conceptions of students and teachers. In addition, there were many different views of which aspects of textbooks are worth of research efforts and interpretations.

Some authors are interested in formulating different theoretical frameworks for analyzing and improving textbooks (Stinner, 1992; Dimopoulos, Koulaidis & Sklaveniti, 2005), while others pay attention to how they present nature of science (Abd-El-Khalick, Waters & Le, 2008) or how nature of science should shape textbooks (Guisasola, Almudi & Furió, 2005). There are also researchers who examine and evaluate more specific features of textbooks, like how textbooks use pictures (Stylianidou, Ormerod & Ogborn, 2002), how they treat analogies (Orgill & Bodner, 2006) or how they present scientists (Williams, 2002; van Eijck & Roth, 2008). Nevertheless, the most popular approach is to analyze how different textbooks deal with a particular theme, from relativity (Arriassecq & Greca, 2007) to digestion (Carvalho, Silva & Clement, 2007).

In this article, I present different aspects of one erroneous idea which holds, contrary to the well established magnitude of the buoyant force, that the "total force" a fluid (air or water) exerts on a body immersed in the fluid is equal to the product of the corresponding pressure and the surface area of the body. The presentation starts with the first documental appearance of this error in "Hydrostatical and pneumatical lectures" by Roger Cotes in XVIII century (Cotes, 1747; Cotes, 1775) and the forms this error took in XIX-century textbooks. After that I present terminological and unit evolution of this error, some of its pedagogical "transformation" and some examples of its geographical distribution. The article is closed by a brief consideration of a few differences between research and teaching cultures. These differences might be seen as possible causes of presence and surprisingly long duration of errors in physics textbooks.

This documental research related to a textbook error differs from the common ones. In those approaches, the authors just denounce particular errors, collecting evidence from a limited educational space and practice, and usually do offer no consideration about their previous historical metamorphosis and possible causes (Lehrman, 1982; Iona, 1987; Bauman, 1992a, 1992b, 1992c; Sawicki, 1996; Gearhart, 1996; Gauld, 1997; Santos-Benito & Gras-Marti, 2005).

The First Appearance of the Error

In 1644 Torricelli demonstrated the existence of a high vacuum above the mercury in the barometric tube. The fact that the mercury does not flow out of the barometric glass tube strongly challenges common sense. It was explained by Torricelli as a consequence of the atmospheric pressure exerted by the air on the surface of mercury in which the open end of the tube is immersed.

Blaise Pascal in his "*Treatise on the weight of the mass of the air*" (Pascal, 1937; Shea, 2003) accepted Torriccelli's idea of atmospheric pressure and used it skillfully to explain many phenomena which were "explained" before as a consequence of nature's fear of void ("horror vacui"), a conception of nature which goes back to Aristotle.

Pascal ends his treatise by a consideration about the total mass of the atmosphere:

> "…Nothing is easier than to compute the weight in pounds of an envelope of water thirty-one feet high, which surrounds the whole earth – for a child who knew how to add and subtract could do it; and in this very way the weight in pounds of the air in nature may be found, for it is the same. If this is done, it will be found that the air weighs close upon eight millions of millions of millions of pounds" (Pascal, 1937, p. 65).

The idea behind Pascal's calculation is to find the volume of spherical water envelope covering the Earth, to express it in cubic feet and to multiply the result with 72 pounds (one cubic fee of water weighs 72 pounds). In modern terms, Pascal found the "total weight of the air" multiplying the then-known value of atmospheric pressure (2,232 pounds per square foot) by total area of Earth's expressed in square feet. Strictly speaking, it is meaningless to speak about the "total weight" of the atmospheric air because the vectorial sum of weight forces on all one-square-meter unit areas of Earth's surface would be equal to zero. Nevertheless, the procedure may be used to estimate the "total mass" of the atmosphere because the mass is scalar quantity and the total mass is an arithmetic sum of the masses of its parts.

Experiments which demonstrate various effects of atmospheric pressure were introduced into college teaching by Roger Cotes (1682 – 1716), widely known for his work on the second edition of Newton's Principia. In 1706 Cotes was nominated to be the first Plumian Professor of Astronomy and Experimental Philosophy at the Trinity College, Cambridge. His first lectures, dictated in 1707, were dedicated to hydrostatical and pneumatical phenomena. Robert Smith published Cote's notes of these lectures in 1738, more than 20 years after Cotes's death. Later editions appear in 1747 and 1775.

In his hydrostatical and pheumatical lectures Cotes presented a calculation of the total mass of the atmosphere (Cotes, 1747; Cotes, 1775, p. 112-113). Knowing that such a big number means very little or nothing to ordinary people, Cotes represented the result in an analogical form: the total mass of the atmosphere is equal to the mass an enormous lead sphere with a diameter equal to almost 60 miles!

It is interesting to note that Cotes didn't mention Pascal's calculation of the total mass of the atmosphere, although he knew very well about Pascal's work related to atmospheric pressure.

By examining his published notes, one can find out that Cotes was the first to speculate erroneously about the magnitude of the "whole pressure" exerted by the air on human body:

> "… Ordinary pressure of the air, which our bodies are continually exposed to, which is equal at least to that of water at the depth of thirty two feet, or twenty thousand pounds" (Cotes, 1747; Cotes, 1775, p. 9).

In the case of an under-water diver, Cotes also applies this erroneous speculation twice:

> "… The whole pressure to which a diver is exposed at thirty two feet under water is about forty thousand pounds" (Cotes, 1747; Cotes, 1775, p. 9).

To calculate the whole water pressure of 20,000 pounds for a diver being 32 feet below the sea surface, Cotes took the value of 10 square feet for the area of human body. His numerical elaboration of the idea of "whole pressure" had this form:

> "Let it be required to find the pressure which a diver sustains when the center of gravity of the surface of his body is 32 feet under water. The surface of a middle-sized human body is about 10 square feet. Multiply then 32, the depth of the center under water, by 10, the surface of the body, and the product, or 32 times 10 solid fee, will be a magnitude of water whose weight is equivalent to the pressures which the diver sustains,… A cubick foot of water has been found by experiment to weigh 1000 averdupois ounces, therefore 32 time 10 feet, or 16 times 20 feet of water, will weigh 16 times 20000 averdupois ounces of 20000 averdupois pounds. This therefore is the pressure of the water to which a diver at 32 feet depth is exposed" (Cotes, 1747; Cotes, 1775, p. 43).

In order to comprehend this calculation, those readers who are not familiar with these old units should be told that "one averdupois pounds" is equal to "sixteen averupois ounces".

Atmospheric Pressure on Human Body in XIX-Century Textbooks

By the end of XVIII century and during XIX century, the idea of Cotes about atmospheric pressure over whole surface human body was widely used in English textbooks to impress general public by a false "fact": big crushing action which humans do not notice!

The "progress" was that the relation between the "total pressure" and "pressure on one square foot" became quite transparent. To get "total pressure" on human body, one has to multiply the "pressure on one square foot" by number of square feet contained in the surface of the average human body. Here come some examples:

> "…The atmospheric pressure on one square foot is 2,160 pounds. Multiply this sum by fifteen, the number of square feet on the surface of the human body, and the product will be 32,400 pounds, or somewhat more than fourteen tons, or the weight of more than fourteen ordinary cart-loads of heavy goods" (Dick, 1799, p. 27).

> "The pressure of the atmosphere on the body of a middle sized human being (reckoning its surface equal to 12 square feet) is 12 times 2088; that is 25056 pounds, or upwards of eleven tons" (Cavallo, 1813, p. 296).
> "… If we suppose the surface of the human body to be 11 square feet, the pressure upon it will be 22,968 pounds, or more than 10 tons…" (Willits & Smith, 1830, p. 175).

> "Upon so large a surface, therefore, as that of the human body, the pressure

amounts to no less than 13 or 14 tons; but being so uniformly distributed within and without, and on all sides, it is, when the air is at rest, scarcely perceptible" (Olmsted, 1835, p. 8).

This erroneous idea was not only an English syndrome, but was present in France, too. Textbook authors of two leading nations in science and science teaching shared the same error.

Below come two French example taken from Biot's and Ganot's textbooks:

"It was calculated up to how much can rise the totality of that pressure over the body's surface of a regular man and it was found that surpass 33000 pounds, or 16000 kilograms with a short difference" (Biot, 1826, p. 166).

"The surface of the body of a man of middle size is about 16 square feet; the pressure, therefore, which a man supports on the surface of his body is 35,560 pounds, or nearly 16 tons" (Ganot, 1877, p. 120).

The error entered into the XX-century textbooks "dressed" with now familiar unit (14.7 pounds per square inch) and with a new terminological construct "total atmospheric pressure":

"*Total Pressure Exerted by Atmosphere on Human Body* – The pressure of the air at sea level is about 14.7 pounds per square inch… Every square inch of the surface of the human body is subjected to a pressure of 14.7 pounds. Since the total surface of the body is equal to hundreds of square inches, the total atmospheric pressure upon the body amounts to a number of tons. It has been calculated to exceed 15 tons, or 30,000 pounds, for an average-sized person" (Miller & Foerste, 1903, p. 19).

Total Atmospheric Force in Actual Textbooks

In actual textbooks, the authors "corrected" erroneous idea of "total atmospheric pressure" by giving to the "product of pressures and total surface" the name "total force" or, shortly, "force". Namely, even students should know that the product of a pressure and a surface can not be a kind of pressure but must be a kind of force.

The spread of the error of "total force", being in air or in water is really global. In one or other form, the error is present in physics textbooks published and used in very different educational and cultural contexts, from India to America to Italy. I begin with the case of physics textbooks in India:

"*Pressure on human body* – Taking the total area of an average human body to be about 1.5 m^2, for force on a human body due to atmospheric pressure is

$$F = pA = (1.013 \times 10^5)(1.5) \approx 1.5 \times 10^5\ N$$

which equivalent to 1.5×10^4 kgf or 15 ton (nearly)" (Bhatnagar, 1996, p. 53).

"*Atmospheric Pressure on Human Body* – The atmospheric pressure is nearly 1 x 10^5 N/m^2. It means each 1 square metre of earth's surface experiences a force of nearly 1 x 10^5 N or 10,000 kg wt. The surface area of a normal human being is 1.5 m^2. Therefore, a total thrust of 1.5 x 10^5 N or 15,000 kg wt always acts on a human body…" (Prakash, 2007, p. 716).

The situation in American textbooks is important one because these textbooks are sold on the most competitive national market and have a strong influence in international markets, like those of Canada and Australia. In addition, via its Spanish translations those textbooks shape considerably physics teaching in Latin America. Nevertheless, even in American textbooks, one could find erroneous idea of the total force of the atmosphere on human body.

Serway and Faugh presented it in 1992 as a "fact":

"It is interesting to note that the force of the atmosphere on our bodies is extremely large, on the order of 30,000 lb! (Assuming a body area of 2000 in^2)" (Serway & Faugh, 1992, p. 259).

In 1996, they added only a slight change in wording:

"It is interesting to note that the force of the atmosphere on our bodies (assuming a body area of 2000 in^2) is extremely large, on the order of 30,000 lb!" (Serway & Faugh, 1999, p. 266).

Kirkpatrick and Wheeler used SI unit for the total force and gave to their students a hint how the number for that force came out (supposing the students knew that the atmospheric pressure is about 100,000 N/m^2):

"A typical human body has approximately 2 square meters (3000 square inches) of surface area. This means that the total force on the body is about 200,000 newtons (20 tons!)" (Kirkpatrick & Wheeler, 1992, p. 173).

In 1999 the error of "total force" was detected in some high-school American physics textbooks and denounced in leading pedagogical journal for physics teaching *The Physics Teacher*:

"Several books, in discussing the total force exerted on a body by the pressure of the atmosphere, add the forces on each surface, as if the force were a scalar, rather than a vector. Quoting from one book, "This pressure is called atmospheric pressure; the force it exerts on our bodies (assuming a body area

> of 2 m^2) is extremely large...” Actually, of course, the total force is approximately zero” (Entwistle et al., 1999).

Total force fluids exert on an immersed motionless body is the buoyant force. As everybody knows, it is equal to the weight of displaced fluid. In the case of air, its value can be found easily. A man whose mass is about 80 kg has volume of about 80 liters. That is, also, the volume of displaced air. Taking the density of air as 1.3 g/l, the mass of displaced air is about 100 grams. Being so, the buoyant force of air on a middle-sized man or woman is approximately equal to 1 N.

One could expect that after this error was denounced in such a widely read journal, it should disappear rapidly from the textbooks which contained it. Namely, at least some of many physics professionals involved in textbook business (authors, editors, reviewers and professors who recommend the textbooks to their students) should detect the denounced error and try to eliminate it from future editions.

Strangely enough, it didn’t happen, at least for the American physics textbooks mentioned above:

> “It is interesting to note that the force of the atmosphere on our bodies (assuming a body area of 2000 in^2.) is extremely large, on the order of 30,000 lb!” (Serway, Faugh, Vuille & Bennett, 2006, p. 281)

> “A typical human body has approximately 2 square meters (3000 square inches) of surface area. This means that the total force on the body is about 200,000 newtons (20 tons!)”(Kirkpatrick & Francis, 2004, p. 241; Kirkpatrick & Francis, 2009, p. 248).

Pedagogical Transformations of “Total Force”: Students should Calculate its Values for Humans and Other Objects

As it was demonstrated before, the error in question changed its form in textbook presentations, both in terminological and unit aspects. In addition, pedagogical changes took place, too.

One change is the following. Instead of being told “a fact” about the “total force of the air” on a person, students are given the task to calculate its value:

> “If your weight were 150 pounds, the surface of your body would have an area of about 17.3 square feet. What would be the total force of the air on your body?” (Black & Davis, 1932, Problem 9, p. 100).

The other “pedagogical transformation” is to change the context, from a familiar one (total force of air on a person) to abstract one (total force of air on a minimally - specified object).

For some authors, that abstract object can be a sphere and the task is not to find the value of the total force but its change:

> "If the mercury in a barometer falls from 29.8 to 29.4 inches, find the difference in the total forces which the atmosphere exerts on the outer surface of a sphere 2 feet in diameter" (Duncan & Starling, 1927, Exercise 1, p. 271).

The given answer is: 356 lb. wt. (ibid, p. 1070).

For other authors, the total forces are "explored" for two boxes:

> "You have two boxes. One is 20 cm by 20 cm by 20 cm. The other is 20 cm by 20 cm by 40 cm... How does <u>the total force of the air</u> compare on the two boxes?" (Zitzewitz, Neff & Davids, 1995, Concept Review 1.1, p. 277).

Justified answer presented by the authors is:

> "Force is proportional to surface area. The surface area of the first box is 6 (20 cm)(20 cm) = 2400 cm^2. The surface area of the second box is 2 (20 cm)(20 cm) + 4(20 cm)(40 cm) = 4000 cm^2, so force is (4000 cm^2)/(2400 cm^2) = 1.67 times as on the second"(ibid).

In the case of a box it is quite obvious that air forces on opposite sides should cancel. In addition, the calculations imply that the boxes are not resting on the ground (common sense knowledge) but that they are levitating in the air.

Even university physics textbooks, written having scientists and engineers on mind, suggest that it is physically acceptable to sum up the forces as if they were scalars:

> "A hollow stainless steel sphere of radius 20 cm is evacuated so that there is a vacuum inside. (a) What is the sum of the magnitudes of the forces that act to compress the sphere?…" (Fishbane, Gasiorowicz & Thornton, 1996, Problem 9, p. 456; Fishbane, Gasiorowicz & Thornton, 2005, Problem 9, p. 485).

Identical answers, 5.1×10^4 N, the authors gave in both editions (Fishbane, Gasiorowicz & Thornton, 1996, p. 0-7; Fishbane, Gasiorowicz & Thornton, 2005, p. 0-8) show that in almost a decade between two editions nobody in the community of professionals who revised or used these textbooks noted how meaningless and misleading is the task students have to deal with.

In what follows, a mini "case study" of the total-force tasks is carried out for two examples found in two Italian high-school physics textbooks (Amaldi, 1999; Caforio & Ferilli, 1997). One of them (Amaldi, 1999) is considered as the most influential physics textbook in Italy. The analysis is done with sufficient details to call attention to a neglected issue in research on school physics learning: possible negative effects that implicit incoherence of school physics tasks might produce in students' physics knowledge. Italian physics textbooks also illustrate global presence of the error in question.

"Total force" in Italian textbooks: Implicit incoherency of school tasks and possible negative effects in students' knowledge

Before entering into the analysis of implicit incoherency of the tasks related to the "total force", it is in place to ensure the readers that both textbooks state the Archimedes principle about the magnitude of buoyant force:

> "A body, immersed in a fluid in equilibrium, receives a buoyant force directed upward and equal in magnitude to the weight of displaced liquid" (Caforio & Ferilli, 1997, p. 249; Caforio & Ferilli, 1998, p. 331).

> "A body immersed in a fluid receives a buoyant force directed upward equal to the weight of the displaced liquid" (Amaldi, 1999, p. 280).

What both textbooks do not do is to treat pedagogically the research results that students are not able to accept easily scientific vies about buoyant force. Namely, students consider many fine details floating and sinking as important ones and are not able to abandon them only by being exposed verbally to the canonical knowledge.

Students believe, for instance, that the buoyant force depends on the weight of the immersed body or on its depth, or that "ability to float" or "ability to sink" is an intrinsic property of any body not depending on the fluid it is immersed in. Due to these deeply-rooted beliefs, traditional teaching is not successful and instead a specially designed teaching, based on the "learning circle" for buoyant force, should be implemented in classrooms (Su, 1995).

The incoherence defect of school physics knowledge is the following one:

> Textbook authors, when designing numerical problems, forget the canonical knowledge they stated at another page.

In other words, the text of some numerical problems contradicts, implicitly or explicitly, established canonical knowledge. Needless to say, such a lack of coherency is hardly possible in research culture of professional physics. Further comments on this and other differences between school and research physics culture will be given in concluding remarks.

To demonstrate the existence of mentioned incoherency and to speculate about its likely impact on some students' knowledge and learning, I will analyze, from a hypothetical students' point of view, two examples of the "total force" tasks in above mentioned textbooks and "correct answers" given by their authors.

The examples of "total force" tasks are:

> *Example 1*
> "Calculate the force which acts on surface of an iron ball with radius of r = 0.50 m which is placed at the depth of 100 m under the sea level. Density of the sea water is equal to 1,028 kg/m^3" (Amaldi, 1999, Exercise 13, p. 21).
>
> *Example 2*
> "A body with a surface of 1 m^2 is immersed at a depth of 100 m under the sea level. Knowing that the density of the sea water is 1.03 g/cm^3, calculate the force acting on the body" (Caforio & Ferilli, 1997, Problema 4, p. 447; Caforio & Ferilli, 1998, Problem 4, p. 390).

It is interesting to note that these tasks are, in a strict physical sense, similar to the problem of finding "total pressure" suffered by a diver under water surface, considered conceptually and numerically by Roger Cotes. The difference is already-mention shift from a familiar context (diver) to an abstract (a body) or unlikely one (an iron ball at the depth of 100 m).

To answer the question in the Example 1, the students could try to use directly the canonical view on the magnitude of the buoyant force (presented in the textbook):

> The resultant force F is equal to the weight of displaced salt water whose volume V is that of the immersed sphere.

Formula which quantifies the buoyant force is:

$$F = \rho V g$$

where ρ is the density of the salt water and g is the strength of Earth's gravitational field.

It is plausible to suppose that both quantities don't change too much regarding their value at the surface, even if the depth were 100 m.

The volume of a sphere with radius r = 0.50 m is V = 0.52 m^3. Taking ρ = 1,028 kg/m^3 and g = 9.8 N/kg, the resultant (buoyant) force on the body in question would be:

$$F_1 = 5.24 \cdot 10^3\ N.$$

Surprisingly for the students, this is roughly 1,000 times smaller than the result given by the author: 3.5×10^6 N (Amaldi, 1999, p. 53).

In the second example, no quantity in the formulation permits to calculate the exact volume of the body. Namely, the authors did the "dirty work" and prepared everything for a "clean application" of the formula:

$$F = p \cdot S,$$

where p is the corresponding pressure and S is the given area.

Nevertheless, some bright students, knowing that for a given area a spherical body has the greatest volume, could conclude that it is possible to determine upper value of volume and, consequently, the upper limit of the buoyant force. As a sphere with area of 1 m^2 has a volume of 0.094 m^3, the maximum value of buoyant force would correspond to the weight of see water having that volume.

Taking ρ = 1,030 kg/m^3 and g = 9.8 N/kg, these students would reach the conclusion that the force on the body cannot be greater than:

$$F_2 = 9.49 \cdot 10^2\ N \approx 10^3\ N.$$

As the result given by authors is 10^6 N, the difference is again a factor of about 1,000 and the students would be left again with a big confusion.

What Some Students might Think and Do?

Believing that textbooks are always right, many students will try to "learn physics" which would help them to get the "correct answer". Trying to "understand" the "correct" answers the authors gave, they might start to create an alternative conception regarding the resultant force by which a fluid allegedly acts on immersed bodies.

After some mathematical exercises in the style "let us see what comes out", they might be able to reconstruct the "correct answers" discovering the "truth" that "deep water" resultant force F_{deep}, by which a fluid acts on a deeply-immersed body, is given by the formula:

$$F_{deep} = p \cdot S,$$

where p is "pressure" on the place where the body is located and S corresponds to the total area of the body.

Students taught by a teacher who follows the textbook of Amaldi would have to conclude that the "correct pressure" is equal to the absolute pressure in a fluid at the depth of h:

$$p_A = p_0 + \rho g h,$$

where p_0 = 1,01 x 10^5 Pa is atmospheric pressure at the see level, while ρ and g are the same as defined above.

That idea is based on the "fact" that such a formula leads to the "correct result". Namely, in Example 1, the values of the quantities involved are:

$$h = 100 \text{ m};$$
$$\rho = 1{,}028 \times 10^3 \text{ kg/m}^3; \text{ and}$$
$$g = 9.8 \text{ N/kg}.$$

Inserting these values in (3), one gets $p_A = 1{,}11 \times 10^6$ Pa. As the area of a sphere with $r = 0{,}50$ m is $S_1 = 4\pi r^2 = 3{,}14$ m^2, the resultant force, according this conception, would be:

$$F_A = 3{,}49 \cdot 10^6 \, N,$$

what is very close to 3.5×10^6 N (the result given by the author).

At the other hand, the students taught by a teacher who follows the textbook by Caforio and Ferilli, would have to conclude that the "correct pressure" is only hydrostatic pressure:

$$p_{CF} = \rho g h.$$

Again, only such a formula leads to the "correct result".

In *Example 2*, the values of the quantities involved are:

$$h = 100 \text{ m};$$
$$\rho = 1{,}03 \times 10^3 \text{ kg/m}^3; \text{ and}$$
$$g = 9.8 \text{ N/kg}.$$

Inserting them in the last equation, one gets $p_{CF} = 1{,}01 \times 10^6$ Pa. As the area of the body $S_2 = 1$ m^2, the resultant force, according this conception, would be:

$$F_{CF} = 1{,}01 \cdot 10^6 \, N,$$

again very close to 1×10^6 N (the result given by the authors).

In other numerical problems, students have to construct a different idea related the value of pressure at some depth. The total pressure is calculated summing hydrostatic and atmospheric pressure. So, for the students using textbook written by Caforio and Ferilli, the fragmentation becomes more complicated and the formula to be used for calculating pressures depends on the task:

"hydrostatic pressure only" is used when calculating force on the deeply immersed body, and

"hydrostatic plus atmospheric pressure" is used when calculating the value of total pressure.

In order to avoid conflicts with the idea of the buoyant force, equal to the weight of displaced water, the students might likely connect:

(a) “old” buoyant force with “shallow” situations or with the situation when the body is immersed in the water in a vessel, and
(b) “new” alternative conception of “total force” with “deep” situations.

This phenomenon of constructing many different pieces of knowledge, every one being valid only in a very specific situation, is known as “fragmented knowledge” (Bagno, Eylon & Ganiel, 2000; Linn & Eylon, 2000). As many results of novice-expert research paradigm show, “fragmented knowledge” is a common feature of novice students’ way of science learning. A good teaching design should help students get closer to expert-like knowledge integration (Linn, Clark & Slota, 2003). While other types knowledge fragmentation are due to limited practical experiences and lack of vision of the nature of scientific knowledge construction, in the above “total force” tasks “fragmented knowledge” might likely be caused by incoherency of school physics “knowledge” as presented in textbooks.

In addition, those students who like to look at the same theme in different textbooks might be confused even more. They could note, after a fine-grained analysis, that different authors differ strongly regarding what the pressure p giving the “total force” should be (for Amaldi it is “hydrostatic plus atmospheric pressure” and for Caforio and Ferilli it is only “hydrostatic pressure”!).

There is no easy “shallow/deep” remedy for this important discovery about physics textbooks. The real way out for the students is to conclude that some textbook authors make mistakes and that everything said in textbooks must be taken cum grano salis. To promote that important idea in students’ beliefs about physics learning in school settings, I designed for the physics textbooks I wrote a section named “Do not believe everything you read” (Slisko, 2002; Slisko, 2003; Slisko, 2008; Slisko, 2009). In this section, examples of authentic textbooks errors (without mentioning names of authors and titles of textbooks) are presented and students are guided to understand the nature and implications of these errors.

Some Concluding Remarks: How are Research and School Physics Different?

A decade ago, disturbing considerations about important differences between doing and teaching physics were formulated by Rigden (1998) and Redish (1999). Rigden was troubled, for instance, by little or no peer-reviewing in physics teaching. Redish, almost desperately, asked:

> “What is it that allows us to build our knowledge of physics in a cumulative way while in physics education we seem to be doomed to everlasting cycles of pushing the Sisyphian rock up the hill only to have it roll down again?” (Redish, 1999).

Considering physics textbooks as a very relevant element in physics teaching and learning, the presence of errors in them reveal some additional troubling features of "culture of teaching": While writing textbooks, even most distinguished research physicists do, here and there, careless things they would never do (or, even better said, they would never ever be allowed to do!) in research.

For example, one of Italian authors, who presented the "total fluid force" error in their textbooks, is Prof. Ugo Amaldi. He is not a low-profile physics teacher but a well known research physicist (see Amaldi's short but still impressive CV at Amaldi, 2004). Here come some contrasting details between teaching and research culture.

While a textbook author, Amaldi invents an irrelevant situation as an appropriate "context" for students to "learn" physics. Does anybody care about the force on a metal ball 100 m under the surface? In real world, who would ever create such a situation? In contrast, while writing a research proposal, the problem situation to be explored theoretically and experimentally with public or private money, must be convincingly justified as "a relevant one" for a real progress of physics knowledge.

Secondly, for that irrelevant situation Amaldi suggests an erroneous conceptual and numerical treatment which contradicts established canonical knowledge. By definition, the buoyant force is the total force exerted by the fluid on immersed (stationary) body. In addition, contrary to the suggested calculation, in real-world the atmospheric pressure doesn't matter and the buoyant force depends only very slightly on the depth (water density minimally increases with depth). So many errors related to a simple physical law are almost impossible to happen in research paper, due to numerous quality-control mechanisms existing in research community (talks and discussion at research seminars, preprint circulations inside a group of experts and peer-reviewing in research journals).

Thirdly, Amaldi and teachers who use his textbook didn't think critically about physical meaning of the result they gave to the students as "correct one".

For those who might say that the mentioned difference between teaching and research culture is an exaggerated generalization based on "only one error of only one research physicist", a few more examples of obvious and subtle conceptual errors made by famous physicists are in place.

Speaking about planetary motion, Victor Weisskopf said that "the centrifugal force is just balanced by the attractive force of gravity" (Weisskopf, 1992).

Nobel Prize Winner, Sheldon Glashow has completely erroneous drawing and calculation of the image position of a diamond ring resting at the bottom of a swimming pool. Based on them, he says: "The ring appears to be much further from the edge than it really is" (Glashow, 1994). Other Nobel Prize Winner, Richard Feynman made a number of errors and erroneous statements regarding real and inertial forces in rotating systems (Tiersten and Soodak, 1998).

It is quite normal in research that, from time to time, some semi-grasped conceptual ideas lead physicists in their calculations. Nevertheless, these ideas are normally quickly improved thanks to critical thinking of research community. The fact that the concept of the "total force" appears as a "correct physics application" in so many textbooks shows that critical thinking is not a necessary, every-day practice in the culture of teaching.

The "total force", or better said, the "ghost force" created by the above conception is in collision with everything what is known about the relevant forces which do act in considered situation (buoyant force and gravitational force).

If magnitude of a force is more than a number coming from a formula, one should generally stop and think about its effects on the body it acts on.

Huge value of the "ghost force" should have been enough reason to activate some doubts about its existence in real-world, physics as science supposedly deals with. For the metal sphere with radius r = 0.50 m, that "force" is more than 600 time bigger than buoyant force and more than 80 times stronger then gravitational force. So, the "ghost force" would be, in the first approximation, the only acting force in the situation, and, consequently, it would give to the metal ball a tremendous initial acceleration.

The natural question is: In which direction would the sphere accelerate or, what is similar, in which direction is the "ghost force" acting? Upward, downward or sideward? If the answer does not come out easily, for a critically-thinking person it would be another signal to examine this "force" more closely.

Another checking strategy, commonly used in research, is to apply an emerging conception to some real and well known system in a similar condition. As it was already said, a solid metal sphere at the depth of 100 m is a very artificial situation, which can hardly happen in any purposeful human activity, except in end-of-chapter exercises of school physics.

If such a "force" really existed, what would be its effect on real objects like submarines, which are hollow vessels going deeper in the see and having greater surface/volume ratio than a solid sphere? As no strange and huge accelerations have ever been detected during submarine deep-sea trips, the only conclusion is that such forces act only in the careless imagination of some textbook authors.

When that imagination is a part of their private world, nobody should complain. But when this imagination enters into schools and starts to be something what students should "learn", suffering all types of negative feelings (ranging from frustration to confusion) and having to construct a false belief that only important knowledge is that one leading to "correct" textbook answers, then physics teaching community must be very concerned. These concerns should be even greater, if a similar situation was imagined and erroneously treated by Roger Cotes three centuries ago.

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