

# What is your favourite particle and why?

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**Abstract.** We have conducted a large-scale international study with high-school teachers (N=530) and high-school students (N=959) from all around the world to investigate and document what they consider as their favourite particles. We found five particles to be highly prominent in both groups, namely the Higgs boson, the neutrino, the electron, the photon and the gluon. Moreover, we did not find any significant differences with regard to the teachers' and students' nationality or gender. In this article, we present our findings in detail and give insight into the teachers' and students' justifications of why they chose a specific particle.

## 1. Introduction

When introducing the Standard Model of particle physics at secondary level, high-school teachers and high-school students are faced with various abstract concepts and lots of novel terms. Among the many challenging terms is the infamous “particle zoo”, which stems from the early days of particle physics, when every newly discovered hadron was believed to be a distinct elementary particle [1]. Since then, the Standard Model of particle physics has been colloquially compared with the variety of species in a zoo on a regular basis [2, 3].

Here, it is assumed that such a representation of the Standard Model of particle physics can have a negative impact on students' understanding of the fundamental concepts underpinning particle physics, namely fundamental interactions between elementary particles. Indeed, a careful educational reconstruction of the subject matter is key when introducing particle physics in the classroom [4]. Specifically, within the framework of constructivism, it is indispensable to take students' conceptions into account and to focus instructional strategies on already existing conceptions [5].

Therefore, we decided to add another layer to the ongoing education research in the field of particle physics, by investigating the conceptions of both high-school teachers and high-school students regarding their favourite particles. Indeed, since the announcement of the discovery of the Higgs boson in 2012, the topic of particle physics has received ever-increasing attention in the media and also within the physics education research community [6]. However, little is known about the perception of different particles and how high-school teachers and high-school students make use of them. Hence, this was the starting point of our international study, which is presented in this article.

## 2. Research Question

To investigate teachers' and students' conceptions about the Standard Model of particle physics, we have conducted this study with high-school teachers and high-school students from all around the world. Our aim was to document the variety of particles, which is considered by high-school teachers and high-school students and quantify their selection on an international level by looking for differences between and within the different nationalities. Moreover, we also collected individual explanations from every participant to document why they decided to choose a specific particle and to trace back their decisions to possible sources. Specifically, we addressed the topic through the following research question: *Which particle is chosen by high-school teachers and high-school students as their favourite and how do they justify their decision?*

### 3. Methods

Every year, CERN offers international programmes for both high-school teachers and high-school students. Among them are the *International High School Teacher Programme* and the *International Teacher Weeks Programme*, which are professional development programmes directed at in-service high-school science teachers from all around the world [7]. In addition, CERN’s hands-on learning laboratory, S’Cool LAB [8], offers the *S’Cool LAB summer camp*, which is designed for 16-19 year-old high-school students from all around the world.

For these three programmes, interested candidates have to fill out and submit an extensive application form, which contains both open-ended and closed-ended questions. In addition, applicants need to provide a short video to present themselves and explain why they are the ideal candidate to take part in the respective programme. Indeed, every year, we receive hundreds of applications from highly motivated high-school teachers and high-school students for CERN’s international programmes. Thus, we decided to make use of this diverse pool of self-selected high-school teachers and high-school students and to use part of the application process for our physics education research.

Specifically, we included the question “Looking at the Standard Model of particle physics, which particle is your favourite? Why?” to all three application forms. Answers were collected by means of a free text field, which was limited to 350 words. Our sample contains applications for the international teacher programmes 2017 & 2018 and for the S’Cool LAB summer camp 2018. Indeed, we collected all answers from eligible candidates, who successfully completed their application form, which resulted in a total of 530 high-school teachers from 78 different countries and 959 high-school students from 82 different countries. Moreover, the gender ratios for both groups are similar, with 232 female and 298 male teachers, and 393 female and 566 male students (see table 1).

**Table 1.** Demographic overview of all high-school teachers and high-school students, who took part in this study.

	N	Female [%]	Male [%]	M [years]	SD [years]
<b>Teachers</b>	530	43.8	56.2	40.5	9.9
<b>Students</b>	959	41.0	59.0	17.2	0.9

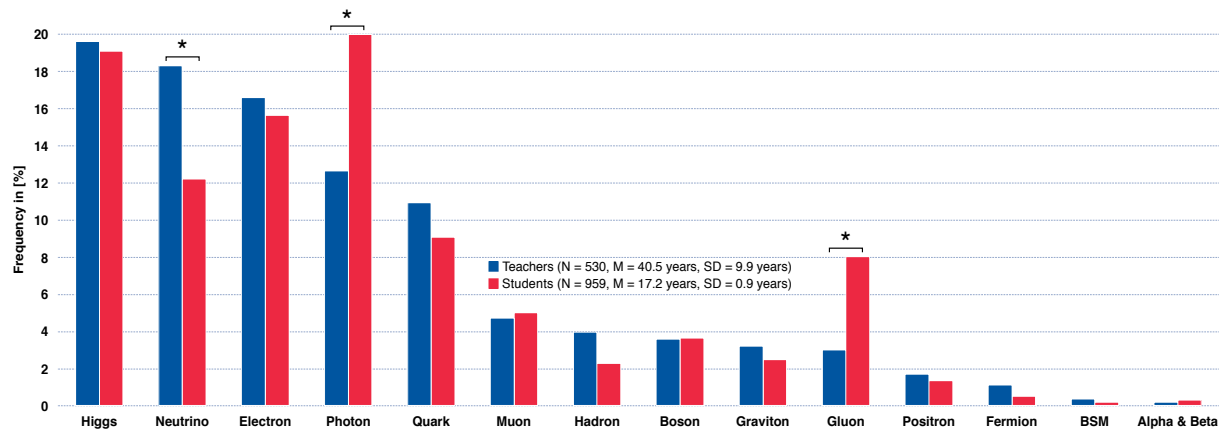
First, a qualitative content analysis was applied to both the high-school teachers’ and the high-school students’ answers to categorise their responses accordingly. Here, we mostly used the particles as categories themselves, but also decided to group, for example, exotic particles into one category. Indeed, the category *Beyond the Standard Model* (BSM) contains both the tachyon and the axion, which were only rarely mentioned. The same is true for the categories of the neutrino and the quark, which contain all different types of neutrinos and quarks, respectively. When analysing the justifications of the high-school teachers and high-school students, however, we used individual categories (i.e. electron-neutrino, muon-neutrino, tau-neutrino and up-quark, down-quark, charm-quark, strange-quark, top-quark, bottom-quark as well as their respective antiparticles), to avoid omitting relevant information.

We then limited the quantitative analysis of our findings to the five most popular particle categories, which were chosen by more than 70% of high-school teachers and high-school students, respectively. In doing so, this selection allowed us to analyse differences between the groups of high-school teachers and high-school students, and between female and male participants. Frequencies of particle categories were compared using chi-squared tests [9]. Significant differences are reported including the corresponding effect size by using Cramér’s V [10]. The significance level of the chi-squared tests has been adjusted to multiple comparisons ( $m = 15$ ) using the Bonferroni correction [11]:  $p^* < \alpha / m = 0.05/15 = 0.003$

#### 4. Results

When looking at the teachers' and students' responses and comparing them with each other, we found only a few significant differences. Indeed, the choices of both groups follow a similar pattern. Specifically, five particle categories cover 70% of the teachers' choices and 75% of the students' answers. These are the Higgs boson, the neutrino, the electron, the photon and the gluon. A full overview of all particle categories and the frequencies with which they were chosen by teachers and students is shown in figure 1.

However, we found three significant differences with small effect sizes, which concern the neutrino, the photon and the gluon. Here, our research shows that the photon is the most favourite particle of high-school students ( $\chi^2(1, N = 1489) = 13.26, p < 0.001, V = 0.1$ ), while in comparison high-school teachers prefer neutrinos more ( $\chi^2(1, N = 1489) = 10.33, p = 0.001, V = 0.1$ ). Furthermore, in comparison to high-school teachers, the gluon appeals far more to high-school students ( $\chi^2(1, N = 1489) = 14.63, p < 0.001, V = 0.1$ ). Thus, we focused our detailed qualitative analysis on the justifications of teachers, who chose the neutrino as their favourite particle and on justifications of students, who either chose the photon or the gluon as their favourite particle.

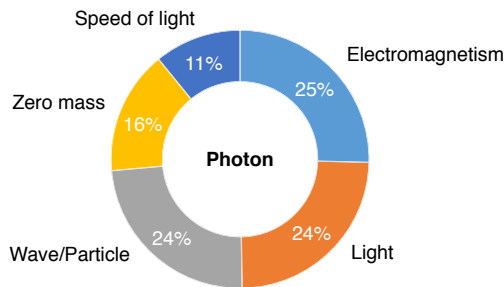


**Figure 1.** Overview of all particle categories, which were chosen by high-school teachers and high-school students. Significant differences between the two groups are highlighted.

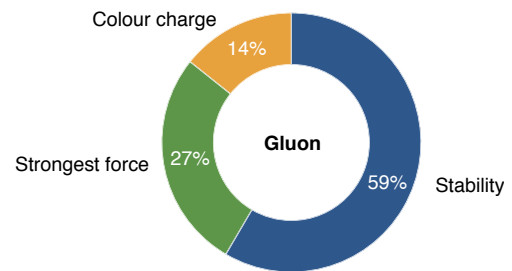
First, we analysed all answers by teachers, who chose one of the neutrinos as their favourite particle. Indeed, we noted that not only was the neutrino one of their top choices, but many teachers even selected a specific neutrino flavour. For example, the electron-antineutrino was prominently featured among the teachers' choices. This seemed to be a peculiar detail at first, but it later turned out that the main justification for choosing the antiparticle of the electron-neutrino was the important role it plays when discussing the muon transformation. Specifically, teachers referred to the process of a muon at the end of its lifetime transforming into a muon-neutrino via a virtual W-Boson, which itself transforms into an electron and an electron-antineutrino. Here, the teachers justified their decision by highlighting conservation laws that are key when discussing transformation processes in particle physics and used the electron-antineutrino as a prime example for conservation of charges.

Second, we analysed all answers by students, who chose the photon as their favourite particle. Here, we identified five different categories among the students' justifications, namely electromagnetism, light, wave/particle, zero mass and speed of light (see figure 2). Indeed, we believe it is safe to say that the photon is one of the most prominently featured particles in the physics classroom, as it is discussed both in a classical and a modern context. Thus, it did not come as a surprise that the photon was the most favourite particle among all students' answers and we could further divide our analysis in two equal parts into classical physics (electromagnetism & light) and modern physics (wave/particle, zero mass, speed of light).

Third, we analysed all answers by students, who chose the gluon as their favourite particle. Indeed, the “gluon peak” was a curious detail of our findings. We identified three different categories, namely stability, strongest force and colour charge (see figure 3). Here, it became apparent that students consider the gluon to be highly relevant for their daily lives, as they acknowledged its responsibility for holding quarks together and thus enabling particle systems to form stable matter. In addition, we noted that the majority of students even compared the gluon to their personality as a “very social particle”, which holds groups together. These findings corroborate previous research, which has shown that middle-school and high-school students transfer macroscopic aspects and every-day experiences into the world of particles by attributing them with emotions and feelings [12]. However, while we did not find any similar justifications for other particle categories, we do want to add the cautionary note that this interpretation may be limited by the setting of our study. Indeed, the fact that we collected our data through an application form for a summer camp might have triggered students to find creative ways of adding additional information about their personality to their application. Here, the gluon would have presented itself as a prime candidate in terms of social behaviour. Thus, while we are intrigued by the “gluon peak”, we do not want to put too much emphasis on it as more detailed research is needed to shed more light on our preliminary findings.



**Figure 2.** Overview of the five different categories to summarise the students’ justifications for choosing the photon as their favourite particle.



**Figure 3.** Overview of the three different categories to summarise the students’ justifications for choosing the gluon as their favourite particle.

Having analysed our findings from a qualitative perspective, we then also looked for significant differences among our data set with regard to the teachers’ and students’ nationality and gender. Here, we again limited our analysis to the five most popular particle categories, namely the Higgs boson, the neutrino, the electron, the photon and the gluon. However, we did not find any significant differences among groups from different nationalities or between female and male participants, neither for teachers (see table 2) nor for students (see table 3).

**Table 2.** Gender comparison of frequencies of particle categories mentioned by teachers.

	N	Female Teachers	Male Teachers	$\chi^2$	df	p
<b>Higgs</b>	104	38 (16%)	66 (22%)	2.75	1	0.097 <sup>n.s.</sup>
<b>Neutrino</b>	97	36 (16%)	61 (21%)	2.14	1	0.144 <sup>n.s.</sup>
<b>Electron</b>	88	37 (16%)	51 (17%)	0.13	1	0.720 <sup>n.s.</sup>
<b>Photon</b>	67	29 (13%)	38 (13%)	0.01	1	0.931 <sup>n.s.</sup>
<b>Gluon</b>	16	9 (4%)	7 (2%)	1.04	1	0.307 <sup>n.s.</sup>

**Table 3.** Gender comparison of frequencies of particle categories mentioned by students.

	N	Female Students	Male Students	$\chi^2$	df	p
<b>Higgs</b>	183	80 (20%)	103 (18%)	0.70	1	0.403 <sup>n.s.</sup>
<b>Neutrino</b>	117	49 (13%)	68 (12%)	0.05	1	0.833 <sup>n.s.</sup>
<b>Electron</b>	150	64 (16%)	86 (15%)	0.21	1	0.647 <sup>n.s.</sup>
<b>Photon</b>	193	69 (18%)	124 (22%)	2.73	1	0.098 <sup>n.s.</sup>
<b>Gluon</b>	77	31 (8%)	46 (8%)	0.02	1	0.893 <sup>n.s.</sup>

## 5. Conclusions

Our study led to very promising findings. Indeed, we could show that on a general level the choices of high-school teachers and high-school students regarding their favourite particles follow a similar pattern. Specifically, only five particle categories cover the majority of the choices of both groups. These are the Higgs boson, the neutrino, the electron, the photon and the gluon. Here, the Higgs boson, which was prominently featured in recent media coverage, seemed to appeal greatly to both high-school teachers and high-school students from all around the world. We consider this to be a very important aspect of our research as it shows that modern physics and especially current high-energy physics have arrived in physics classrooms.

Moreover, when looking at our results, we found significant differences between the high-school teachers' and high-school students' choices of particle categories. Specifically, the photon is the most favourite particle of high-school students, while in comparison high-school teachers prefer neutrinos more. Indeed, based on our analysis we want to emphasise that the photon presents itself as a prime candidate to discuss particle physics in the classroom. Since the photon is usually introduced both in a classical context and in a modern context, it can support high-school teachers in their challenging endeavour to transition between both of them. However, we want to point out that presenting photons in the classroom requires a careful didactical reconstruction and suitable models, as depending on the context it can be discussed both from a particle perspective [13] and a field perspective [14].

Next, the gluon seems to be another well-suited particle to introduce the topic of particle physics in the classroom, as it greatly appeals to high-school students. Indeed, given the stark contrast between high-school teachers' and high-school students' responses, we consider this the most promising finding of our study. Specifically, our findings suggest that high-school students are curious to learn about gluons in the classroom. Such an introduction of the gluon and quark model would enable high-school teachers to appropriately introduce more advanced concepts like colour charge [1] in the classroom and to make current fundamental research in the field of high-energy physics more accessible to high-school students.

Last, we want to emphasise that our findings are limited by the fact that our sample of high-school teachers and high-school students was self-selected. Indeed, additional research is required to shed more light on our preliminary findings and to investigate how our findings can be best implemented in an educational setting. However, we were pleased to see that within our sample there are no significant differences with regard to the participants' nationality and gender. It is in this sense that we consider our findings to be highly promising for educators and policymakers as they show the topic of particle physics to be appropriate and well-suited for introduction in physics classrooms around the world.

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