Survey on physics knowledge to evaluate the effects of gender gap on orientation towards STEM courses

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Abstract. The aim of this research is to monitor the gender gap in a sample of high school and university students, through a survey by multiple choice test in a well-defined sector of physics teaching (Nuclear Physics). The survey results were analyzed and compared with a fixed threshold reference value and used as a measurement of empathy toward hard-science topics. The comparison with gender numerousness in the five pupil populations can be used as a parameter to understand how gender unbalance can influence the attitude toward STEM courses of male/female.

1. Introduction: the Italian landscape of gender balance in STEM

The persistent underrepresentation of women in STEM fields across European higher education represents a multifaceted challenge that intersects educational policy, social equality, and economic development. While women now constitute the majority of university students in Europe [1], their participation in STEM disciplines remains disproportionately low, with recent data showing they account for only about a third of STEM enrollments. This disparity varies significantly both geographically and by field: while life sciences approach gender parity, so called hard sciences like as physics, engineering and computer science maintain substantial gaps, particularly in some countries [2]. Despite two decades of targeted initiatives and policy interventions at both EU and national levels, progress has been incremental. Multiple factors perpetuate this imbalance, including cultural stereotypes, institutional and economic barriers, race/ethnicity and systemic bias in educational settings [3]. A recent study focusing on German university students found significant intergenerational associations between the gender typicality of parental occupations and the students' chosen majors. The research suggests that the transfer of occupation-specific resources from parents to children plays a crucial role, and that the transmission of gender roles partially explains these associations, especially between fathers and sons [4].

Addressing these disparities has become increasingly crucial as emerging technologies reshape the European job market and drive economic growth. The challenge extends beyond numerical representation, reflecting deeper structural issues that influence academic and career choices, ultimately affecting Europe's capacity for innovation and its competitive position in global scientific research. It is known that in terms of access to STEM course in Italy the gap between genders is not as accentuated and so unlike what happens in other international educational contexts both the high school and university segments are highly inclusive by gender [5, 6, 7]. This is due to the lower number that characterizes more in general the STEM courses in Italy. Recently a few authors stressed that female students often are more attracted by healthcare programs as part of a progressively broader concept of

STEM courses [8]. A second fact is that in Italy around 50% of high schools are STEM inclusive (scientific high schools) and the importance of early contact with science for STEM choices has been illustrated [9].
However, the focus of this article is not to make a statistically exhaustive review of the problem but to provide the scientific community with a case study well defined both geographically (the northern district of Milano) and from a disciplinary point of view (Physics). The population density of the district concerned and the presence of important universities in the area make it certainly interesting as a case study. The choice of nuclear physics, as already illustrated in a previous work [10], is considered by the authors to be of particular interest due to its characteristics of a disciplinary sector that is well circumscribed educationally but with numerous connections both towards other disciplines and for the issues of energy sustainability that have emerged in recent years.

2. The survey on Nuclear physics

Nuclear physics has been a consolidated body of knowledge for over a century. It has applications in various disciplines, including those outside of physics (philosophy, medicine, economics, history, etc.), and its experimental and theoretical aspects can be made accessible to all levels of education, from the simplest, purely narrative subjects in primary school to the most advanced research specializations at the university level.
In the "National guidelines for scientific high school" (Education Ministerial Decree D.M. 211 7/10/2010) nuclear physics is mentioned only and exclusively as a field of verification of the equivalence between mass and energy in the theory of special relativity. In the 54 pages of the ministerial document, only one line is dedicated to nuclear physics. These factors create an inexplicable gap in students' educational paths. According to this approach, many students will fail to acquire an understanding of the fundamentals of nuclear physics, including the description of the nucleus, its decays and behavior, and nuclear applications in energy and the military, as well as in medicine, astrophysics, and cultural heritage. To address these issues, subjects involved in nuclear physics, such as universities, polytechnic schools, research centers, the Istituto Nazionale di Fisica Nucleare (INFN), and other institutions (Ministry of Education, Italian government) have developed a renewed interest in teaching and its improvement.
In this context, it is evident that while the educational offer in the scientific field has expanded quantitatively, this has often occurred in favour of sections of classical physics (Education Ministerial Decree D.M. 211 7/10/2010), in some cases modern physics (atomism, relativity), and little or not at all as far as nuclear physics is concerned. This picture is exacerbated by the training and development of teachers, who are the real decision makers behind the teaching schedule. Often, most of them lack a solid background in nuclear physics, either because they have a degree in mathematics or engineering, or because, despite having a degree in physics, they have not studied nuclear physics in depth. All this suggests that student preparation in this area is inadequate for the academic prospects of those who intend to pursue STEM studies. Furthermore, more generally, it suggests that students should not make informed choices about active scientific citizenship that include an adequate background in nuclear physics. Some authors in the past have emphasized that nuclear physics issues are not particularly interesting or relevant for students because they are alien to their personal experiences [11,12]. It follows that the important contribution that nuclear physics would bring to STEM students and, more generally, to citizens is reduced to a completely accessory role in the Italian school system.-[13].
Teaching nuclear physics would also help reduce the gender gap in STEM subject choice. As mentioned in Italy, unlike other countries, the percentage of cis-female students who complete scientific high school and access STEM courses is very high, and gender inequality is more contained than in other European countries (Fig. 1). It remains to be highlighted that these students often enroll in degree courses aimed at teaching and personal care, while they are much less present in scientific degree courses in the strict sense or economics [14].

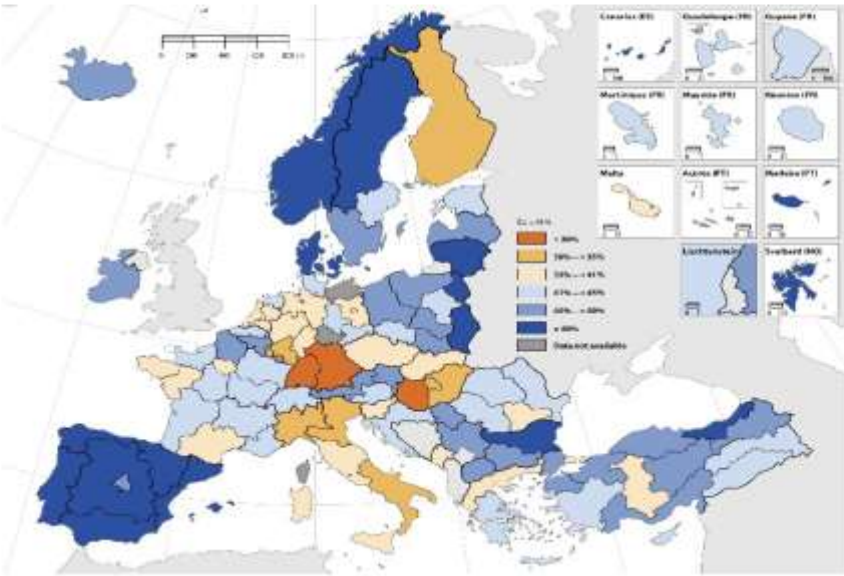

Figure 1: Percentage of women scientists and engineers, gender gap referred to graduated female students in Europe in 2020 (Eurostat source).

This suggests that preparing students in this area could be adequate to identify those who intend to continue in STEM and, more generally, to make ~~conscious~~ informed choices of active global citizenship through a scientific education [15]. To assess knowledge in this field, we developed a multiple-choice questionnaire structured into two sections. The first section gathered demographic and background information about the participants, while the second focused on their understanding of the fundamentals of nuclear physics. The nuclear physics section was divided into three levels of complexity: descriptive, formal, and applied knowledge. This section included 28 questions in total. We set an acceptability threshold, denoted as **S**, at 13 correct answers, which corresponds to a basic level of descriptive knowledge in nuclear physics. [16]. The questionnaire was administered at the end of the high school course. To minimize external influences and standardize testing conditions, the survey was conducted face-to-face under the supervision of the administrator. However, in order to gather larger and more homogeneous samples operating simultaneously, we also employed CAWI (Computer-Assisted Web Interviewing) and BYOD (Bring Your Own Device) methods. Our choices regarding the survey format, methodology, and sample composition helped avoid issues commonly encountered with subgroups that have low digital literacy [17]. In other contexts, such limitations have often led researchers to prefer a dual-channel approach (CATI/CAWI) over purely online methods. However, in our case, the use of CAWI alone proved effective and appropriate. [18].

3. Populations under investigation

To assess the state of nuclear physics knowledge among students in the transition from high school to university and to correlate their educational experience with learning outcomes, we selected several samples. We administered a questionnaire to obtain quantitative results on the situation [10]. To maintain a homogeneous picture, we analyzed groups of students coming only from scientific high schools or enrolled in the first year of STEM university courses. The survey has been proposed to six different population of students (17-20 years old) involved in scientific curricula at different levels, in the last year of high schools in wealthy area of north Milano (HS 1-2-3) and to the students of the first year of three Milano universities degrees Bioengineering (U-E1) Computer science engineering (U-E2) and Physics (U-P). In all cases before carrying out the courses in modern physics or part of it in other courses (chemistry, advanced physics, etc.). Table 1 reports the data and essential characteristics of the six populations investigated as well as the average score obtained overall. Gender are indicated as F = cis-female, M = cis-masculine, T = transgender, NA = not declared. For what concerns HS* we stress that about 95% of pupils followed the same courses for the 5 high school years.

The inclusion of first-year university students prior to their exposure to modern physics ensured that the responses reflected knowledge acquired primarily through secondary education, rather than university-level instruction. This condition was critical to maintaining comparability with the high school cohort and to isolating the effects of pre-university educational experiences.
The three university groups (U-P, U-E1, U-E2) were composed of full cohorts from their respective degree programs, without any form of academic pre-selection or filtering, thereby ensuring a representative cross-section of students enrolled in those disciplines. Similarly, the high school groups (HS1, HS2, HS3) were drawn from public scientific high schools within the same regional network, ensuring geographic and curricular consistency. These institutes partly cover the catchment area of the universities to which groups U-P and U-E* belong. Administering the same instrument across these different educational levels provided a coherent dataset for assessing knowledge trends and identifying conceptual gaps. Furthermore, it enabled the investigation of potential correlations between institutional type, course focus and student performance on questions categorized by increasing levels of complexity (descriptive, formalism, application). Designing this comparative framework also allowed us to explore broader educational issues, such as the effectiveness of secondary physics teaching in preparing students for the conceptual and formal demands of university-level physics, particularly in the field of nuclear phenomena. These findings can inform curricular decisions and support targeted interventions to address the knowledge gaps observed during this transition to STEM education.

Table 1. Summary of the high schools and university degrees under investigation.

Group	F/tot	M/tot	T/tot	NA/tot	Score (points)	Short description, curriculum
HS1 (SA+ST)	46%	51%	3%	-	14,00	A big high school, with two different curricula, Traditional and Applied
HS2 (SA)	24%	76%	-	-	9,24	A little high school, with only Applied curriculum coming from a former technical high school
HS3 (SA+ST)	41%	57%	-	2%	11,07	A medium size high school, with two different curricula, Traditional and Applied
U-E1	56%	43%	1%	-	12,20	An engineering course (1st year of degree) with female prevalence
U-P	31%	63%	6%	-	13,67	A course of Physics (1st year of degree) with male prevalence
U-E2	22%	70%	-	8%	11,16	An engineering course (1st year of degree) with male prevalence

4. Results, discussion and limitations

For what concerns the HS* students 70% declare that they have not followed NP courses in the physics discipline. The remaining 30% also addressed NP in related disciplines (chemistry) or non-scientific (history, civic education). Table 2 reports the scores of the different samples (F, M T-NA), while in figures 2, 3a, 3b are depicted the score distributions of cis female and cis-male population.

Table2. Scores of the six populations divided per gender and female index F/M (the ratio of cis-female population with respect to the cis-male one.

Curriculum	Average score	Standard deviation	F	M	T-NA	F/M
HS1	14,00	4,20	13,60	13,97	21,50	0,902
HS2	9,24	2,59	8,16	9,58	-	0,316
HS3	11,07	2,53	10,59	11,68	10,00	0,719
U-E1	12,20	2,40	12,10	11,97	14,00	1,302
U-P	13,67	3,99	12,73	14,30	11,80	0,492
U-E2	11,16	3,42	9,75	11,85	9,00	0,314

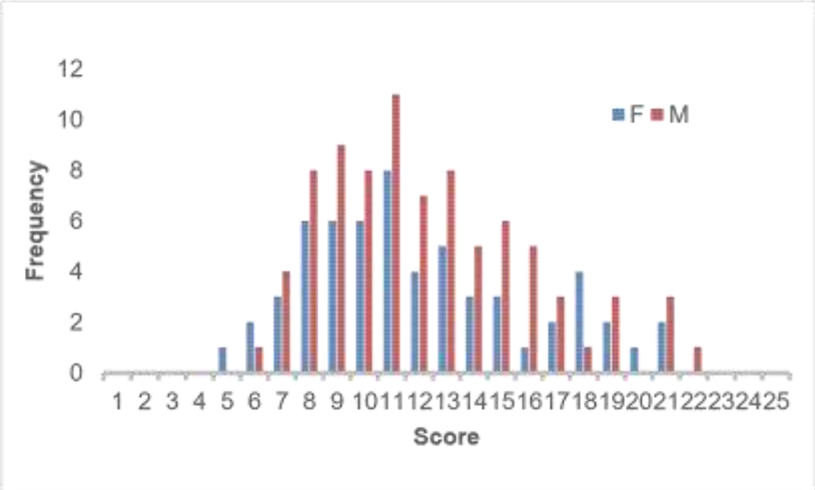

Figure 2: Score distributions of cis-female and cis-male student population in the three high school examined.

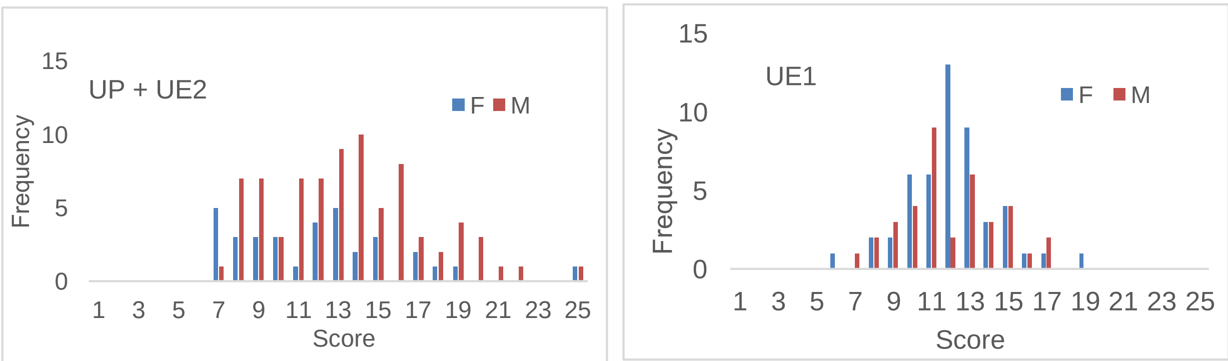

Figure 3a (left) and 3b (right): Score distributions of cis-female and cis-male student population in the two groups of first year university degree.

In order to look for any trend that could be representative of the discrepancy in attraction by the different gender toward STEM courses we tried a first simplified representation of the delta score cis-F/cis-M as a function of the fraction of Cis-F over cis-M population. Figure 4 shows the delta score obtained in each population from the Cis-female group (Delta score). The delta between the scores of cis-female students and that of cis-male clearly tends to linear decrease with the gender ratio, the size of the cisfemale population within the sample population. In this representation, the linear fit of the data has a regression coefficient (R^2) of 0.934.

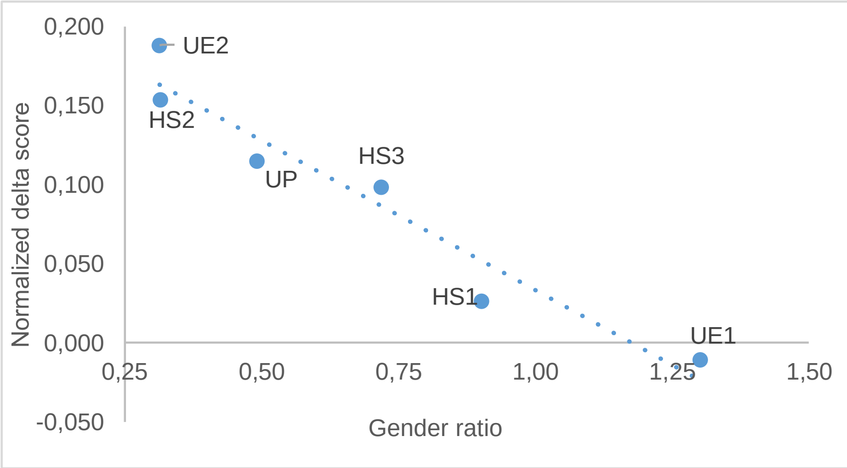

Figure 4: Delta score obtained by each of the six populations by the Cis-female group (Delta score) as a cis-F/cis-M fraction.

The relationship represented in figure 4 seems to be a very interesting key to understanding the female propensity towards STEM courses and how it is influenced by their percentage in a group. We emphasize that the graph depends critically on the meaning of "female versus male population" on the x-axis. In our first phase of research presented here, the HS population is in fact composed of a select group of students chosen by their teachers and does not represent the entire high school population. In a subsequent phase of the research we will submit the investigation to entire classes which in the Italian HS are made up of the same members for all years of the course and constitute the cultural and anthropological environment of reference for the students.

Furthermore, we analysed more in details the result of the three more unbalanced populations. In the university populations the gender polarization is observable in two specific cases, U-P (cis-male 63%, cis-female 31%) and U-E2 students (cis-male 70%, cis-female 22%), while for what concerns the secondary school only in HS2 (cis-male 76%, cis-female 24%). In all these cases, cis-female students obtain scores below the average for significant values (-6.9% for U-P, -11.7% for HS2, -12.6% for UE2), very far from those obtained by cis-male students of the same subsample (+4.6% U-P, +3.7% HS2 and +6.2% U-E2). In this case a high gender gap disadvantages the cis-female score. Results even better focused on gender differences can be found by directly comparing the F score to the M score as reported in Table 3. Table 3 reports the □F for the six populations calculated as follows:

$$\Delta F = \frac{S_M - S_F}{S_T}$$

Where S_F S_M S_T are the mean scores obtained respectively by cis female, cis-male and the entire group.

Table3. Score unbalance ΔF in strong gender unbalanced populations and in gender balanced population

gender unbalanced populations		gender balanced populations	
	ΔF		ΔF
HS2	-15.4%	HS1	-2.6%
U-P	-11.5%	HS3	-9.8%
U-E2	-18.8%	U-E1	+1.1%

The results can be summarized in two short sentences:

- where the gender gap is minimal, the scores of both the F and M populations are on average higher than in situations where the gender gap increases;
- where the gender gap increases compared to the number, i.e. where the F population represents a minority, the score delta of the cis-female population increases.

Finally, the authors observed that even out of any statistically significance, trans-gender or non-declared show among the highest/lowest scores in all cases. Declared transgender T or not declared gender students (NA) are also reported, their presence is un-uniform but often affects results both with exceptionally high or poor scores.
One of the limitations of this research is the low sample size. However, although the sample is small compared to the university population as a whole, it should be emphasize that we had a very high level of responses from the students involved both thanks to the curiosity that the topic of NP has aroused and to the collaboration of the teachers who allowed access to the test during class time. Although voluntary, the number of participating students exceeded 90% of those attending and can therefore be considered a representative sample of the specific classes involved (high schools, ancillary engineering and physics).
The research conducted so far has shown that the test conducted is reliable because it reflects in different types of population what is a known trend of female students' disaffection towards STEM. However, in the authors' thinking it allows us to go deeper by observing students in the crucial junction between the last year of high school and the first year of university. Last but not least was the interest that the topics of the survey aroused in the students, it in itself had the ability to increase the interest in topics of nuclear physics in both teachers and students.

Statistical note: the overall HS* sample is composed by 145 selected students, the University sample of 208, (53% cis-male, 44% cis-female, 3% others) the score mean value is 12,68, p-value 0,501. Any additional questionnaire data can be found in [10].

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Ethical note
Informed consent to participate in the study and publish the results was obtained from the participants, who were all over 18 years old. We conducted the study in accordance with the principles outlined in Physics Education ethical policy, as confirmed by the ethical Committee of the Università degli Studi di Milano (Approval letter #102.23 of 19 September 2023).

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