Identifying First-Year Science Students' Difficulties: Results From The Online French Physical Society Questionnaire

Estelle Blanquet[a] and Daniel Hennequin[b]

Corresponding author: Estelle Blanquet (estelle.blanquet@u-bordeaux.fr)
[a]LACES, INSPE de l'Academie de Bordeaux, University of Bordeaux, France, orcid : https://orcid.org/0000-0003-0143-9077
[b]PhLAM, University of Lille & CNRS, UMR 8523, France

Keywords: Physics Assessment, First year at University, online questionnaire

Abstract

A large-scale study involving 5891 first year science students from various French tertiary education tracks (University, preparatory classes for engineering schools and technological university institutes, etc.) conducted over 9 years allows us to document the understanding of physics concepts and the mastery of basic mathematical tools after completion of the baccalauréat (French high school exit examination). We observe a level of mastery well below the skills expected at the end of high school, which first-year university teachers rely on to organize their courses. We also observe a significant decline over time of student achievement scores during the 9 years of the study. We discuss the need to adapt first-year university courses to the actual skills of new students, rather than those they are assumed to have acquired.

Introduction

In the past few decades, the once rather selective French curriculums in science have undergone transformations. At the same time, first-year lecturers at numerous French universities and members of the French Physical Society (SFP) are pointing to a growing gap between traditional expectations of first-year students and what they perceive to be their actual level of ability in the sciences.

More specifically, first-year lecturers from nearly fifteen universities have told the SFP Education Committee of their growing difficulty in adapting to a population whose level of ability is below their expectations, while at the same time the French Ministry of Education claims that the lycée curriculum (Ministry of French National Education, 2019) is well suited to students entering higher education, and perhaps even with a more varied scientific culture than previous generations of students have been able to afford (Inspection Generale, 2022). Some universities have set up placement tests to help them organise additional lessons, but there is no national system to monitor the evolution of students' understanding of physics concepts and mastery of basic mathematical tools, and no large-scale studies, hence no consensual overviews, were available.

In 2013, the French Physical Society decided to address the matter by developing a questionnaire (SFP QCM, http://qcm.sfpnet.fr/ available online with registration) to assess the entry level in tertiary science education and to help University teachers identify their students' difficulties (Georgiou & Sharma, 2020). To this date, more than 6000 first-year science students, from a variety of university courses, have taken this test. The purpose of this article

is to present these results, and to discuss the evolution of understanding of phenomena by cohorts of students over nearly a decade.

The French Context: *Baccalauréat* and various science tracks

In France, all senior high school students (17-18 y.o., typically) take a national examination, the *baccalauréat* (K12). Once rather selective, with well-identified specializations more or less determining their future orientation (such as "Bac S" for science, "Bac L" for literature, etc.), the *baccalauréat* has been deeply reinvented. First, the official objective is now for at least 90% of all young French people to obtain this diploma. While this objective isn't fully attained yet, the success rate for those actually taking the exam is indeed above 90% (79,3% of the 2023 age group, Ministry of French National Education, 2023). While some claim that these results correspond to a betterment of the general education levels, other tend to consider that, to the contrary, they are obtained by lowering the level of the exam (Le Monde, 2018).

Second, the various high school tracks (S, L, etc.) have been replaced by a system of options (*spécialité*). For their next-to-last year of high school (*première* in French), sophomores have to choose first three options (*spécialité*) among thirteen available to them. In their last year, seniors have to reduce this number to only two options. A direct corollary is that students who choose 'Physics & Chemistry' and Mathematics as their options no longer receive any teaching in biology or in 'science & engineering', which constitute different options. Each option is subject to a national curriculum and a number of teaching hours set by the French Ministry of Education: students receive 3 hours of teaching per week and then 6 hours of teaching per week during their last year of high school.

Any high school student having passed their *baccalauréat* is entitled, by law, to a place in the tertiary education system. Since the number of places offered by the universities in their Bachelor in Physics courses is usually higher than the number of candidates, any laureate, regardless of their high school options, is virtually guaranteed a place in these programs.

This state-funded, hence financially very accessible, university-track in physics is in competition with four other, usually more selective tracks:
- Preparatory classes for engineering schools. Most of these *classes préparatoires aux grandes écoles* (CPGE) are also state-funded but are selective and include intensive training.
- "Integrated" engineering school, somewhat less prestigious, with a five-year program integrating the preparatory (2 year) and specialized (3 year) tracks. Such schools can be either state-funded, or private and rather expensive.
- "Specialized Technician" courses (BTS). These selective and usually state-funded two-year professional course, aim at a rapid integration into professional life as technician.
- University Bachelor of technology (BUT) are state-funded and selective three-year professional course; they also aim at a rapid integration into professional life as technician; contrary to the BTS, this diploma allows students to continue their studies in a Master-level degree.

Online Physical Society of France Questionnaire

The latest statistics show that only a small fraction of students who have followed a scientific course in high school choose to go to university for studying science (General Inspection, 2022). Many students therefore enter university as a second-choice stream after being rejected by selective streams. Even if this phenomenon is known and identified, including at the

ministerial level, it has yet to be accurately documented using data from ParcoursSup, the software that all students wishing to enter higher education (university and other streams) must go through. Considering the lack of national data, the French Physical Society decided to create a nation-wide and anonymous multiple-choice questionnaire to provide information about two issues, not reported by the French Ministry of Education:

a) what are the impacts of the reforms of the high school national curriculum on the understanding of the concepts taught in physics by students and:
b) what are the actual difficulties of the students entering higher education?

The French Physical Society (SFP) has designed an online questionnaire (MCQ, 2013, available at this address: http://qcm.sfpnet.fr/) to help university teachers identify their students' difficulties. The teachers participate in the operation on a voluntary basis, the information being disseminated on the SFP website and sent to all its members as well as to the members of the CPGE teachers' association. Registration and creation of a session are easy to implement (less than two minutes for a teacher).

The MCQ has been designed to obtain in a very limited time (one hour) an overview of the knowledge and understanding of their students. For this reason, the questions are short and the answers are equally short, with the systematic possibility for students to answer “I don’t know”, the questionnaire being anonymous. With four parts (basic mathematics, mechanics, waves and scientific culture) and around 100 questions, it provides immediate feedback to students and their teachers on the answers provided. Each part must be validated before the student can move on the next and the order of questions is the same for all students. It also allows for the collection of data from all over the country.

This MCQ, the content of which was chosen to comply with the high school curriculum (MEN, 2021), consists primarily of questions testing the understanding of concepts (almost no calculations). It is based on situations identified as likely to induce reasoning difficulties (Viennot, 1996) or on basic content (Kamcharean & Wattanakasiwich, 2016) and is inspired by existing questionnaires (FCI, 1992 for example). Designed by the first author, the questions were validated by members of the teaching commission of the SFP, the French Mathematical Society and the association of French physics-chemistry teachers in high schools, both in terms of content and wording. To ensure that they were well understood by the students, twenty second and third year students enrolled in a multidisciplinary bachelor in 2012 took a first version, the taking of the questionnaire being followed by an exchange with the students to ensure their good understanding of the questions asked. Even if ten years later, the understanding of certain synthetic formulations could appear more complex for the students, we made the choice to keep the initial questions intact over time (the test being identical in all administrations).

Data collection

Launched in 2013, this questionnaire was taken by a grand total of 5891 students (Table 1) entering mostly either preparatory classes for engineering schools (4009) or universities (1882) between September and end of October, two to four months after their baccalaureat success. It provides an admittedly partial view (but the only one available to our best knowledge) on the evolution of French students' understanding of concepts by the end of high school.

Table 1. Numbers of participants in the MCQ, by tracks

	2013	2014	2015	2016	2020	2021	2022
CPGE	637	63			1824	826	659
Universities	713	336	225	133	15	95	365
Total	1350	399	225	133	1839	921	1024

The variation in the number of respondents from one year to the next depends on the effectiveness of the communication of the SFP and its partners with first-year university teachers and the large number of participants in September 2020 reflects the concerns related to the effects of confinement on student results.

Basic mathematics questions

The first mathematical section contains 36 questions and begins with basic questions designed to build student confidence: powers of ten, then unit conversion, calculus on polynomials, fractions, derivative and integral of trigonometric, logarithmic and polynomial functions, projections on axes, proportionality, surfaces and volumes (sphere and cube):

- Ma1: *n objects cost x euros, how much do 6 objects cost?* nx/6 ; 6x/n ; 6n/x €
- Ma2: *1 cubic centimetre corresponds to*: 1dL / 1cL / 1 mL
- Ma3: *the surface of a disk of radius R is:* $4/3\pi R^3$ / 2π / πR^2
- Ma4: *Consider the relation U=RI. U remains constant. When R increases I*: increases / decreases / stays constant
- Ma5: *In a cube of 10 cm side, how many cubes of 1 cm side can you put?* 100 / 1000 / 10 000
- Ma6: 1/a + 1/b =: 1/(a+b) ; ab/(a+b) ; (a+b)/ab

Waves questions

In addition to knowledge questions (speed of light and sound in air), the part on waves (15 questions) probes the students' ability to manipulate the relationship between frequency and period, wavelength and frequency, to distinguish the difference in nature between an electromagnetic and sound wave and the memory of different notions acquired in high school (diffraction, Doppler effect, energy/frequency relation):

- W1: *The louder a sound is, the faster it travels through the air:* True / False
- W2: *A sound wave of frequency 100 Hz travels at 300 m.s*$^{-1}$. *Its wavelength is*: 3m / 3000 m / 30 000 m
- W3: *As the period of a wave increases, its frequency increases*: True / False
- W4: *Sound waves are electromagnetic waves corresponding to wavelengths outside the visible range*: True / False
- W5: *when a sound source of a given frequency quickly approaches an observer the frequency of the perceived sound increases*: True / False

Mechanics questions

Most of the 26 questions on mechanics focus on understanding the relativity of motion and Newton's three laws in different contexts, some of which are likely to raise misconceptions. The comparison of the answers of a same student to the questions posed in different contexts then makes it possible to test the robustness of his understanding. This part also includes several

questions to check their ability to reactivate knowledge (weight/mass relationship, period/length relationship for a simple pendulum, work and kinetic energy, definition of acceleration, etc.):
- M1: *A child is on a merry-go-round. His mother, sitting on a bench, sees it spinning at a constant speed. In relation to the child, it is not the merry-go-round but his mother who is spinning*: True / False
- M2: *A train moves at a constant speed in a straight line horizontally. A passenger drops his wallet. It falls*: far behind him/far in front of him/at his feet
- M3: *For an observer sitting in a meadow watching the train go by and for a passenger on the train sitting watching the event, the forces on the wallet are the same*: True / False
- M4: *In a Galilean frame of reference, two bodies of different masses are subjected to an identical force. The one subject to the greater acceleration is*: the most massive / the less massive
- M5: *A footballer kicks a ball. The action of the air is neglected. As the ball rises, there are two forces acting on it: its weight and a force tangential to the movement*: True / False
- M6: *The pull of the Sun on the Earth is much greater than the pull of the Earth on the Sun*: True / False
- M7: *On a flat road, a person pushes his broken-down car. The force he exerts on the car is greater than the force the car exerts on him*: True / False
- M8: *A juggler is in a tram that moves at a constant speed in a straight horizontal line. To catch the balls he throws, he has to throw them*: a little in front of him / vertically as if he were on solid ground
- M9: *A juggler (wearing a spacesuit) is on the moon. He moves in a straight line at a constant speed. To catch his balls, he has to throw them*: a little in front of him / vertically as if he were standing still.
- M10: *On Earth, the weight of a person weighing 60 kg is approximately:* 6N / 60N / 600N

General knowledge questions

The General knowledge part contain 28 questions and cover other fields of the high school curriculum (relation between pressure/temperature, pressure/altitude, ideal gas law, change of state of matter, thermal transfers, astronomy) but also areas for which we felt that a student leaving the education system should have minimum knowledge:
- G1: *As altitude increases, atmospheric pressure increases*: T/ F
- G2: *The boiling temperature of water increases with altitude*: T/ F
- G3: *Helium can be cooled to -290°C*: T/ F
- G4: *A stone and a feather are dropped on the Moon from the same height. They arrive on the ground at the same time*: T/ F
- G5: *It is warmer in summer than in winter because the Earth is closer to the Sun*: T/F
- G6/G7: *An ice cube / vodka bottle is taken out of from the freezer (-18°C) and its temperature is measured immediately. What do we find?* -18°C / -10°C / 0°C

Data analysis

The French Ministry of National Education has launched a profound reform of high schools leading to the arrival in September 2021 of the first students from the reform. We decided to take this cohort as a reference cohort to compare the evolution of student scores in physics over time and before and after the reform. The students were divided into four groups of similar numbers and the cut-off percentages corresponding to these different groups were used to distribute the students of the previous and following years.

Results

Global results of CPGE classes and university students from 2013 to 2022

Based on the 2021 cohort, four groups with similar numbers of students were determined: scores less than 49%, scores between 49% and 59%, scores between 59 and 70% and scores above 70%. Table 2 and table 3 show, respectively, the distribution of the students in CPGE classes and university students in the different groups and their evolution among time.

Table 2. Distribution of the CPGE students in the different groups and evolution between 2013 and 2022

Scores CPGE	2013	2014	2015	2016	2020	2021	2022
≤ 49 %	6,9%	4,8%			12,2%	24,1%	17,8%
≤ 59 %	25,1%	34,9%			26,3%	25,4%	32,0%
≤ 70%	32,7%	33,3%			29,7%	25,7%	28,5%
> 70%	35,3%	27,0%			31,9%	24,8%	21,7%
Nb. of participants	637	63			1824	826	659

In 2013, a large proportion of CPGE students had high scores and very few had low scores, which was to be expected given the selective nature of their recruitment (the CPGE welcoming a limited number of students for intensive training preparing them to take the competitive exams to enter engineering schools). The year 2021, which is taken as a reference and which is both the year of arrival of the first students resulting from the reform of the programmes and where the incoming students had received a disrupted education following the Covid, appears to be the year with the most students with the lowest scores. While the proportion of students with more than 59% of correct answers is high, it falls between 2013 and 2022, from 68% to 50.2%, while the number of students with less than 49% correct answers almost triples from 6.9% to 17.8%.

Table 3. Repartition of the university students in the different groups and evolution between 2013 and 2022

Scores Universities	2013	2014	2015	2016	2020	2021	2022
≤ 49 %	28,8%	33,3%	32,4%	27,8%	33%	47,4%	34,0%
≤ 59 %	33,2%	31,3%	36,4%	29,3%	40%	24,2%	38,4%
≤ 70%	24,1%	24,7%	21,3%	26,3%	7%	20,0%	22,5%
> 70%	13,9%	10,7%	9,8%	16,5%	20%	8,4%	5,2%
Nb. of participants	713	336	225	133	15	95	365

For university students in 2013, there is a large proportion of students with low scores and very few with very high scores. The year 2021 taken as a reference appears to be the year with the most students with the lowest scores. While the proportion of students with more than 59% of correct answers is about 38% in 2013, it falls between 2013 and 2022, to 27.7% (2020 results can not be compared to the others groups due to a very small sample size).

Evolution of the understanding of basic mathematical skills between 2013 and 2022

Questions Ma1-6 were deliberately testing very basic mathematical skills, corresponding to levels expected from junior high school (Ma3, 5 & 6) or even elementary school (Ma1, 2 & 4)

pupils, and which could *a priori* be considered as fully mastered by high school graduates, and especially by those choosing a physics track in superior education.

The first obvious result of this study is, unfortunately, to support the observation of many teachers, that even very elementary skills cannot be implicitly considered as such. While the most striking statistics concern basic conversion skills (less than 60%, and down to less that 24% for some populations, of students able to convert cm^3 into mL, Ma2), the fail rate always remains above 5% for all 6 questions and all populations, and in most cases closer to 20% or even 40%.

The results (table 4) confirm the expected difference in level between the more selective CPGE classes and universities populations. They also document, for both tracks, albeit at different rates, a significant decrease between 2013 and 2022 of the population in the group with the highest scores (within the hypothesis of a normal distribution (Gaussian statistics) the expected standard deviation would be around 4% for a N=637 sample. The observed evolutions lie between 0,9% (Ma3, Universities) and 8,9% (Ma1 CPGE). We thus considered evolutions >4% (more than one standard deviation) to be significant and above 8% (more than 2 standard deviation as highly significant).

Table 4. Evolution of basic mathematical skills between 2013 and 2022

	CPGE				Universities				
	2013	2020	2021	**2022**	**2013**	2014	2015	2021	**2022**
Ma1	**79,6%**	72,6%	69,5%	**70,7%**	**68,1%**	69,0%	64,9%	66,3%	**63,6%**
Ma2	**46,6%**	57,5%	52,1%	**50,8%**	**49,6%**	28,6%	23,6%	34,7%	**43,0%**
Ma3	**80,8%**	82,1%	72,7%	**71,6%**	**62,7%**	59,8%	54,2%	63,2%	**63,6%**
Ma4	**94,8%**	92,7%	87,4%	**92,6%**	**85,4%**	86,0%	80,0%	76,8%	**78,4%**
Ma5	**72,8%**	72,4%	65,4%	**67,4%**	**52,4%**	49,7%	54,2%	63,2%	**57,8%**
Ma6	**94,2%**	93,5%	88,3%	**90,6%**	**84,6%**	73,5%	76,9%	82,1%	**77,3%**

Evolution of the understanding of basic wave concepts between 2013 and 2022

While questions W1-5 were designed to address high school level concepts, the success rates (table 5) appear generally comparable to those obtained with the more elementary mathematical skills.

Table 5. Evolution of the understanding of basic concepts wave between 2013 and 2022

	CPGE				Universities				
	2013	2020	2021	**2022**	**2013**	2014	2015	2021	**2022**
W1	**84,3%**	80,8%	75,1%	**78,8%**	**72,1%**	67,9%	72,4%	71,6%	**59,7%**
W2	**74,3%**	69,2%	52,7%	**59,3%**	**53,4%**	53,6%	56,9%	40,0%	**50,4%**
W3	**92,5%**	90,1%	77,9%	**84,5%**	**81,5%**	73,2%	76,9%	65,3%	**66,0%**
W4	**74,4%**	67,9%	54,2%	**52,5%**	**49,7%**	52,1%	48,0%	36,8%	**36,2%**
W5	**87,6%**	86,8%	79,4%	**72,7%**	**73,0%**	76,5%	79,1%	70,5%	**73,4%**

Evolution of the understanding of mechanics between 2013 and 2022

The same two general tendencies are also observed with the questions concerning Mechanics (table 6). Yet, since many of them concerned the concept of Galilean relativity, these particular

results appear to be biased by the strong Copernican paradigmatic pressure, and their careful interpretation called for a more detailed discussion of the exact formulations, triggering or not, of the questions, which fall outside the scope of this article, and is presented separately in (Blanquet & Picholle, 2019).

Table 6. Evolution of the understanding of mechanics between 2013 and 2022

	CPGE				Universities				
	2013	2020	2021	**2022**	**2013**	2014	2015	2021	**2022**
M1	**82,3%**	82,8%	79,5%	**77,8%**	**71,3%**	67,3%	71,1%	72,6%	**72,1%**
M2	**81,8%**	82,5%	79,3%	**79,7%**	**76,2%**	72,6%	72,9%	83,2%	**71,5%**
M3	**41,0%**	37,3%	45,0%	**43,1%**	**39,8%**	39,9%	48,0%	40,0%	**40,3%**
M4	**51,2%**	51,0%	52,2%	**51,3%**	**46,2%**	44,3%	44,0%	29,5%	**45,5%**
M5	**43,2%**	27,2%	31,5%	**33,7%**	**28,3%**	27,4%	26,2%	22,1%	**17,0%**
M6	**65,0%**	59,9%	49,4%	**47,0%**	**48,7%**	48,5%	46,7%	31,6%	**33,4%**
M7	**37,4%**	33,3%	31,5%	**31,4%**	**36,3%**	34,8%	27,1%	25,3%	**31,0%**
M8	**85,7%**	83,4%	79,4%	**78,5%**	**76,3%**	76,2%	73,8%	72,6%	**77,3%**
M9	**26,8%**	30,2%	26,6%	**29,0%**	**30,1%**	33,9%	25,8%	18,9%	**27,7%**
M10	**76,3%**	76,9%	72,3%	**77,2%**	**57,4%**	56,3%	52,9%	68,4%	**57,0%**

Nevertheless, the comparison of answers to physically equivalent questions, but presented with different contexts and formulation (e.g. M2, 8 & 9; M6 & 7) allowed us to apply a more stringent test directed to the actual understanding of the corresponding physical concepts, which would presumably yield the same correct answer to all equivalent questions, and eliminate a part of 'chance' or 'guesswork' correct answers, unavoidable in MCQ (bellow).

	2013	2020 (only CPGE)	2021	2022
Total of participants	1350	1839	921	1024
% of correct answers to M2, M8 and M7	20,2%	22%	18,8%	13,7%
% of correct answers to M6, M7 and "The force with which I attract the Earth towards me has the same intensity as the force with which the Earth attracts me towards it"	22%	21,1%	17%	10%

This more demanding interpretation still confirms the general tendencies at work, but with a severe additional drop in the supposed level in physics of the first-year students.

Evolution of the students' General knowledge between 2013 and 2022

Finally, while the general scientific knowledge questions (table 7) also confirm the general tendency of a better level of the CPGE track students, the difference with the university track students appears less pronounced than with the other categories of questions.

More surprising is the stability, and in some case the slight increase, in the proportion of correct answers between 2013 and 2022, in contradiction with the general tendency with more technical questions.

Table 7. Evolution of the students' General knowledge between 2013 and 2022

	CPGE				Universities				
	2013	2020	2021	**2022**	**2013**	2014	2015	2021	**2022**
G1	**60,8%**	60,1%	64,0%	**59,0%**	**52,1%**	44,6%	40,0%	50,5%	**42,5%**
G2	**62,0%**	59,9%	56,0%	**55,7%**	**61,8%**	57,1%	57,3%	60,0%	**58,4%**
G3	**40,8%**	36,7%	36,9%	**36,9%**	**36,4%**	38,4%	29,3%	28,4%	**29,0%**
G4	**64,2%**	71,9%	69,2%	**65,3%**	**57,6%**	64,0%	61,8%	62,1%	**57,0%**
G5	**51,8%**	51,8%	53,1%	**53,4%**	**48,2%**	44,3%	44,0%	51,6%	**51,2%**
G6	**64,4%**	67,4%	61,8%	**64,0%**	**63,0%**	58,0%	64,4%	51,6%	**64,7%**
G7	**57,9%**	55,4%	50,4%	**52,5%**	**47,6%**	39,6%	44,9%	40,0%	**42,2%**

Similarly, the comparison of answer to physically equivalent questions with slightly different formulations (e.g. G6 & 7, ice cube vs. vodka bottle) induce a significant drop in the supposed level, but less pronounced than with Mechanics questions (bellow).

	2013	2020 (only CPGE)	2021	2022
% of correct answers to G6 and G7	35,8%	40,8%	34,2%	23,8%
Total of participants	1350	1839	921	1024

Conclusion

The study therefore confirms, with all the reservations linked to the constitution of the sample, that the level of the students admitted to the university is significantly lower than what is expected at the end of the high school year, in particular regarding the basics skills in mathematics, which can only cause difficulties in their learning of physics if these widespread lacks are not taken into account by their university teachers.

The study also shows a steady decline in the level of students in recent years, despite the several reforms aimed at improving it. However, due to the deterioration of teaching conditions linked to the Covid crisis that occurred at the same time as the entry of the reformed students into higher education, it is probably too early to draw conclusions and the results of the students in 2023 and 2024 will allow us to identify if this is a basic trend or if the reforms nevertheless could induce positive effects for future cohorts.

Unsurprisingly, CPGE students score better than university students, but like university students, their scores decline over the years with fewer and fewer students reaching the high scores.

Finally, there is a decline in the understanding of concepts among all students, with difficulties that remain very prevalent even though the new curricula were designed with the aim of remedying some of them. The results of the students' questionnaires therefore provide material for their teachers to identify these concepts and take them into account in their teaching.

Comparison with the results obtained in other education systems with students entering higher education on comparable issues would allow an assessment of the extent to which these results are comparable or specific to French students on the concepts surveyed. This exploration remains to be done.

References

Blanquet, Estelle & Picholle Éric (2019). Emergence Of Conformist Thinking Under Strong Paradigmatic Pressure: The Case Of (Galilean) Relativity. https://arxiv.org/abs/1912.04110

Kamcharean Chanwit & Wattanakasiwich Pornrat (2016). Development and Application of Thermodynamics Diagnostic Test to Survey Students' Understanding in Thermal Physics. *IJISME*, 24(2), 14-36.

Georgiou Helen & Sharma Manjula D. (2020). Engaging science academics with evidence based practices: Use of concept inventories in chemistry and physics across eight universities. *IJISME*, 28(4), 28-43. https://doi.org/10.30722/IJISME.28.04.003

Hestenes, David, Wells, Malcom & Swackhammer, Gregg (1992). Force Concept Inventory. *The Physics Teacher* 30, 141. https://doi.org/10.1119/1.2343497

Inspection Générale - Ministry of National Education (2022). Presentation at the "Adaptation of higher education pathways to baccalaureate graduates resulting from the new reform of the physics curriculum" days. Nice, 2022.

Le Monde, 2018. Bac : peut-on dire que le niveau baisse ?
https://www.lemonde.fr/les-decodeurs/article/2016/06/16/bac-peut-on-dire-que-le-niveau-baisse_4951762_4355770.html

Ministry of National Education (2019). Programmes de Terminale en physique-chimie. Bulletin official n° 8, 2019 https://eduscol.education.fr/1648/programmes-et-ressources-en-physique-chimie-voie-gt [in French]

Ministry of National Education (2023). Le baccalauréat 2023 - Session de juin, https://www.education.gouv.fr/le-baccalaureat-2023-session-de-juin-378728

Questionnaire de la Société Française de Physique (2013). http://qcm.sfpnet.fr/

Viennot, Laurence (1996). *Reasoning in Physics: The Part of Common Sense.* Springer.