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Analysis of pseudoscientific beliefs in quantum mechanics of high school students and teachers

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The COVID-19 pandemic has increased the interest in the possible causes of the spread of science-based fake news. Indeed, such phenomenon can lead to a generalized distrust of science with serious consequences for our society, ranging from vaccine avoidance to climate change denial. Research in educational psychology has only recently begun to explore the psychological drivers and relationships between misinformation, conspiracy theories and pseudoscientific beliefs. However, existing studies have not focused on specific scientific domains and have involved samples with individuals of different age and sociocultural background. In this empirical study, we focus specifically on the pseudoscientific beliefs of high school students and teachers in a science area where fake news are spreading rapidly on websites and social media, namely, quantum mechanics (QM). To this end, we used a 21-item instrument specifically developed by our group in a previous study to measure pseudoscientific beliefs in QM. The cross-sectional sample included $N = 1119$ high school students (female students = 52%) and $N = 125$ high school teachers. The data collected were analyzed using the following methods: confirmatory factor analysis to establish the validity of the instrument; multiple correspondence analysis, to transform categorical variables measuring sociocultural background into continuous variables; repeated measures analysis of variance and linear regression to describe which factors most influence students' and teachers' pseudoscientific beliefs. The results show that, for students, endorsement of pseudoscientific beliefs in QM depends on the following factors: trust in public and science institutions, scientific content consumption, type of high school attended, and QM literacy. For teachers, endorsement of pseudoscientific beliefs in QM depends on the type of degree obtained, QM literacy, perceived usefulness of teaching QM, and confidence in teaching QM. Our study suggests that outreach and popularization interventions for high school students focused on QM, as well as teacher training courses on QM, should also incorporate elements of the nature of science, i.e., on how we develop scientific knowledge, to provide more effective tools to help teachers and students distinguish between correct claims and plausible but false claims, using both prebunking and debunking approaches.

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I. INTRODUCTION

Quantum mechanics (QM), since the early years of its formulation, has fascinated and continues to fascinate many physicists and lay people [1]. Although this is due to several reasons, including the revolutionary character of the theory for the time (early 1900s) [2] and the numerous technological applications [3], the most interesting characteristic is the existence of different interpretations that challenge students' conceptual development in QM [4] and represent a well-known point of discussion in the foundations of physics and in the philosophy of science discourse [5]. As a consequence, in the didactical approaches of QM, philosophical controversies and different interpretations remain often overlooked [6]. This pragmatic approach has led, especially at the university level, on the one hand to emphasize the mathematical aspects of the QM theory—which provides excellent results in terms of predictions and on the other hand to overlook phenomena and physical reality that the specific formalism wants to represent [7]. In such a way, the notable differences between the macroscopic and the microscopic world are often misinterpreted and generate conceptual difficulties when teaching QM [8].

In summary, even if QM continues to provide the most accurate experimental predictions and boasts numerous

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confirmations in laboratories around the world, the complex mathematical formalism, the widely debated different interpretations, and the counterintuitive behavior of particles and substances at the microscopic level contribute to make it so peculiar that it can generate a sense of mystery and strangeness, even more so for nonexperts and lay people [9,10]. This sense of QM "weirdness" has contributed to the advent of numerous unfounded, *pseudoscientific*, theories as, e.g., quantum-based medication or quantum channeling [11], which manipulate the real meaning of some QM concepts as, e.g., the Heisenberg uncertainty principle, the wave function, or entanglement [12]. Therefore, as for pseudoscientific beliefs about vaccines [13], it would be important to investigate whether teaching and learning about QM may help students to identify unwarranted theories and false arguments that distort experimental evidence and misuse QM formal language. However, despite the space that QM is gaining in school curricula across the world [14], there is still very scarce evidence of how teachers and students deal with generic pseudoscientific claims about QM they encounter when navigating the internet and social media.

To this aim, in the present study, using a psychometric instrument developed by our group to measure pseudoscientific beliefs related to QM, we investigate the sociocultural factors that affect students' and teachers' endorsement of such beliefs.

In the following section, we first present the theoretical background of generic pseudoscientific beliefs and discuss how we adapted it to describe pseudoscientific beliefs in QM. Then, we review previous studies that explored the psychological factors underlying the endorsement of pseudoscientific beliefs on behalf of students and teachers.

II. BACKGROUND

A. Characterization of pseudoscience

To understand what pseudoscience is, it is first necessary to differentiate it from what we call "science" [15]. The demarcation between science and nonscience in general is not a mere epistemological question but an intellectual endeavor whose ultimate goal is to discover how to determine and justify the validity of beliefs and knowledge [16]. Over the years, there have been numerous attempts at demarcation to provide easily identifiable and commonly accepted criteria to separate, with relative simplicity, science from nonscience. For instance, a typical argument was that if a doctrine is considered as a science, then it will also be so in the future, while this is not true for nonsciences as well as for pseudoscience [17]. This argument, however, does not take into account the tentativeness of science, so the demarcation cannot be based on a time-based argument: science is not timeless. Another argument was based on the famous Popper's concept of falsifiability of science [18], namely, that one can determine whether a theory is scientific if it produces statements that can be proven false. Despite its popularity, this criterion turned out to be an imprecise tool to demarcate sciences from nonscience, and especially from pseudosciences since one of the characteristics of many of these, such as astrology or homeopathy, is precisely the possibility of producing falsifiable claims [19]. A further attempt to define a univocal criterion was carried out by Kuhn [20]. According to Kuhn's criterion, a discipline could be classified as scientific if it requires the resolution of problems that arise in its own domain. For instance, if an astronomical prediction failed, the problem can be solved through more accurate analysis or by testing a new theory. On the contrary, astrology does not have this characteristic since there is no constructive revision of the astrology tradition if an astrological prediction fails. However, this criterion does not account for pseudoscientific theories that try to address their own inconsistencies, as the flat Earth theory. Finally, building upon Popper's criterion of falsifiability, Lakatos proposed the demarcation criterion of "sophisticated falsifiability." Lakatos argued that scientific theories should be seen as part of a research program that can predict novel facts, rather than being evaluated in isolation [21]. This criterion accounts for a theory's predictive power and its ability to be empirically tested over time. Thus, a scientific theory should not only be potentially falsifiable but also exhibit a history of empirical success that nonsciences and pseudoscientific theories typically lack. Despite being more restrictive, however, this criterion does not consider that a theory could be scientific even if there is not yet evidence in favor of it, as, for instance, string theory, and, similarly, a theory could be nonscientific or pseudoscientific even if there is a large body of evidence in support of it. In response to the failure of the single criterion approach, philosophers of science turned to multicriteria approaches.

A first attempt to demarcate science specifically from pseudoscience throughout a multicriteria approach was carried out by Martin Gardner and Brian Baigrie, who proposed that pseudoscience is a (i) nonscience; (ii) which claims to appear as science [15]. While useful, these criteria are still too broad, since they may lead to consider as pseudoscientific activities that meet both criteria, but which are not easily classifiable. For instance, the phenomenon of "scientific fraud," namely, the practice aimed at showing a result as scientific and proven when in reality it is not, meets the criterion, but it can be due either to an unwanted error (e.g., a wrong experimental design) or to a proper scientific misconduct (e.g., use of fake data). Drawing from this example, Hansson proposed to refine the above criteria defining pseudoscience as follows: (1) it is not scientific, and (2) it is part of a nonscientific doctrine whose followers try to create the impression that it is scientific [22]. According to these criteria, an activity as the clairvoyance is not strictly a pseudoscience since clairvoyants do not consider themselves scientists. Similarly, religious beliefs cannot be considered pseudoscientific beliefs since religious promoters do not pretend these beliefs to appear as such. Other authors have proposed a list of typical characteristics that define pseudoscience: disregard of counterevidence to evaluate existing theories, reliance on a single theory, formulation of *ad hoc* hypotheses to explain anomalous data, lack of control studies, and use of ambiguous or obscure language to describe phenomena [23,24]. A final refinement has recently been proposed by Fasce and Picó, based on a review of multicriteria approaches to the demarcation problem [25]. They defined pseudoscience as an epistemic product that (1) is necessarily presented as scientific knowledge and (2) may refer to entities outside the domain of science; (3) uses unjustified methodology; and (4) is not supported by evidence. In the next subsection, we describe how, using this multicriteria approach, pseudoscience becomes a multidimensional construct, while not exactly coinciding with any of its dimensions.

B. The dimensions of pseudoscience

The dimensions of the pseudoscience construct should identify the different ways in which pseudoscience manifests in individuals' beliefs. In the multicriteria approach adopted by Fasce and Picó, pseudoscientific beliefs are rooted in three epistemologically different, while highly correlated, systems of beliefs: (i) magic or mysticism, (ii) conspiracy theories, and (iii) science denial. Magic or mysticism concerns those phenomena that are supposedly beyond the domain of science, as the existence of the voodoo or ghosts [26]. Early research has shown that paranormal and magical or mystical beliefs are widespread in the population and may coexist with scientific views [27]. Conspiracy theories are unjustified beliefs that are grounded on unnecessary assumptions and that disregard more rational and more likely explanations [28]. Research has highlighted that endorsers of a conspiracy theory are more likely to believe also in other unrelated conspiracy theories [29] and embrace authoritarian and identity-protective psychological mechanisms [30,31]. Science denial refers to a set of beliefs which ideologically, emotionally or lucratively rejects well-established scientific theories [22]. Such beliefs simulate a skeptical attitude towards scientific evidence and promote false controversy among scientists [32]. These three dimensions can be useful not only to more precisely define what is pseudoscience but also to identify features of pseudoscientific beliefs in specific areas, such as QM.

C. The framework for pseudoscientific beliefs about QM

As already pointed out, the popularization of quantum mechanics has led to a proliferation of unjustified theories and false arguments which distort experimental evidence and frequently misuse scientific language. These theories and arguments tend to form a system of pseudoscientific beliefs that mostly concern entities outside the field of investigation of QM, reject any rigorous methodology or rationale, and hardly refer to experimental evidence. Therefore, we adopted a multi-dimensional conceptualization also for quantum pseudoscience. The first dimension is related to magic or mysticism. The link between QM and magic or mysticism has its roots in books of the early 1980s, in which the noncausal and nondeterministic features of quantum mechanics, or even Bell's theorem, were seen as possible explanations for metaphysical and paranormal phenomena [33]. The later appearance of the quantum world in New Age literature has further strengthened this trend [34]. An example of pseudoscientific beliefs related to this dimension is quantum healing, where the concepts of measurement and wave function are extensively exploited to make the claims appear scientific [12]. More specifically, in the context of quantum healing, the wave function is interpreted as a kind of vibration of a holistic substance that permeates the universe and is capable of collapsing instantly upon a voluntary act of cosmic consciousness [10]. Other pseudoscientific beliefs can be categorized in this dimension. For example, advocates of extrasensory perception wrongly use Heisenberg's uncertainty principle to argue that reality can be determined by external human intervention [35]. Similarly, nonlocality has been used to justify the claim that human consciousness can transcend the individual and connect the human mind to the Universe [36]. Not unexpectedly, entanglement has been widely exploited as a theoretical basis to justify telepathy [12], sometimes manipulating controversies or different interpretations of this phenomenon [37]. Similarly, although not initially cited, QM was later used as a possible explanation of the famous experiments about the existence of paranormal phenomena carried out in the 1970s [38]. The second dimension refers to the conspiracy theories about QM. Quantum mechanics can be seen as a powerful body of knowledge [39], surrounded by an aura of elitism and abstraction [40], which could lead the general public to believe that only the "chosen ones" can really learn quantum mechanics, in order to preserve the role of physics in society as the most complicated discipline, whose doors are guarded by rigid guardians [41]. The origin of these conspiracies is to be found in the very nature of quantum mechanics, which, as has been pointed out on several occasions, contains some "weirdness" that are not easy to understand, even for the expert's eyes. Thus, it is not very surprising the emergence of conspiracy theories, which see quantum mechanics as a mystical and elitist discipline (also in view of its complex mathematical formalism) that only few can learn to protect its "secrets" [42]. The third dimension, science denial, is related to the perceived revolutionary nature of QM, which requires the learner to reconsider, and in some cases reject, key concepts of classical physics such as measurement or trajectory [43]. For example, if the uncertainty principle is misconstrued or

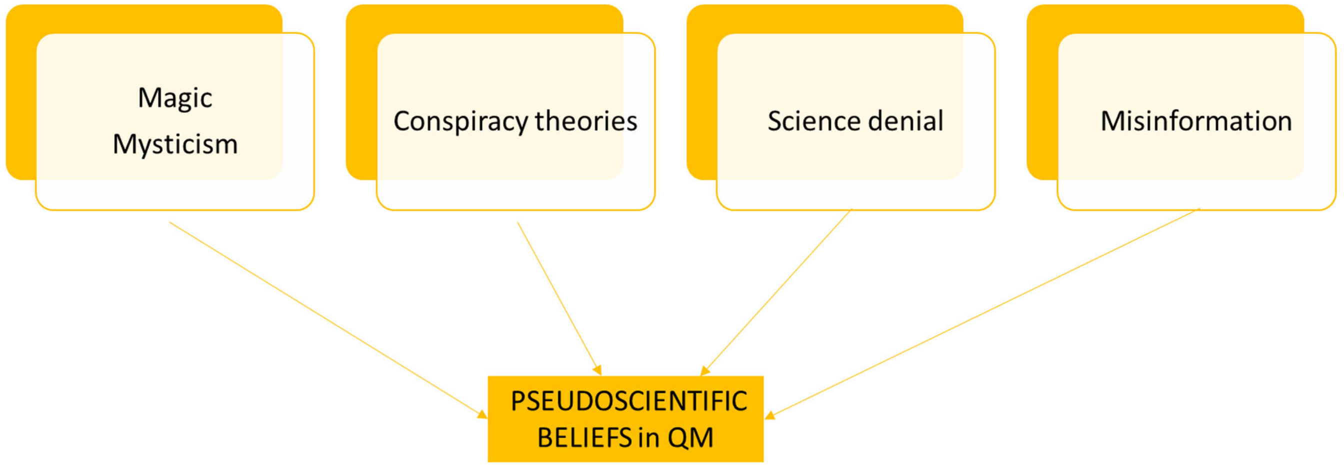

FIG. 1. Model of pseudoscientific beliefs in quantum mechanics.

misinterpreted as a sort of general indeterminacy affecting the macroscopic world, this could lead to the erroneous conclusion that the results obtained by QM are false or to the belief that science cannot provide precise answers, thus fostering a form of science denial [44]. The above three dimensions do not account for a specific aspect of pseudoscientific beliefs about QM, namely, the use of ambiguous but impressive statements that are deliberately misleading and may vary in truth and accuracy [12].

We call this dimension that is specific to QM, quantum misinformation. Similar to scientific fraud, which attempts to conform to established scientific theories [15], this dimension includes unverified claims that do not deny the consensus view of the scientific community, as it happens with topics such as vaccines or global warming, but, rather, support unjustified applications of QM in real life. Our model of QM-related pseudoscientific beliefs is summarized in Fig. 1.

D. Previous studies on students' and teachers' pseudoscientific beliefs

Studies on pseudoscientific beliefs have been mainly carried out with undergraduate students [25,45,46], while only a few studies have focused on upper secondary school students [47]. For instance, Afonso and Gilbert [45] interviewed about 50 Portuguese science and nonscience undergraduate students exploring their beliefs on water dowsing, namely the ability to find groundwater using a forked wooden stick. They found that both science and nonscience students accepted this practice as a traditional way to find water and made reference to its apparent success as supporting evidence. However, science students were more able to justify their rejection of the belief using arguments based on their scientific knowledge. In a study with 380 Taiwanese science and nonscience university students [48], the authors explored the impact of TV programs on pseudoscientific beliefs. The study investigated different types of pseudoscientific beliefs, such as fortune telling, health practices (magnetic therapy; Feng-Shui) and paranormal activities (telekinesis). The results show that exposure to pseudoscientific TV programs was a predictive factor for pseudoscientific beliefs and that majoring in science moderated such a relationship, in particular nonscience students expressed more favorable attitudes toward pseudoscientific beliefs than science students. In the first validation study of their instrument, Fasce and Picó [25] investigated whether university students' pseudoscientific beliefs were related to trust in science, scientific literacy, gender, and political affiliation, and pre-university education. The sample included 292 Spanish students of different degrees (psychology, philosophy, education). Results showed no significant differences due to gender, and political orientation but there were significant differences due to different levels of trust in science and scientific literacy.

At the secondary school level, in a study in the UK [47], students of different grade levels (11–18 yr old) were asked the extent to which they agreed on 8 pseudoscientific beliefs (e.g., astrology, ghosts, superstition). Results show that older students were more skeptical, with female students generally being less skeptical than males, independently on grade level. In a study with 148 students in Taiwan [49], the authors found that an online argumentation environment helped subjects in the control group to decrease the level of agreement on 10 pseudoscientific beliefs (e.g., horoscopes, divination, magnetic therapy). More recently, in a correlational study with 303 students in Slovak [50], the authors found that scientific reasoning was negatively related to conspiracy beliefs and authoritarian, thus confirming the results obtained in [51], who found that right-wing authoritarianism is a predictor of pseudoscientific beliefs.

Few studies investigated in-service teachers' beliefs about pseudoscientific claims. In one of their studies carried out in late 1990s with 76 Italian, Argentinian, and Uruguayan upper secondary school teachers [51], the authors found that more Italian teachers were unable to give a judgment about the scientific nature of astrology and psychoanalysis than Latin American teachers. Moreover, they also found that teachers of both groups rejected pseudoscientific statements in a rather vague way ("because it does not belong to science"). In a subsequent study with 217 Italian and 23 Brazilian teachers [27], the authors found that science teachers were more likely to disagree on pseudoscientific beliefs (e.g., magic, parapsychology, spiritism) than nonscience teachers, whereas the Brazilian teachers were more likely to agree on pseudoscientific beliefs and less likely to agree on scientific ones. More recently, a study with 780 Turkish in-service elementary, physics, and science teachers [52] investigated the views about the demarcation of science from pseudoscience, specifically why astronomy is considered as a science and why astrology a pseudoscience. By analyzing open-ended responses, the authors found that the teachers identified six distinct dimensions to distinguish science from pseudoscience: universality, source, verification, methodology, aims, progressiveness. Coherently with the results reported in Vicentini *et al.* [27,51], the teachers' responses included several elements of logical positivism as a dominant philosophical framework. Astrology was considered a pseudoscience since it is subjective, relies on unproved suppositions and beliefs and lacks a definite knowledge. Moreover, the conceptions of teachers were not aligned with the contemporary views of the nature of science.

Other studies involved samples of preservice teachers. In a study with 578 pre-service Spanish teachers [53], the authors investigated whether the sample differed from a group of subjects of the same age (15–24 yr). They used 6 items from a national survey investigating the beliefs in paranormal phenomena, acupuncture, horoscope, homeopathy, healers, lucky numbers. The results show that the preservice teachers did not significantly differ in their conceptions about pseudoscientific beliefs from subjects of the same age. In particular, they were likely to believe in acupuncture, homoeopathy, paranormal phenomena, and lucky numbers. Amongst the factors that affected such beliefs, age was the prominent one, while level of scientific knowledge had a significant but small effect. In a study with 159 preservice Turkish teachers [54], the authors investigated whether there was a correlation between preservice science teachers' epistemic beliefs, understanding of NOS, and pseudoscientific beliefs (e.g., paranormal phenomena). The results show no significant correlations between the endorsement of pseudoscientific beliefs, epistemic beliefs and views about the NOS. A very similar study was carried out with 172 preservice science and nonscience teachers in Turkey [55]. The results show that teachers in the sample did not hold informed views about NOS and that they were more likely to agree on pseudoscientific beliefs about medical therapies and practices.

III. RESEARCH QUESTIONS

The above review shows that, despite the alarming rise of pseudoscience in the second decade of the new millennium, and especially after the pandemics, research on how students' and teachers deal with pseudoscientific beliefs is still an underexplored issue. In particular, existing studies on pseudoscience did not focus on specific scientific domains, but rather addressed generic beliefs. On the contrary, our review shows that, among the most important factors that have contributed to the growth of pseudoscientific beliefs in various fields, from health to agriculture, there are the ambiguous misrepresentations of concepts in a very specific physics area, such as QM. Moreover, previous studies involved samples with individuals of different age and socio-cultural background, while many authors identified secondary school grade level as a key stage to address such beliefs. Finally, most studies were carried out with limited samples or used instruments with limited reliability and validity. To address these gaps in the literature, in this study, we use a previously validated instrument to explore high school students' and teachers' both generic and QM-specific pseudoscientific beliefs. The research questions that guided the study were

- RQ1. To what extent does a sample of high school students and teachers endorse pseudoscientific beliefs in QM with respect to other generic pseudoscientific beliefs?
- RQ2a: Which factors affect the endorsement of QM pseudoscientific beliefs of high school students?
- RQ2b: Which factors affect the endorsement of QM pseudoscientific beliefs of high school teachers?

IV. METHODS

A. Sample and procedure

An initial convenience sample of $N = 1649$ high school students attending extracurricular activities at different Italian universities as part of the *Piano Lauree Scientifiche* (PLS) Project, promoted by the Italian Ministry of University and Research (MUR), was involved in the study. The extracurricular activities were carried out in presence during the period Winter 2022–Spring 2023. The students were recruited after formal application of the respective school institutions to participate in the activities. Overall, more than 60 schools applied to participate in the activities. Upon acceptance, the students were informed in advance about the study and its main objective and purposes. School teachers were in charge of collecting informed consent forms signed by the students' parents asking permission to participate in the study and to use the students' responses for research purposes. An identification code was assigned to each student to ensure anonymity. A maximum of 5 students from the same class was allowed to participate. The correspondence between the code and student's name was unknown to the researchers. Before running the analysis, we first eliminated from subsequent analysis $N = 350$ students who did not return the informed consent to participate in the study. Then, we eliminated from the dataset also the students who did not correctly respond to control items (e.g., *indicate 4 to this question*) or who had missed some responses in the survey. After this preliminary screening, we retained 1199 subjects. All subjects were Italian native speakers between 15 and 19 yr old (mean age = 17.3 yr, SD = 0.7). About 46% of the students identified themselves as female, 39% as male, while about 15% preferred to not identify themselves. Most students came from a science and math oriented high school (55%), about one-third from an applied sciences high school (32%), while only a small percentage came from a humanities oriented high school (8%) or technical or vocational institutes (5%). Details are reported in Table I.

The teachers' initial sample included $N = 214$ high school teachers following a professional development course about Quantum Technologies at one of the authors' universities. Overall, 89 teachers did not give the consent to use their responses for research purposed, resulting in a final sample of $N = 125$ teachers (71% female). Teachers were mostly graduated in mathematics (46.4%), while about one third (28.0%) were graduated in physics. About one fourth (25.6%) were graduated in engineering. The great majority of teachers (57%) had about 20 yr of teaching experience, one fourth (26.5%) had an experience between 20 and 30 yr of teaching, while 17.5% had more than 30 yr of teaching experience.

TABLE I. Final sample characteristics ($N = 1199$).

Students' sample	
Gender	*N*
Female students	553
Male students	465
Do not respond	181
Grade Level	
10th grade (15 yr)	62
11th grade (15–16 yr)	372
12th grade (16–17 yr)	392
13th grade (18–19 yr)	373
Type of high school	
Science and math oriented	660
Applied science oriented	386
Humanities oriented	91
Technical/vocational oriented	62
Teachers' sample	
Degree	
Physics	35
Mathematics	58
Engineering	32
Teaching experience (years)	
Less than 20	73
Between 20 and 30	32
More than 30	20
Confidence in teaching QM	
No or a little	80
Quite or a lot	45
Value of teaching QM	
Depends on the type of school	30
Quite valuable	44
Very valuable	48

Most of the teachers (64%) had no or little confidence in teaching QM and 36% had quite or a lot of confidence in teaching QM. Finally, about 38% of the teachers thought that teaching QM is very valuable regardless of the type of school, 35% that it is quite valuable independently on the type of school, and about one fourth that the teaching of QM is valuable but depending on the type of high school. Details are reported in Table I.

B. Instruments

Six measures were used in the study.

Pseudo-QM scale—This original 21-item instrument was validated by our group in a previous study [56]. The items can be grouped according to the theoretical framework described above. In particular, seven items refer to the magic or mysticism dimension (e.g., *the quantum energy inside our body is not destroyed after death but returns to the universe*), two items refer to the conspiracy theories dimension (e.g., *true quantum physics is not taught in universities, but in restricted circles reserved for people of the highest rank*), seven items concern the denial of science dimension (e.g., *quantum physics, through the uncertainty principle, states that every event can happen, and it is not possible to make any prediction*) and five items concern the dimension of misinformation (e.g., *quantum physics, with the concept of entanglement, has scientifically proven that we can have information about every particle in the universe*). While the four dimensions were used to inform the design of the items, our previous study showed that they were not psychometrically different, so the scale can be considered substantially unidimensional.

Pseudoscientific beliefs scale-short version—This unidimensional instrument was adapted from [25,57] and included 11 items about science denial and promotion of pseudoscience.

Generic conspiracy ideation scale—We used an abbreviated 15-item version with high reliability ($\alpha = 0.93$) [58]. Participants indicated on a scale of 1 to 5 how true they consider each item, with 1 as definitely false and 5 as definitely true.

Trust in public and science agencies scale—This scale, adapted from a previous study in educational psychology by Salvatore and colleagues [59], included 20 items on a 4-level Likert scale (from *not at all reliable* to *very reliable*) and investigates the views of students and teachers about the reliability of public agencies and services (e.g., public transportation, national health system, school, police, political parties), science agencies (e.g., scientists, universities, research centers), and media (e.g., TV, social media, newspaper). The scale is reported in the Appendix.

Consumption of science contents scale—This instrument aimed to investigate the frequency with which both students and teachers deal with scientific contents by, e.g., reading scientific books, watching popular science programs on TV, or by visiting science museums. The scale includes 6 items with a score from 1 to 4 (*never, rarely, sometimes, often*). The scale is reported in the Appendix.

Quantum literacy scale—This scale asked students and teachers to evaluate their own recognition of terms specifically used in QM. Specifically, they were asked to rate, on a three-level Likert scale (*very little, somewhat, very much*), how familiar they were with 13 specific terms of QM such as, e.g., photon, entanglement or wave-particle dualism. The complete scale is reported in the Appendix.

C. Data analysis

We preliminarily checked the factorial structure of the PSEUDO-QM, pseudoscientific beliefs and generic conspiracy ideation scales using confirmatory factor analysis (CFA) on the sample of students. We estimated the model parameters using a maximum likelihood method and calculated the following indices to establish the quality of model fit: chi-square or degrees-of-freedom ratio ($\chi^2{}_{\mathrm{min}}$) [60], normed fit index (NFI) [61], comparative fit index (CFI) [62], Tucker-Lewis index (TLI), sometimes labeled non-normed fit index (NNFI) [63], root-mean-square error of approximation (RMSEA) [64]. Values of $\chi^2{}_{\mathrm{min}}$ less than 5, CFI, IFI, TLI above 0.90, and RMSEA less than 0.08 are indicative of good model fit [65–68].

Then, to answer our first research question, we contrasted the means in the three scales through a one-way repeated measures analysis of variance (ANOVA), using the three scales as within-participant factor. We first checked the normality of the distribution of the three scores, while sphericity assumption, namely, that the variances of the differences in the three conditions are equal, was assessed using Mauchly's test [69]. We inspected *post hoc* differences using the Bonferroni method [70].

To answer our second research question, we first performed a series of multiple correspondence analysis (MCA) [71–73] on students and teachers' responses to the *trust in public and science agencies, consumption of science contents*, and *quantum terminology knowledge* scales, respectively. MCA is a generalization of principal component analysis to categorical variables and aims at identifying patterns of associations existing between the different modalities of the items' responses. MCA allows us to extract one or two factorial dimensions that explain most of the variance in the data. As a result of MCA, both individuals and items' modalities are identified by a score in the factorial dimensions. Since categories that are close together indicate stronger association between them, by comparing individuals and modalities scores, it is possible to interpret the individual's factorial score in terms of a combination of the modalities of the items. In other words, the factorial score obtained by individuals indicates the degree to which they choose different modalities of the same items. Then, we performed a series of regression analyses to inspect whether the students' and teachers' scores in the PSEUDO-QM scale were predicted by the concurrently measured variables. In particular, for students, we used three independent categorical variables—gender, type of high school attended, school grade level—and the factorial scores in the trust in public and science agencies, consumption of science contents, and QM literacy scales as continuous predictors. The categorical variables were entered into the regression as dummy variables. We adopted a male student from a science and math oriented high school attending the 13th grade as reference. For teachers, we used as independent variables the confidence in teaching quantum mechanics, views about the value of teaching QM at high school level, gender, type of degree, teaching experience, as well as trust in public and science agencies, consumption of science contents, and knowledge of quantum terminology. We adopted a teacher graduated in mathematics with more than 30 yr of experience, little or no confidence in teaching QM but with a view that teaching QM is important independently on the type of school as reference. For both regressions, we checked collinearity through variance inflation factor (VIF) [74] and normality of residuals through the Durbin-Watson index [75]. Acceptable values of VIF are lower than 10 [76], while acceptable values of Durbin-Watson index are around 2 [77]. In all regression analyses, we used default standard errors. The reason for not using clustered standard errors is that we were interested in the association between pseudoscientific beliefs related to QM and a series of concurrent measures in two particular populations—students and teachers—so we did not adopt a group-randomized trial design or a specific sampling at class, school, or geographical area level.

IBM SPSS 29 [77] and AMOS 29 [78] were used for all statistical analyses. SPAD v. 5.6 [79] was used to perform the MCAs.

V. RESULTS

A. RQ1. To what extent does a sample of high school students and teachers endorse pseudoscientific beliefs in QM with respect to other generic pseudoscientific beliefs?

Initial fit of the PSEUDO-QM 1-factor scale was not adequate, so we decided to remove four items with poor loadings (<0.30). When removing these items, resulting fit indices improved (see Table II). Reliability of the resulting scale (see Table III) is good. The retained 17 items are reported in the Appendix. Similarly, the initial fit of the

TABLE II. CFAs indices and McDonald's omega for the PSEUDO-QM, pseudoscientific beliefs and generic conspiracy ideation scales. (Students' sample, $N = 1199$).

Scale	Items	χ^2_{min}	CFI	IFI	TLI	RMSEA
Pseudo-QM	17	2.599	0.95	0.96	0.94	0.037
Pseudoscientific beliefs	9	2.546	0.95	0.95	0.95	0.036
Generic conspiracy ideation	15	4.690	0.96	0.96	0.95	0.055

TABLE III. Correlations and descriptive statistics for the PSEUDO-QM, pseudoscientific beliefs, and generic conspiracy ideation scales (students' sample, $N = 1199$).

	PSEUDO-QM	Pseudoscientific beliefs	Conspiracy beliefs
PSEUDO-QM	0.83[a]	...	...
Pseudoscientific beliefs	0.62**	0.86[a]	...
Generic conspiracy ideation	0.55**	0.53**	0.91[a]
Mean	2.70	2.52	2.60
Dev. St.	0.51	0.55	0.76
Min	1.00	1,00	1,00
Max	4.35	4.22	4.73
Kurt.	0.657	−0.078	−0.599
Asymm.	−0.581	−0.177	−0.103

[a] McDonald's omega.
** $p < 0.01$.

1-factor pseudoscientific beliefs scale was also not adequate, so we removed two items with poor loadings. Resulting fit indices and reliability are good (see Tables II and III). Finally, the initial fit of 1-factor generic conspiracy ideation scale was adequate (see Table II), so we retained all the 15 items, which had also excellent reliability (see Table III).

Descriptive statistics for the three scales for students and for teachers are reported in Tables III and IV, respectively. When performing the repeated measures ANOVA, we first note that the sphericity assumption did not hold, Mauchly's $W = 0.841$, d.o.f. $= 2$, $p < 0.001$. However, both Greenhouse-Geisse and Huynh-Feldt estimates were close to 1, $\varepsilon = 0.863$ and $\varepsilon = 0.864$, respectively. We hence used the Greenhouse-Geisser correction since the estimates are greater than 0.75 [77]. Overall, given our large sample, we considered that our data have not a substantial deviation from sphericity.

Results show an overall significant difference between the three scores, Greenhouse-Geisser's $F(1.725, 2067.127) = 58.614$, $p < 0.001$, $\eta^2 = 0.047$. Moreover, *post hoc* tests shows that students scored significantly higher in the PSEUDO-QM scale with respect to both pseudoscientific beliefs scale, $F(1, 1198) = 194.155$, $p < 0.001$, $\eta^2 = 0.139$, and the generic conspiracy ideation scale, $F(1, 1198) = 28.488$, $p < 0.001$, $\eta^2 = 0.023$. We also note that the scores in the generic conspiracy ideation scale are significantly higher than those in the pseudoscientific beliefs, $F(1, 1198) = 20.766$, $p < 0.001$, $\eta^2 = 0.017$.

TABLE IV. Correlations and descriptive statistics for the PSEUDO-QM, pseudoscientific beliefs, and generic conspiracy ideation scales (teachers' sample, $N = 125$).

	PSEUDO-QM	Pseudoscientific beliefs	Conspiracy beliefs
PSEUDO-QM	0.93[a]	...	...
Pseudoscientific beliefs	0.72**	0.86[a]	...
Generic conspiracy ideation	0.73**	0.74**	0.93[a]
Mean	2.27	2.37	2.09
Dev. St.	0.67	0.60	0,68
Min	1.00	1.00	1.00
Max	4.18	3.56	3.93
Kurt.	−0.420	−0.582	−0.519
Asymm.	−0.101	−0.276	0.349

[a] McDonald's omega.
** $p < 0.01$.

Assumption of sphericity was met for the sample of teachers, Mauchly's $W = 0.996$, d.o.f. $= 2$, $p > 0.05$. Results of the repeated measures ANOVA show an overall significant difference between the three scores, $F(2, 248) = 21.055$, $p < 0.001$, $\eta^2 = 0.145$. Moreover, scores in the PSEUDO QM are significantly lower than scores in the pseudoscientific beliefs scale, $F(1, 124) = 4.721$, $p > 0.05$, $\eta^2 = 0.037$, but they are significantly higher than scores in the generic conspiracy ideation scale,$F(1, 124) = 16.792$, $p < 0.001$, $\eta^2 = 0.119$. We also note that the scores in the pseudoscientific beliefs scale are significantly higher than those in the generic conspiracy ideation scale, $F(1, 124) = 42.890$, $p < 0.001$, $\eta^2 = 0.257$.

B. RQ2a. Which factors affect the endorsement of QM pseudoscientific beliefs of high school students?

Before running the MCAs and regression analysis, we first checked reliability of the three concurrent measures scales, *trust in public and science agencies*, *consumption of science contents*, and *quantum literacy*. The three scales had an excellent (0.84), good (0.78) and excellent (0.83) reliability, respectively. The MCA of the *trust in public and science agencies* scale extracted two factors that explained most of the variance, 57.8% and 28.4%, respectively.

When inspecting the modalities of the responses associated with the extracted factors, we found that both separated students who trusted institutions, public agencies and services from less trustful students. Therefore, the two factors carry essentially the same information. Taking also into account that the first factor explained double the variance in the data, we chose to retain only the first extracted factor for subsequent analyses.

The MCA of *consumption of science contents* also returned two factors, which in this case explained more variance in the data, 72.2% and 21.9%, respectively. By inspecting the modalities of the responses associated with the scores in the two factorial dimensions, we interpreted the first factor as an indicator of the consumption of science mainly through internet, television, and social media, while the second factor as an indicator of a way to acquire information about science that includes both new and traditional media. Therefore, we retained both factors in the subsequent analysis.

Finally, the MCA of responses to the quantum literacy scale returned two factors, the first explaining significantly much more variance than the second, 92.1% and 7.4%, respectively. On such ground, we retained only the first factor. By inspecting the association between the modalities and the factorial scores, we noted that negative values corresponded to a perceived good knowledge of terms as orbital, energy level, photon, and wave-particle duality which are all taught at the high-school level, while positive values were associated with a scarce perceived knowledge. Therefore, after reversing the factorial direction, we interpreted the score in the retained factor as an indicator of the overall QM literacy of the subjects. More details about the MCA of the three scales are reported in the Supplemental Material [80].

Results of the regression analysis for students are reported in Table V. Standardized coefficient β quantifies the relationship between the predictor variable and the dependent variable, in our case the PSEUDO-QM score. We report the coefficients for only those variables that have a significant effect on PSEUDO-QM score. The final model, $F(6, 1054) = 13.591$, $p < 0.001$, explained about 7% of the variance ($R^2 = 0.072$). Durbin-Watson index is 1.352, which suggests a slight positive autocorrelation of the residuals. However, its value is higher than the recommended threshold of 1. VIF values for all independent variables are around 1, which suggests absence of collinearity among the predictors.

Overall, the results show that female students are significantly less likely than boys to endorse pseudoscientific beliefs about QM. Moreover, the higher the perceived knowledge of QM terminology and the trust in public and science agencies, the lower the score in the PSEUDO-QM instrument. Concerning the type of high school attended, we found that students attending a humanities oriented schools are less likely than students of math and science

TABLE V. Standardized regression coefficients β of the PSEUDO-QM score (students' sample, $N = 1199$). Only significant predictors are reported.

		95% C.I.		
Predictor	β	Lower bound	Upper bound	VIF
Female[a]	-0.090^{**}	−0.15	−0.03	1.063
Trust in public and science agencies	-0.079^{**}	−0.07	−0.01	1.013
QM literacy	-0.191^{***}	−0.12	−0.06	1.073
Technical or vocational institute	0.067^{*}	0.01	0.27	1.104
Humanities oriented school	-0.073^{*}	−0.23	−0.02	1.059

[a] Gender was coded as 1 = female, 0 = male.
$^{*}p < .05$.
$^{**}p < .01$.
$^{***}p < .001$.

oriented schools to endorse pseudoscientific beliefs in QM, while the reverse happens for students attending technical and vocational schools. We also found that attending a school grade different from the 13th grade does not significantly affect the PSEUDO-QM score. To further support the validity of our findings, we report in the Supplemental Material [80], an alternative analysis carried out by means of a person-centered approach (latent profile analysis).

C. RQ2b. Which factors affect the endorsement of QM pseudoscientific beliefs of teachers?

For the sample of teachers, reliability is excellent for *trust in public and science agencies* (McDonald omega $= 0.86$) and for the *QM literacy* scale (McDonald omega $= 0.94$), while it is good for the *consumption of science contents* scale (McDonald's omega $= 0.70$). The MCA of the *trust in public and science agencies scale* extracted two factors, the first explaining 40% of the variance, while the second explained 27% of the variance. We hence retained only the first factor, which is associated, at the positive end, to greater trust in public agencies, while, at the negative end, to lower trust.

The MCA of the *consumption of science contents* scale extracted two factors, the first explaining 44% of the variance, the second 31%. For this sample, higher positive scores in the first factor are associated with a greater frequency in using books, magazines, TV to obtain scientific information, while the second factor was not associated in a clear way with the item modalities. Therefore, we retained only the first factor. Finally, for the *QM literacy* scale, the MCA extracted two factors, the first explaining 63% of the variance, the second about 36%. We hence retained only one factor, as for the students.

Results of the regression analysis for teachers are reported in Table VI. Also in this case, we report only those variables that have a significant effect on PSEUDO-QM score. The final model, $F(6, 111) = 8.613$, $p < 0.001$, explained about 30% variance in the data ($R^2 = 0.318$). Durbin-Watson index is 1.925, which suggest independence of residuals. VIF values for all independent variables are lower than 3, which suggests absence of collinearity among the predictors. The results show that having a physics or engineering degree significantly decreases the likelihood of endorsement of QM-related pseudoscientific beliefs. Moreover, a higher QM literacy and higher confidence in teaching QM are significantly related to lower scores in the PSEUDO-QM instrument. Finally, we found that perceiving the teaching of QM as valuable independently on the type of school significantly increases the likelihood of endorsing QM-related pseudoscientific beliefs.

VI. DISCUSSION

The recent proliferation of pseudoscientific beliefs on the internet has prompted science education researchers to better understand the mechanisms underlying this phenomenon [81,82]. However, previous studies have measured generic pseudoscientific beliefs held by the general public, while little research has been conducted on specific disciplinary areas with students or teachers. To fill this twofold gap, we used an instrument—the PSEUDO-QM—which we validated in a previous study to measure pseudoscientific beliefs in QM among a convenience sample of high school students and physics teachers. The reason for focusing on QM is that pseudoscientific beliefs in this area are particularly harmful, for example, by encouraging the use of unlicensed medical practices that can cause permanent damage to health [11,12]. Below we discuss the evidence we have gathered to answer our research questions.

A. RQ1. To what extent does a sample of high school students and teachers endorse pseudoscientific beliefs in QM with respect to other generic pseudoscientific beliefs?

First, we found that the three measures, QM-related pseudoscientific beliefs, generic pseudoscientific beliefs,

TABLE VI. Standardized regression coefficients β of the PSEUDO-QM score (teachers' sample, $N = 125$). Only significant predictors are reported.

		95% C.I.		
Predictor	β	Lower bound	Upper bound	VIF
Degree: Physics	-0.274^{*}	−0.41679	−0.01521	1.670
Degree: Engineering	-0.255^{**}	−0.48325	−0.06543	1.805
QM literacy	-0.216^{*}	−0.42522	−0.08478	1.194
Confidence in teaching QM: quite or a lot	-0.261^{*}	−0.48179	−0.04021	2.014
Value of teaching QM: depends on the type of school	-0.248^{**}	−0.42860	−0.06805	1.338
Value of teaching QM: quite valuable independently on the type of school	-0.328^{***}	−0.51255	−0.14273	1.422

$^{*}p < 0.05$.
$^{**}p < 0.01$.
$^{***}p < 0.001$.

and generic conspiracy ideation, are highly and significantly correlated, confirming that the endorsement of a pseudoscientific belief in a specific disciplinary area is also strongly associated with the endorsement of generic pseudoscientific beliefs and conspiracy beliefs [50]. In other words, when individuals hold a certain type of epistemically unjustified belief, they also tend to accept other types of unjustified beliefs. We also found that, on average, students scored significantly higher on the PSEUDO-QM scale than on the scales for generic pseudoscientific beliefs and conspiracy theories. This result is consistent with those obtained in a previous study using a single item about QM in a generic scale [57]. Specifically, the authors found that students scored higher on the item about QM (*quantum mechanics has great implications in explaining consciousness and/or in the treatment of disease*, $M = 2.26$ out of 5) than on items about, for example, reflexology (1.89), intelligent design (1.78), parapsychology (1.56), emotional carcinogenesis (1.84), and pseudoarcheology (1.61), antivaccination (1.28), which we used in the generic pseudoscientific beliefs scale. As we will discuss in detail in the next subsection, this evidence could be related to a lower familiarity of high school students with many concepts and terms used in the QM-related pseudoscientific claims, contrary to what happens with the terms used in generic pseudoscientific beliefs. There are also significant differences between the PSEUDO-QM score and the score on the conspiracy theories scale. These results are in line with previous studies, in which the authors found that scores on the scale measuring conspiracy theories were on average lower than scores on the scale measuring paranormal and generic pseudoscientific beliefs [46]. Finally, we found that teachers scored significantly higher on the generic pseudoscientific beliefs scale than on the PSEUDO QM scale. This result confirms previous findings that also teachers, like the general public, may hold pseudoscientific beliefs [53], partly due to uninformed views about NOS [83]. The higher score for generic pseudoscientific beliefs not only confirms previous findings in the Italian context [27,51], despite the many societal changes that have occurred since when the studies were carried out, but also suggests that teachers are hardly aware of the demarcation between science and pseudoscience [84]. In contrast, teachers seem to be more aware of conspiracy theories, confirming previous findings in other international contexts [85].

B. RQ2a. Which factors affect the endorsement of QM pseudoscientific beliefs of high school students?

For the student sample, we found that trust in both public and research institutions is negatively associated with the PSEUDO-QM score, confirming our previous findings [56]. Moreover, this result supports recent findings that trust in experts is essential for identifying pseudoscientific claims [86]. Similarly, our results are in line with previous studies that found that lower levels of trust in public institutions are negatively associated with liberal democratic views and positively associated with populist and authoritarian views, which in turn are positively correlated with pseudoscientific beliefs [87]. In contrast to our previous study, we did not find a significant association between the consumption of science-related content, namely, the frequency with which individuals deal with scientific contents by, e.g., reading scientific books, watching science programs and visiting science museums, and the score on the PSEUDO-QM scale. However, we note that in our previous study the association was also very weak, so, in essence, our findings do not fully support research results that consuming science contents through generic media can reduce the belief in pseudoscientific beliefs [50,88]. In contrast, we found a significant negative relationship between QM literacy and score on the pseudo-QM scale, namely, an higher perceived familiarity with terms related to QM (e.g., wave-particle duality, entanglement) may reduce the likelihood of endorsing pseudoscientific beliefs in this content area. To improve QM literacy, teachers can use not only online sources [10], but also the increasing presence of QM discourse in mainstream media, see, for example, the Oppenheimer movie or the big bang theory series. Of course, while our study cannot establish whether a better conceptual understanding of QM leads to a reduced likelihood of endorsing QM-related pseudoscientific beliefs, our findings suggest that teaching QM content at high school level may reduce the risk of students endorsing such claims. In particular, this view is supported by the finding that students who do not study scientific and QM-related content in depth, such as those attending technical or vocational schools, are significantly more likely to endorse such QM-related pseudoscientific beliefs. Moreover, regression analyses suggest that students in humanities oriented high schools may compensate for the lack of specific content instruction in evaluating the plausibility of claims by explicitly teaching skepticism and the nature of scientific knowledge [47,89]. Future studies may further address in a more systematic way if the teaching of scientific contents that are misused in pseudoscientific beliefs—vaccines, chemical bonds, planetary motion—may result in a lower likelihood to endorse related pseudoscientific beliefs—autism from vaccines, homeopathy, astrology [50].

C. RQ2b. Which factors affect the endorsement of QM pseudoscientific beliefs of high school teachers?

Several factors appear to influence teachers' endorsement of QM-related pseudoscientific beliefs: QM knowledge, type of degree, confidence in teaching QM and perceived value of teaching QM. Regarding the first factor, the results obtained with the teachers' sample confirm those obtained with the students, suggesting that the perceived familiarity with QM terms may be helpful in identifying pseudoscientific beliefs independent of age and education received, similar to what happens for vaccine hesitancy [90]. The results on the predictive value of the teachers' degree also seem to suggest that a deeper understanding of QM-related content and a more profound knowledge of the quantum nature of matter may reduce the likelihood of endorsing QM-related pseudoscientific beliefs, in the same way that scientific literacy is negatively related to the endorsement of generic pseudoscientific beliefs [82]. This could be achieved by requiring prospective teachers to attend specific professional development courses on QM. Professional development courses may also be useful to increase confidence in teaching QM and awareness of the value of teaching QM at the secondary school level. Specifically, previous studies have shown that teachers' confidence in teaching QM is lower compared to other contents [91]. Possible interventions to increase teachers' confidence in teaching QM include, for example, discussing examples and applications of QM to increase students' interest [92]. Finally, our results suggest that teachers who critically discuss the value of teaching QM at the high-school level may be more aware of QM-related pseudoscientific beliefs. This finding suggests that these teachers are likely to be more able to reflect on the epistemic and philosophical implications of QM [93], which in turn may have led to a greater awareness of the falsity of typical QM-related pseudoscientific beliefs. To this aim, specific professional development courses about QM focused on explicit teaching of NOS can improve future teachers' capability to distinguish between scientific and pseudoscientific views [94]. We will further discuss this aspect in Sec. VIII.

VII. LIMITATIONS

Three main limitations should be taken into account when interpreting our results. First, the use of two convenience samples limits the possibility to generalize our results to the populations of students and teachers. In particular, while we involved students attending a wide range of high schools, and teacher from different backgrounds, a better sample stratification could have led to more general results.

Second, and related to the first limitation, despite our study did not adopt a group-randomized trial design and our data are not nested, the standard errors may still be underestimated due to unobserved clustering at the individuals' level. However, note that it would be highly unlikely that residuals of our response variable, namely, the students' and teachers' responses to the PSEUDO-QM scale, were correlated at class, school, or geographical level since the scale does not measure QM conceptual knowledge or any related construct that could be influenced by belonging to a specific class, attending a specific school, or living in a specific geographical area.

Third, while we tried to account for previous knowledge and perceived familiarity about QM concepts, also the present study cannot discriminate subjects who consciously endorse pseudoscientific claims from those who simply have not sufficient knowledge about QM.

VIII. CONCLUSIONS

It has been well documented in the literature that pseudoscientific beliefs are not only the consequence of insufficient knowledge or lack of information but are due to a combination of several cognitive and socioaffective factors [95]. Overall, in this study, we found very different mechanisms underlying the endorsement of QM-related pseudoscientific beliefs by students and physics teachers.

For students, we found that they are more likely to endorse QM-related pseudoscientific claims than other types of pseudoscientific beliefs. This worrying finding is only partially compensated by the encouraging result that increasing QM literacy may contribute to decrease the likelihood of endorsing such beliefs. Thus, QM literacy may possibly counteract the tendency of individuals to use peripheral cues when processing information, similar to what happens with scientific literacy [96]. Second, students who have more trust in science and public authorities are less likely to endorse QM-related pseudoscientific beliefs. Thus, increasing the trust in reputable sources, such as scientific agencies or universities, may lead to the mistrust of news coming from untrustworthy sources, such as websites or social media accounts specifically dedicated to spreading pseudoscientific beliefs. Finally, our study calls for students to be introduced to common debunking and prebunking techniques in order to critically evaluate information and make evidence-based decisions. By incorporating debunking strategies into the curriculum, teachers can foster critical thinking skills and skepticism [97]. Implementing such techniques in high schools is consistent with the broader educational goal of developing informed citizens capable of contributing positively to the discourse on scientific and societal issues [98], regardless of the specific high school stream attended.

Regarding teachers, we found that not only is QM literacy a significant predictor of reducing the likelihood of endorsing QM pseudoscientific beliefs, but the teacher's study background and their perceived competence and value in teaching QM both play a prominent role. Three main implications arise from these results. First, in order to improve teachers' epistemic beliefs and become more aware of pseudoscientific related to QM, professional development courses should aim at developing an informed understanding of NOS. The reason is that teaching NOS in the context of QM can show how existing scientific theories and models are not rejected but re-framed in a new perspective so that completely new concepts can be developed [99]. Considering that pseudoscientific beliefs in QM include also the science denial and misinformation dimensions, addressing NOS aspects in professional development courses about QM can help teachers become better prepared in demarcating science from pseudoscience. Such competence can be developed for instance with suitable training materials, as reported in a recent study with physics teachers in Netherlands [100]. In such a way, teachers could also be encouraged to adopt approaches that on the one hand explore the evidence and rationale behind scientific claims and, on the other hand, increase skepticism towards pseudoscientific beliefs [101]. Second, in order to improve the perceived value of teaching QM in the classroom, teachers may be involved in professional development courses about the latest applications of QM technologies and the related work possibilities [102]. Third, teachers can benefit from professional development programs in QM that provide pathways to improve their self-efficacy in teaching basic QM content, such as collaborative discussions with peers to further refine not only their knowledge of basic QM concepts, but also their ability to critically evaluate QM-related information. In such a way, teachers can put more emphasis on the content of a pseudoscientific claim itself rather than emphasizing the trustworthiness of the source, so to overcome negative spillover effects on trust in public and science agencies [103].

IX ETHICS STATEMENT

This study was approved by the Ethical Committee of the Italian National Council of Research. To fulfil the requirements of Italian law, informed consent forms by the students' parents were collected for study participation and research purposes. Refer to the following document for the Italian regulation of this matter [104].

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APPENDIX

A. PSEUDO-QM 17-item version

In the following, we report the 17 items of the PSEUDO-QM scale retained after the CFA. In bracket and italics, for each item, the corresponding dimension of the theoretical framework adopted is also indicated.

CONSP: Conspiracy theories; MIS: Misinfomation; MYST-SPIR: Magic Mysticism; SD: Science Denial

1. Through quantum physics all of humanity's energy problems could be solved, but this information is not disclosed (*CONSP*)
2. True quantum physics is not taught in universities but in restricted circles reserved for people of the highest rank (*CONSP*)
3. In quantum superposition, a particle appears to be in two places at once (*MIS*)
4. Quantum physics predicts that it is possible to teleport our body from one place to another (*MIS*)
5. Quantum physics states that there are infinite multiverses, namely all the realities that could have existed if a choice of a human being had been different really exist (*MIS*)
6. Quantum physics, with the particle wave dualism, predicts that each organ of the human body has its own natural frequency, which if excited can lead to healing serious diseases (*MIS*)
7. Quantum physics, with the concept of entanglement, has scientifically proven that we can have information about every particle in the universe (*MIS*)
8. Quantum physics agrees with traditional Chinese medicine that we can correct the energy flows of our body (*MYST-SPIR*)
9. Quantum physics explains how our consciousness is connected with the Universe (*MYST-SPIR*)
10. Quantum physics explains the difference between life and nonlife (*MYST-SPIR*)
11. Quantum physics solves the problem of human awareness and free will (*MYST-SPIR*)
12. Quantum physics states that it may be possible to change the structure of things with thought alone (*MYST-SPIR*)
13. The quantum energy inside our body is not destroyed after death but returns to the universe (*MYST-SPIR*)
14. Quantum physics can explain what happens to the soul after death (*MYST-SPIR*)
15. Quantum physics in fact states that it is not possible to have any scientifically based certainty, on any topic (*SD*)
16. Quantum physics shows that the excessive human belief in rationality, born with the Enlightenment, was deceptive (*SD*)
17. Quantum physics, through the uncertainty principle, states that every event can happen, and it is not possible to make any predictions (*SD*)

B. Trust in public and science agencies scale

Indicate on a scale from 1 = not at all, to 4 = very, the extent to which you consider the following public and science agencies reliable

1. Companies
2. EU
3. Healthcare
4. Justice
5. Newspapers
6. Parliament

7. Pharmaceutical companies
8. Police
9. Political parties
10. President of Republic
11. Private televisions
12. Public administration
13. Public televisions
14. Public transportation
15. Prime Minister
16. Research centers
17. School
18. Scientists
19. Social media
20. Universities

C. Consumption of science contents scale

Indicate on a scale from 1 = never, to 4 = very, how often do you engage with the following actions

1. Follow science programs on social media
2. Read popular science books
3. Read popular science magazines or newspapers
4. Visit scientific museums
5. Watch popular science programs on the internet
6. Watch popular science programs on TV

D. Quantum literacy scale

Indicate on a scale from 1 = very little, to 3 = very much, how familiar you are with the following topics

1. Energy Level
2. Entanglement
3. Heisenberg principle
4. Orbital
5. Photon
6. Qbit
7. Quantum of action
8. Schrödinger's cat
9. Spin
10. Teletransportation
11. Tunnel effect
12. Wave-Particle dualism
13. Wave function

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