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Understanding first year students' curiosity and interest about Physics - Lessons learned from the HOPE project

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Abstract - This paper focuses on results of an interview based survey of 1st year University physics students, carried out within the EU HOPE project (http://hopenetwork.eu/). 94 interviews conducted in 13 universities have been analysed to investigate the factors that inspire young people to study physics. In particular, the main motivational factor, which was proven to consist in personal interest and curiosity, was unfolded into different categories and detailed interest profiles were produced. The results are arguably useful to help the academic curriculum developers and teaching personnel in physics departments to provide guidance to students in developing and focusing their interest towards specific sub-fields and/or to design targeted recruitment and outreach initiatives.

1. Introduction

Several reports highlight that Europe needs to attract more young people to pursue further studies and careers in Science, Technology, Engineering and Mathematics (STEM-fields) [1, 2]. The demand is particularly high in the field of physical sciences; and to make things worse, many physics departments suffer from high dropout rates, partly caused by students' decrease of interest during their studies [3]. Furthermore, the long-standing issue of gender imbalance in STEM disciplines needs to be addressed.
In order to provide a sound statistical and theoretical basis to research on the above problems, and more directly, to help teachers at all educational levels improve their approaches and practises, the EU-funded HOPE[1] (Horizons in Physics Education) project examined the views of first year Physics students. One of the HOPE working

[1] HOPE (Project number 2013-3710_540130-LLP-1-2013-1-FR-ERASMUS-ENW) is a three-year (2013-2016) project, coordinated by Université Pierre et Marie Curie in Paris. It is based on the collaboration of 71 partners from 26 European countries.

groups (WG-1) was in charge of investigating the inspirational factors that drive the young people to study physics.
In this article, after a brief overview of the main results of the questionnaire on motivational factors which was given to 2485 1st Year university physics students from 31 Partners in 18 different European countries, we will focus on the results of 94 individual, 20-30 minutes interviews to freshmen students, again on the subject of motivational factors, but aimed at exploring the subject more in detail. In particular, the analysis of the interviews allowed to "unpack" general motivational factors such as interest and curiosity, and to produce more detailed interest profiles, which are arguably more useful in understanding the inner drives of students towards physics.
Overall, the main large-scale result which can be read from both the questionnaire and the interviews, i.e. that physics students are primarily motivated by an internal hunger for *some kind* of knowledge, and only secondarily by other factors such as those related to employment perspectives, is well known. Also, many instructors in physics departments are well aware that the high dropout rate after the first year can be related to students losing their interest in the subject, or finding too many obstacles in developing it, because of the curriculum organization (e.g. too much mathematics, very little physics and "motivational" courses). As a consequence, various strategies are being developed to maintain and nourish students' interest during the first year. In Section 6 we will comment on some of these strategies in light of the results from the HOPE survey.
The main purpose of this paper is to help the academic curriculum developers and teaching personnel in physics departments to understand the different perspectives, interests and curiosity about physics among their students. Such understanding may support the development of courses and instruction to better address and progress students' curiosity and interest, and thereby, to keep students active and motivated in their studies and future careers. The initial interest profiles of students can evolve in many ways and take different forms, and it is up to the instructors in each department to decide how to provide guidance to students in developing and focusing their interest towards specific sub-fields. Finally, results can also be useful for designing targeted recruitment and outreach initiatives, which foster interest in physics at pre-college levels.

2. The survey carried out by the HOPE project

HOPE is an academic network funded within the Life Long Learning Programme (2007-2013) whose overall objective is to encourage the best use of results, innovative products and processes and exchange good practice in order to improve the quality of education and training. Among its working groups and goals, one concerns the issue of investigating the inspirational factors that drive the young people to study physics.
For this purpose, a large questionnaire survey, led by Gareth Jones from the Imperial College, London, has been carried out. The questionnaire focused on the motivations for the choice of physics at University of 1st year students, and was designed to be short and simple, in order to make it easier to deliver it in larger numbers. The design process involved the production of four successive drafts, which were tested

on a progressively wider sample of physics students from different countries [4]. At each step of the process, significant revisions to the research instrument were made taking into account the trial results, indications from the literature [5-7] and suggestions from direct discussion with members of the UPMAP [8] and ASPIRES [9] projects.

In the final version of the questionnaire, students were required to rate the importance of 20 factors in their choice of studying physics, in a scale from 1 (not important at all) to 5 (very important). Responses were obtained from 2485 1st Year university physics students from 31 Partners in 18 different European countries. A preliminary analysis of this data allowed some conclusions to be drawn. Among these are the greater importance of factors related to personal, individual interests with respect to those related to the school experience (the teacher, school marks etc.) or recruitment efforts (visits to and from Universities, etc.). Country dependent effects were present, but in most cases weak; gender differences consisted mostly in a moderate, but statistically significant tendency of female students to be more motivated by recruitment efforts, which is consistent with previous findings [10]. Looking at the whole sample, the most important factors were:

- Wish to understand the world around us
- Wish to understand how things work
- Wish to acquire a deep understanding of the universe
- Wish to learn advanced physics

The least important factors were:

- Encouragement from friends or classmates
- Encouragement from a scientist in family
- Visit from University personnel
- Wish to be a teacher

The large scale data (average ratings for questionnaire items, with some more details on the questions) is reported in Figure 1.

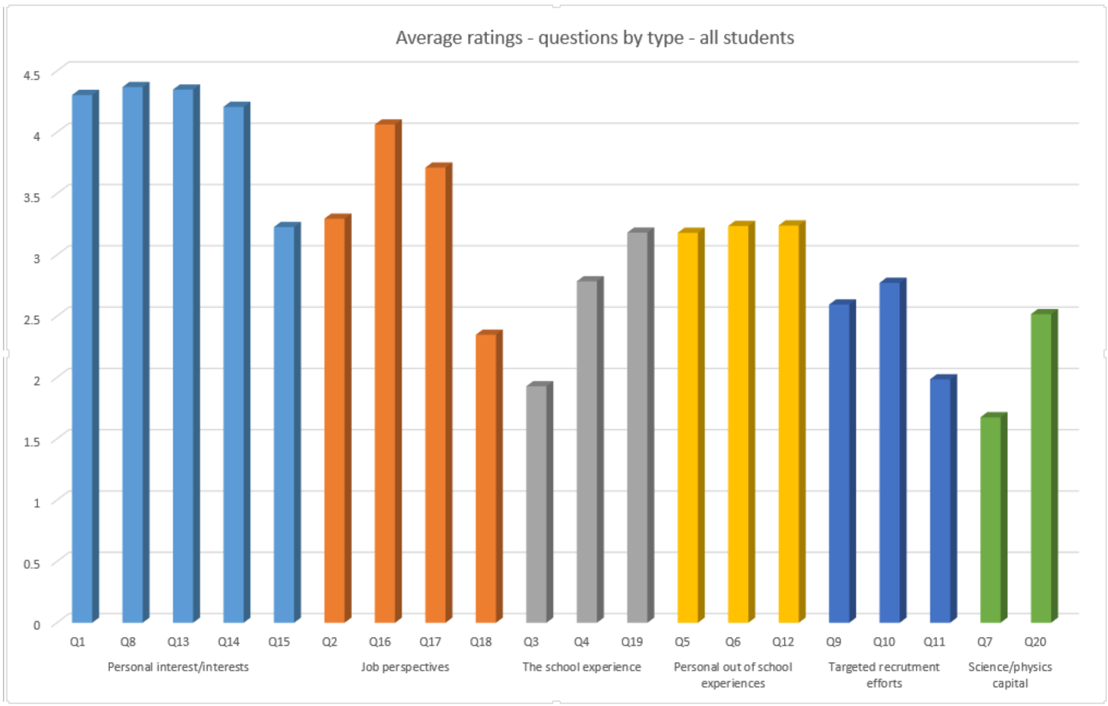

Figure 1 – Average ratings on a 1-5 scale from least to most important for the answers of N=2485 students to the HOPE questionnaire. Items are grouped in categories: “Personal interest/interests” (light blue) includes questions Q1 (“A wish to acquire a deep understanding of the universe”), Q8 (“A wish to understand the world around you”), Q13 (“Wanting to understand how things work”), Q14 (“A wish to learn advanced physics”), Q15 (“Making and/or using a physics-based device”). Category “Job perspectives” (orange) includes Q2 (“A wish to enhance employment prospects”), Q16 (“A wish to get an interesting job”), Q17 (“A wish to become a physics researcher”), Q18 (“A wish to become a physics teacher”). Category “The school experience” (grey) includes Q3 (“Encouragement from friends/classmates”), Q4 (“A physics teacher in school”), Q19 (“Physics was the school subject I did best at”). Category “Personal out of school experiences (yellow) includes Q5 (“Seeing TV documentaries on physics topics”), Q6 (“Reading books or magazines”), Q12 (“Seeing things on the internet”). Category “Targeted recruitment efforts” (dark blue) includes Q9 (“Visits to museums or special exhibitions”), Q10 (“Visits to scientific laboratories”), Q11 (“Visits from university staff or students to your School”). Finally, category “Science/physics capital” (green) includes Q7 (“Being inspired by a scientist in your family”) and Q20 (“Encouragement from parents or family”).

In the second stage of data collection, which was coordinated by Olivia Levrini of the University of Bologna, Italy, 94 semi-structured individual interviews were carried out in 16 universities on a selection of students who had previously answered the questionnaire. One of the goals of the survey was to zoom in on some of the issues investigated through the large scale questionnaire to further explore the reasons of the choice. However, the investigation carried out by the interview team was also largely independent of the detailed results of the questionnaire, and in the final version of the interview protocol (reported as supplemental material to this paper [11]) only one question made explicit reference to the student’s answers to the questionnaire survey. For the purpose of the argument advanced in this article, there is essentially a single, very general result from the questionnaire survey which is highly relevant: the greater relative weight of interest- and curiosity- related intrinsic motivations with respect to other reasons, expectations and influences in orienting students towards choosing physics at University. Such result, as we will discuss in the next Section, is also well founded in previous research.
The aim of this paper is to provide a comprehensive picture of first year students’ interest and curiosity in physics to inform teaching choices. Thus, after a review of how curiosity and interest is addressed in the research in science education, we present the methodological aspects of the interview survey (the survey instrument, the sample and the methods of data analysis) and the articulated picture we obtained from our data.

3. Theoretical/analytical tools: students’ interest and curiosity about physics

Due to the above-discussed shortage of students and professionals in STEM, during past decades a lot of research and reports have been published on factors influencing young people’s choices on their further scientific studies and careers. Common finding in these studies is that university students chiefly use expressions of interest and intrinsic motivation to describe their decision-making on further studies and careers, while expectations of success as well as utility and attainment values play smaller roles in motivating them [12, 13]. Especially among those who choose physics as a field of study at postcompulsory stage, research suggests that interest may be a very important explaining factor [14]. Although the UPMAP project showed that *extrinsic motivation* (access into higher education or future employment prospects) as well as encouragement from the family and the teachers influence 15-year-old students' aspiration to study physics in school [15], those students who choose physics in academia more often tell a different kind of story. This is also in line with physics researchers describing their motivation mostly in terms of interest in natural phenomena and scientific understanding, and that such interest typically arose already in childhood [16].

What is this 'interest', then? Generally, interest has a fundamentally intrinsic character, and it is a crucial facilitator for learning [17]. Individual, dispositional interest in something (an object, activity, field of knowledge, or goal) is considered a relatively stable tendency. Interest can, however, be also situational, i.e. momentary and caused primarily by external factors [18]. Under favourable and recurring conditions, situational interest may develop into a long-lasting, individual form of interest.

A myriad of research on students' interest in science has been published. Unfortunately, a common finding is that many students seem to lose some of their interest as they move through the educational system [19, 20]. A closer look at students' interest in science immediately reveals that interest in a science topic may not necessarily indicate interest in scientific practices and pursuits. Recognising the ways in which students express curiosity to understand the nature of an object, phenomenon, or a given topic may shed light on whether their interest is in the topic itself, or in the line(s) of practice associated with it [21, 22].

Curiosity, in the research literature addressing it, has been defined as "a form of cognitively induced deprivation that arises from the perception of a gap in knowledge or understanding" [23] or "a psychological trait or disposition to prefer uncertainty, novelty, complexity, and exploration" [24]. One of the main issues that is debatable within these strands is to which extent curiosity is an inherently individual and stable disposition or something that can be mediated by and fostered through social interactions with parents, teachers, caregivers, and/or the peer group [25]. There is, however, a lot of research showing parents' role in facilitating curiosity [26, 27] and that school may fail in supporting children's expression of curiosity --- it may even dampen it [28]. Although most of research on science curiosity is on children, it seems plausible that education at academic level can also either strengthen or kill curiosity. This is crucial since intellectual curiosity or a "hungry mind" is a core determinant of differences in academic achievement [29].

To better understand the nuances and viewpoints in students' interest, Luce and Hsi [21] differentiated between six types of curiosity: mechanistic, teleological, inconsistency, cause & effect, engineering or medicine and general knowledge. In this paper we follow their suggestion. We employed and adapted their typology of curiosity, which was originally used to analyse children's perspectives, to better understand university students' curiosity about physics and about its special ways to understand and investigating the world. We argue that some of these fundamental types of curiosity can be found in people at different ages and educational levels.

Yet, our typology for university students became more fine-grained, as discussed in the following sections.

4. Methods

The process of designing, running and analysing the interviews represented a collective work, managed by the interview team. Such a process was articulated in four research phases along the three-years of the project, with the scope of producing a picture as detailed as possible of students' rationale for their choices as expressed in their own words, and going more in depth into the questionnaires results. The semi-structured individual interviews were carried out on a selection of students who had previously answered the questionnaire. Synthetically, the four research phases were carried out as follows:

(1) analysis of a selection of the main existing literature on the topic (ASPIRES [9]; CLASS [30][2]) which led to the design of a first draft version of the protocol with a first rough coding, the criteria to set up the sample and the guidelines to carry out the interviews;
(2) trial and revision of the interview protocol and the refinement of the coding template;
(3) establishment of the interviewer community, accomplishment of interviews, data collection and first local analyses;
(4) process of two-round analysis and coding refinement.

The analysis of the literature highly oriented the design of the protocol, that resulted in a semi-structured protocol organized in two part:

- *Part A*, aimed at zooming in on some issues already investigated by the questionnaire and to further explore the reasons of students' choice; in this part there are questions about family, the self-perception as physics student and the reasons that draw students toward physics;
- *Part B*, aimed at investigating how students' expectations did impact with university reality, to point out possible problematic issues that can turn into reasons for dropping out.

The flow of the questions was organized to result in a total length of each interview of about 20-30 minutes. The protocol was designed in English and translated in each of the national languages by respecting the original formulation.
The interviews were carried out between December 2014 and June 2015 in 16 universities. They were audio-recorded, transcribed and analysed according to the template and the coding scheme.
Consistently with the interviews' scopes, the sample was chosen to cover different dimensions: geography, gender, level of satisfaction about the degree course. The interview team collectively decided that the sensible minimum number of interviews

[2] ASPIRES is a ten-year longitudinal research project studying young people's science and career aspirations of the King's College, London. CLASS: Colorado Learning Attitudes about Science Survey.

was 10-15% of the students who filled in the questionnaire. The graph below (Figure 2) shows how the 94 interviews are distributed among the 13 partners (Padova carried out the interviews both within the Physics and the Astronomy Degree Courses):

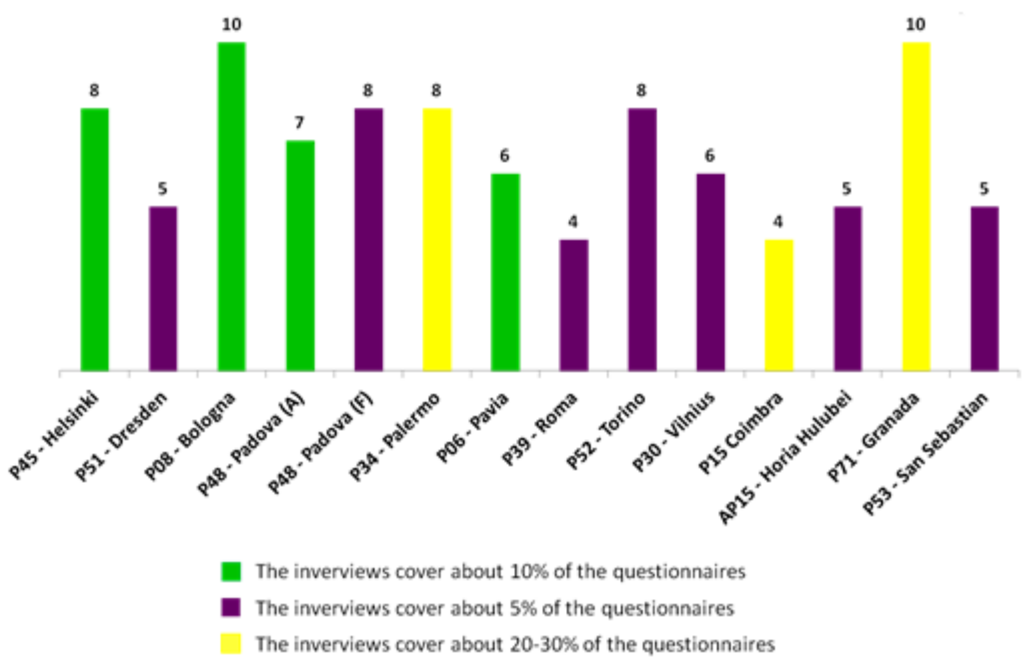

Figure 2 - Interviews' sample across the partners.

The interviews were transcribed and analysed according to the coding scheme built on trials and shared in the working group. At least two scholars per partner individually analysed the transcripts and reported their results in their analysis template. The results were shared and discussed within the local group (triangulation). The group identified the controversial issues (the data that are coded in different ways), reached a consensus and aggregated the results into a table that was sent to the working group. The results collected by all partners that carried out interviews were aggregated to draw a big picture, which allows to identify potential problems of the coding and to refine the data. Finally, a re-analysis of interviews was carried out in order to apply the final version of the coding.

Phase 4 represented a crucial moment in the interviews' work. Indeed, in the first round of data analysis an interesting result was found: in the coding of the questions about students' inner motivation, the category of "curiosity" was overpopulated with respect to the others. This result provided an important feedback on the coding and revealed the necessity of refining it, in order to have a more detailed and informative picture of the data.

The new coding was tested against the interview data of a small group of scholars, in order to check its validity and try its applicability. Finally, it was applied by each partner to their own data.

We are well aware that our interview sample is at present not statistically representative of European students: just to name one evident issue, Italian students are over-represented. In the following we will make use of some general indications coming from our data about the relative size of categories to advance the discussion; but these should not be taken in any way as claims of universality. Our main result is a categorization of first year physics students' interests and curiosities which has proven operative and robust, producing a non-trivial distribution of students in categories when applied to data from several countries.

5. Results

5.1 Overview of the driving factors

As described above, first results from both of the HOPE investigation instruments on 1st year students -- the questionnaire and the interviews – strongly indicated that intrinsic motivation, or simply 'interest', seems to be the predominant factor in the choice to study physics. Some other factors were identified too -- such as reasons relating to applications, careers, societal issues or personal challenge – but they were not nearly as significant as the deeply *internal* factors. Therefore, we focused our analysis on gaining a more fine-grained picture of the different *kinds* of interest and curiosity the students have. The process leading to the following categorization was described in the previous section.

Based on our shared interpretation of themes emerging from the data, the "interest/curiosity" cluster was broken down into two macro categories: A) Curiosity to understand the world, natural phenomena and universe; and B) Interest in physics knowledge as a *special* way of knowing, investigating, questioning and thinking.
Both of these macro categories were then further divided into sub-categories that represent different aspects and perspectives of students' interest/curiosity. The subcategories were formed using a twofold approach: by searching themes emerging from the data, as well as using the literature on interest and curiosity to find fruitful specification. Especially, the macro category A was broken down following the typology of Luce and Hsi [21]:

Category A: Curiosity to understand the world, natural phenomena and the universe
In category **A1: Mechanisms underlying phenomena**, following Luce and Hsi [21] we considered statements in which students express curiosity as a wish to understand *how* something works and *how* processes occur. We include in this category answers in which students express a wish to comprehend cause-effect relationships, or to explain phenomena through principles or laws. In **A2: "Teleological" cluster** we collected answers of students that appeared curious to know *why*- and not only how - phenomena occur. This category refers to the curiosity for big questions about the world that go *beyond* the curiosity of knowing the mechanism. It can include also ontological (what is the real essence of nature?) and theological questions (who created nature?). Answers classified as **A3: Inconsistency/surprise/wonder** expressed curiosity about the element of surprise and inconsistency of observations/explanations with respect to prior knowledge or everyday understanding.

Category B: Interest in physics knowledge as a *special* way of knowing, investigating, questioning and thinking.

Category B collected answers by students that drew their motivation to study physics from an interest in physics as knowledge. These perspectives are not that intimately linked to the nature or the universe, but rather to physics mind-set, practices, skills, thinking categories and methods which characterize physical research and knowledge. The subcategories distinguished between the different interests. Category **B1: Mindset of physicists** was used for students that are driven by their interest in rational thinking and problem solving. **B2: "think different and critical"** collected answers that expressed interest in divergent, critical, counterintuitive and unconventional ways of thinking. Statements about the mathematical formalism of physics as a motivation for the choice of the field were categorised in **B3: Math cluster**. In category **B4: Experiment/real world connection cluster** we collected answers making a reference to the experimental methods of physics as a motivational factor. The **B5: Theoretical cluster** is populated by students that are interested or fascinated by the comprehensive pictures that are provided by the fundamental laws and unifying theories. Students that are driven by the infinite and open-ended process of asking questions and challenges that is intrinsic to physics were classified in **B6: Never-ending questioning cluster**.

Category AB: Generic fascination for physics

In all of the above subcategories students expressed a distinct curiosity or interest in one aspect of physics. There were, however, also interviewees that were not able to specify their interest or curiosity in such a clear way. These students were simply fascinated by physics, or in a few cases made general comments about the beauty of physics; often, such fascination was perceived as having arisen at an early age. In these cases their answers were collected in category **AB: Generic fascination**.

Other driving factors

The internal factors discussed in sections 4.2 and 4.3 were the predominant ones in the interviews as well as in the questionnaire data. However, several other driving factors were expressed by the students.

Students' expressions of wishes to contribute to the technological progress linked to specific areas of applied physics were collected in category **C: Application cluster**.

Answers stating a student's interest in epistemological and philosophical questions as well as the connection of physics to humanities were classified as **D: Philosophy cluster**.

The category **E: Societal engagement cluster** was populated by students whose choice of physics was motivated by their interest in societal (environmental, health-related, political) implications of physics.

Also career opportunities can play a role in the choice of physics. Such responses are categorised in **F: Job cluster**. Category **F2** makes reference to students that clearly stated that they want to become a researcher, whereas **F1** collects all other answers expressing career interests as a motivational factor.

Students' expressions about a wish to develop themselves through personal challenges were collected in category **J: Personal challenge cluster**.

Finally, some other reasons for choosing physics were mentioned. These reasons are too specific of the student to warrant the creation of a new category; for example having been admitted to a certain prestigious physics faculty or college. These are classified as **K: Other**.

A synthesis of the coding and the meaning of the categories is presented in Table 1

A. Curiosity to understand the world, natural phenomena and universe	
A1. Mechanisms underlying phenomena	Curiosity about how something works or how a process occurs. Wanting to understand underlying mechanisms for processes or observations. Wanting understand cause-effect relationships, or to know how the entities in a causal relationship interact. Wanting to explain phenomena through principles or laws.
A2. “Teleological” (that is the wish to know *beyond* the mechanism)	Curiosity about the purpose of things, why things exist, or why processes occur. Curiosity about function, design, purpose. This category includes also ontological and theological questions.
A3. Inconsistency/ surprise/ wonder	Curiosity about an observation that is surprising or inconsistent with prior knowledge.
B. Interest in physics knowledge as a *special* way of knowing, investigating, questioning and thinking	
B1. Mindset of physicists, rational thinking and problem solving	Interest in ways of thinking that deeply characterize physics ways of solving problems, arguing, modelling...
B2. “Think different – and – critical”	Interest in divergent thinking, critical thinking, counterintuitive ideas toward not obvious things, unusual and unconventional ways of thinking.
B3. Math cluster	Interest in the formal/mathematics aspect of physics.
B4. Experiment/real world connection	Interest in the experimental method of physics and/or in the processes of observing, selecting, reproducing phenomena, … .
B5. Theoretical modelling	Interest/fascination toward comprehensive pictures provided by fundamental laws and unifying theories
B6. Never-ending questioning	Fascination toward the never-ending process of physics research, toward the "infinitely open-ended" process of asking questions.
AB. Generic fascination	
AB. Generic fascination	Fascination about the world, generic or sometimes purely aesthetic fascination toward physics.
C-K. Other possible factors	
C. Applications	Interest/wish to contribute to the technological progress and/or to applied physics (e.g. medical physics).
D. Philosophical issues	Interest in the epistemological issues arisen by physics, appreciation of physics’ connections with humanities, … .
E. Societal engagement	Interest in the societal (environmental, health, political,…) implications of physics.
F. Job cluster	**F1:** Wish to have a good/ well-paid/ socially well reputed job; the wish to have good employment prospect. This category includes issues like the wish to have a good social reputation, or to increase one's own employability.
	F2: Wish to become a researcher.
J. Personal challenge	Wish to have the opportunity of self-expression, to expand one’s own abilities, to become an interesting or cool person, to test one’s own self-discipline, ambition, …
K. Other	Not clear factors or other (to be specified).

Table 1 – Synthetic view of the coding specifying the meaning of categories.

5.2 Results of the classification

Figure 3 shows the results for the classification of students' answers according to the categories introduced in section 5.1.

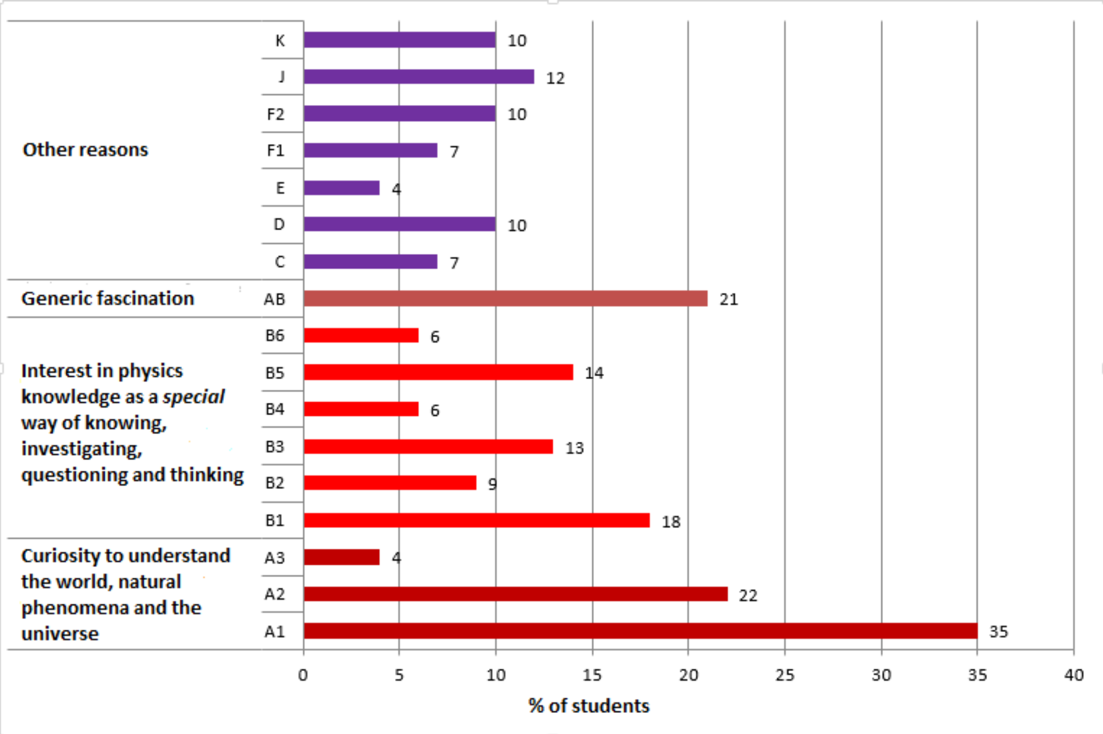

Figure 3 – Classification of students according to the categories of Section 5.1, reporting the percentage of students for each category. An individual student's answers can belong to more than one category.

A total of 50 out of the 94 interviewed students expressed motivational factors classified as **Category A: Curiosity to understand the world, natural phenomena and the universe**. 33 answers were collected in **A1: Mechanisms underlying phenomena**, 21 in **A2: Teleological cluster** and 4 in **A3: Inconsistency, surprise, wonder**.
Some typical answers for these clusters are given in Table 2.

A. Curiosity to understand the world, natural phenomena and universe	
A1. Mechanisms underlying phenomena	"What attracts me most, my main aim at the end of all my studies, it is to understand how the universe works and to explain the laws of the universe. I think that physics helps me to understand the universe, since everything works according to the law of physics." "I want to know how nature works. I've always had this interest."
A2. Teleological (that is the wish to know *beyond* the mechanism)	"Discover the reason why we are here, studying what has created us, stars, as a consequence galaxies, … in a concrete way. I have a strong passion for discovering the reason why we are here… like us there are for sure other places in the universe which are inhabited." "The main reason is to be able to understand what is at the base of everything, something real." "I am a free Christian in a church for all Christians where I read the Bible intensively. I

	had to choose between physics and studies in theology, economics, and mathematics. I chose physics because I understood that science (physics) can give me answers to the question "how a perfect God created the world".
A3. Inconsistency/ surprise/ wonder	"Infinity, that we are infinitely small, who knows what there is out there, it all seems so impossible, for example how is it possible that in the beginning all matter was in a single point, it's a bit all *those mysteries* also that attract me… searching for an answer." "Physics is magic… today's magic is tomorrow's science."

Table 2 – Representative students' answers for the categories belonging to group A.

Out of the 94 interviewed students, 49 mentioned their interest in physics knowledge. More in detail, 17 answers were categorized in **B1: Mindset of physicists**, 8 in **B2: "think different and critical"**, 12 in **B3: Math cluster**, 6 in **B4: Experiment/real world connection cluster**, 13 in **B5: Theoretical cluster**, and 6 in **B6: Never-ending questioning cluster.**
Typical answers for each category can be seen in Table 3.

B Interest in physics knowledge as a *special* way of knowing, investigating, questioning and thinking	
B.1 Mindset of physicists, rational thinking and problem solving cluster	"For my future project, even though it is not yet well defined, I wished to have any scientific education, that is, I was interested to acquire a method, to be able to think in a certain way, to go throughout my life in a certain way. I had in my mind so many scientific disciplines to choose. And then discarding all the others, physics remained, that is also the subject matter where I performed better. Mathematics seemed too little concrete. I removed other faculties such as biology that did not appear to me rigorous enough. So physics left. I chose physics because I think it is the best to acquire a certain way of thinking. " "I'm not interested in memorizing bits of fragmented information, but I want to learn general laws that can be applied to many cases. Physics is like that. In physics you have to understand, not memorize."
B.2 "think different – and – critical" cluster	"Physics can push imagination to levels that probably nobody normally can reach. In spite of this incredible imagination, physics allows you to fantasize while remaining tied to reality. It also allows you - how to say - by studying nature in a certain way, to learn a lot about how to approach, say, life. It is a real school." "A physicist has to be able to question, to abstract himself (herself) from what reality appears to be, to be creative, to think and not accepting everything quietly."
B.3 Math cluster	"I was undecided between physics and math for a while. But then, rethinking about it … I mean math seemed too … only math. Instead physics I could put together the math part and also something else […] work on something. I don't know, that was not only simple math, […], but understanding how things work." "When I was younger, I always wanted to understand equations."
B.4 Experiment/real world connection cluster	"I like physics because it is not purely abstract, but it has applications in the real world. " "Physics is everyday things, relates to everyday life."
B.5 Theoretical cluster	"Physics attracts me because it does explain what other sciences do not. And over all because it is so…it is so beautiful, much more than other sciences." "Physics is comprehensive and tries to explain almost everything." "it's fascinating that Physics studies the smallest and the biggest things in the Universe, and everything in between. Physics is the common foundation of all science, and that's what makes it interesting to me. Physics is, at least for now, the best science for describing the world."
B.6 Never-ending questioning cluster	"What attracts me in physics is to find explanations of things. Although not always the results are achieved, physics tries to do that. Each question opens other ten new questions and this is positive."

	"I am attracted by the idea of science in the sense that it is something infinite, there is always something to be discovered, there is always someone who can add one more small brick …there is still a lot to discover."

Table 3 – Representative students' answers for the categories belonging to group B.

A total of 20 students provided an answer classified as category **AB: General fascination**.
Table 4 shows some characteristic statements for this category.

AB. Generic fascination	"A passion that I've had since I was a child, so it has been nurtured for all these years, it was the only choice I had in mind." "I like everything in physics. I have been fascinated since I was a kid. First I was attracted by astronomy, now I like also particle physics." "My interest in physics arose I was 10 years old, looking at a book on the universe: I was fascinated by the images and the beauty of the universe."

Table 4 – Representative students' answers for category AB.

A majority of students (80 out of 94) mentioned at least one aspect classified in categories **A** or **B**, and in many cases two or even more. Of the remaining students, 9 expressed a general interest or fascination for physics that could be included in the category **AB**, while 5 only mentioned different reasons, included in the categories **C-K**.
Figure 4 shows a compact representation of the data concerning the principal categories as an Euler-Venn diagram.

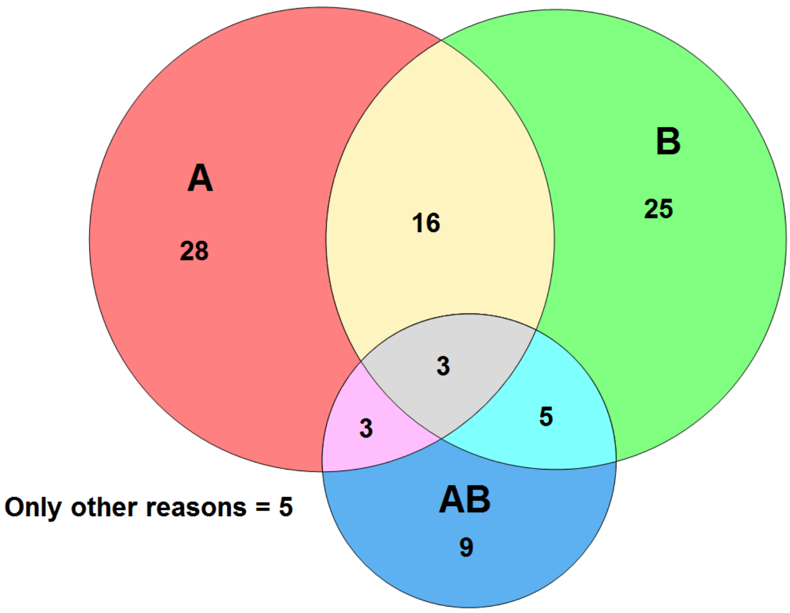

Figure 4 – Euler-Venn diagram showing the distribution of students' answers in the main categories A, B, AB and their intersections.

Motivational factors other than those described by their curiosities or interests were mentioned by 40 students, and 56 times in total. Typical answers are summarized in Table 5.

C. Applications	"Health physics is something that I would like to explore thoroughly, I don't know a lot about it, but from what I know I think that could

	interest me a lot, primarily for applications, because they seem to me very important." "Medical physics fascinates me."
D. Philosophical issues	"It also attracts me a bit from the philosophical point of view, I mean the idea that astronomy is an idea that opens up the mind by itself, I mean thinking about the infinite space…let's say that both my scientific part as well as my humanistic part met and said: Yes, yes, go for it!" "Also philosophy was one of the subjects that I liked most at High School and probably my choice has been inspired also by it."
E. Societal engagement	"In my opinion, a good physicist should not accept the economic conditions and should try to change the world, the life conditions of all living creatures, not only humans." "I wanted to get background knowledge (in physics) to support my studies in geography and environmental sciences."
F. Job cluster	"The knowledge of fundamental laws of nature offer a very wide possibility of studies, not limited to one specific area." "My biggest realization for the future would be working as a researcher, I mean, if I imagine a work for when I'm older I want it to be that. I would like to be a researcher in the astronomical field."
J. Personal challenge	"To be in a community of people where one can express oneself at the best. Since I was a little boy, I watch documentaries and I imagine that if I could work like these scientists do, and study these things, perhaps I would arrive, me too, at important results. I'm interested in all about physics." "In my view, scientific research is somehow like a mission, like a doctor with a patient: I have this idea of fixing a goal, asking questions, looking for answers." "Intellectual problems are nice to work with even though it [physics] couldn't find 'a deeper reality'"
K. Other	"I have been made to like particle physics since I was a child. So I like it but also for family affection [both the parents are physicists and the father is a particle physicist]." "the primary reason was that I knew I would be accepted into here [Dept. of Physics in Helsinki]. Also, this was close to where I live… and other practical reasons"

Table 5 – Representative students' answers for categories C-K.

5.3 Interpretation of the results

From the data it appears that students who start physics studies at university are either strongly motivated by their curiosity in understanding how the world works or are very interested in what characterises physics as knowledge (its practises, methods, and way of knowing and thinking). Often both aspects are present. It seems that students enrolling in a physic degree already have quite deep questions to pose to their studies.

Although many students are interested in the practices involved in doing physics, only 16 students out of 94 mention the career opportunities as one of the reasons for starting physics studies: 9 students talked about their wish to become a researcher (**F2**) and 7 were driven by other career interests (**F1**). So, although students appear very aware and interested in the work done by a physicist, career opportunities do not seem to represent a main issue for them.

Another interesting point is the low number of students motivated by their interest in societal (environmental, health-related, political) implications of physics: in fact only 4 out of 94 students mention this aspect.

5.4 Gender related characteristics

In Figure 5, we show the distribution of answers in relation to gender. The distribution of answer differs slightly, with males more driven by internal curiosity (**A1**: 22 male and 11 female students, with the total sample being composed of 50 male and 44 female), teleological issues (**A2**: 14 male and 7 female students) and personal challenges (**J**: 9 male and 2 female students). The reasons mentioned by females seem more uniformly distributed across the categories. Considering the level of macro-categories, 31 male students made references to aspects belonging to category **A** and 22 to category **B** while for female students, 19 made references to category **A** and 27 to category **B**.

By performing a chi-squared test on the mentioned male-female differences, one finds that only for category J "personal challenge" the null hypothesis is rejected at level of significance p=0.05 (precisely p=0.043 for category J, while p=0.054 for A1 and higher p-values for the other categories). Gender differences in the distribution in macro-categories A and B are not significant at the p=0.05 level. These results were expected as the interview sample size is not large enough for drawing quantitative conclusions. The previous discussion has hence to be taken only as a preliminary indication to be checked in further studies and/or in specific contexts.

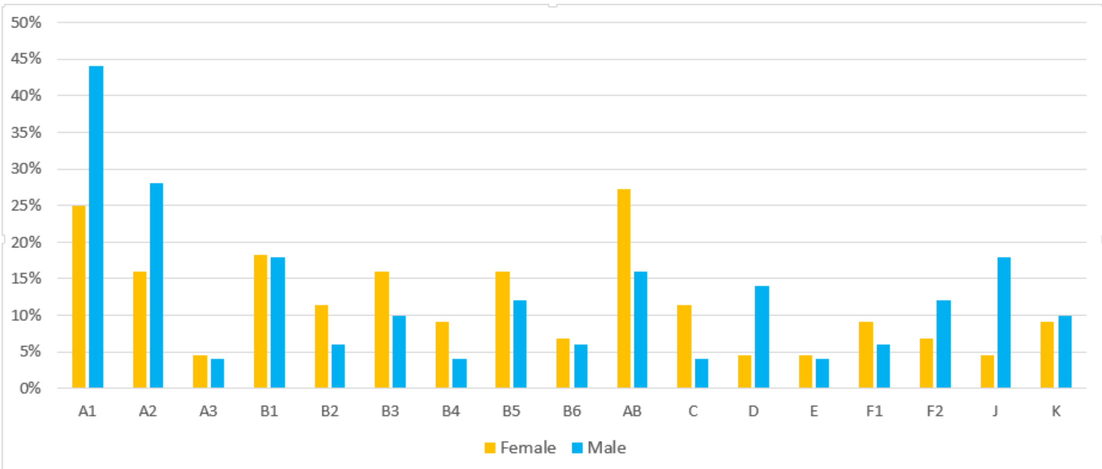

Figure 5 – Gender differences in students' answers. Male students are 50, female students are 44. The percentages reported for each category are with respect to the total numbers of males or females.

6. Discussion and conclusions

By and large the HOPE results – both from the questionnaire study as well as the interviews – support the findings from earlier studies [12, 13, 14]: university students chiefly use expressions of interest and intrinsic motivation to describe factors inspiring them to study physics. This tendency seems to be characteristic of physics majors, but probably also other academic fields. In general, intellectual curiosity is a crucial psychological treat predicting academic achievement [29].

Some differences to earlier research findings were also noticed. For instance, our interviewees did not recognise the encouragement from a scientist in family as a significant factor, whereas the UPMAP project found such effect important [31]. Overall, our interview transcripts suggest that the family supports, or at least does not oppose, the student's choice, but still such support is not perceived as a major motivation, nor do students report identification with a science-associated adult as a source of inspiration. It must be noted that, in our sample, the percentage of cases in which students reported the presence of a scientist of some kind among parents or relatives was, in itself, not exceptionally high (about 36%). We leave to further studies the more in-depth investigation of this interesting discrepancy with previous research.

In the detailed our analysis we identified, by large, the two principal drives that attract students to physics as a) curiosity about nature and phenomena and b) Interest in physics knowledge (its practises, methods, and way of knowing and thinking). The division in subcategories shed more light on the precise nature of such curiosities and interests. The articulated picture of interest and curiosity built in this study is supposed to act as a tool to invent new strategies to support and encourage students' questions since the very beginning of their university studies in physics.

First year physics programs throughout Europe differ, but it is fair to say that they concentrate much more on the training of physics practices (e.g. mathematics, problem solving, and basic laboratory skills) than in favouring the development and articulation of students' curiosities. Typically this issue is postponed to a later stage of the degree program. This does not concern only general curiosities on nature and phenomena included in category A; some important ways of physics knowing and investigating, such as critical thinking and creative questioning, are also often reserved for students in the later years of their degrees [32].

In recent times, this issue has been perceived by University educators confronted with high dropout rates, and indeed in many cases partial answers have been proposed. For example, at the Pavia University in Italy, the traditional lessons have been flanked by a series of more advanced seminars, devoted specifically to freshmen students, in which current research topics are treated using a simple language. In the University of Helsinki, first year Physics students are provided with a whole course introducing the variety of departments' research groups, their personnel, current research projects and advanced topics. These initiatives go in the direction of offering a more stimulating first year experience for students whose main drive consists of questions on Nature, and also of offering a wider perspective on physics ways of knowing and investigating.

Other Universities have employed different strategies, relying more heavily on guidance and counselling for students. In Padova, academic teachers, upper year students and administrative staff are involved in formative tutoring activities meant to help freshmen approach the new University environment in a more successful way. One of the objectives, in this case, is to help students understand what they can and what they cannot expect from the physics degree course, and also guide them in evolving and redirecting their interests. Our data also provides support for the usefulness of such strategy. We remark that a relevant number of students in our sample (21 out of 94) come to physics driven at least in part by curiosities which

either lie outside of the current discourse of physics, or play a marginal role in it (teleological/ontological issues). For these students, the introduction of optional courses dealing with physics topics from a wider perspective, which takes into account historical and epistemological aspects [33, 34], may be a possibility to consider. This may provide students with a clearer view on the nature of science, and help them in better understanding the historical processes by which questions gain and lose legitimacy within the discipline of physics.
The growing popularity of journals, like the European Journal of Physics, devoted to the improvement of University education shows that many instructors have become or are becoming aware of the need of a renewal in educational practices. In particular, we wish to underscore here the potential role which could be played by innovation in laboratory education. In many first year physics programs in Europe, the lab course is the main occasion for having students directly experience significant practices related to the construction of physics knowledge and to improve skills different from the ones related to the understanding of mathematical models and the solving of exercises. However, too often such courses still consist of traditional experiences repeated identically year by year, or only of those kinds of experiment which are significant for the research line of the teacher, and familiar to him. In the last 30 years, educational research has advanced a number of proposals for a reform of the undergraduate laboratory which have only partially and slowly been enacted by Universities [35]. Recent technological advances now allow to perform a number of diverse, exciting and meaningful experiments even using simple and inexpensive materials. Thus, the first year laboratory could, by itself, be used to feed a wide range of curiosities of students, and to help them develop their interest in many of the practices and processes by which physics knowledge is produced. For example, by introducing topics related to advanced fields of physics from an experimental point of view first [36, 37]; by emphasizing aspects of critical thinking [32], problem solving [38], theoretical modelling [39], autonomous investigation and creative design [40, 41].
We believe the present work will be useful to faculties both directly, to inform educational policies and the choice of course contents, and as a theoretical basis to conduct further investigations on their own student population. Current and future plans of the HOPE working group devoted to "Inspiring the young to study physics" include extending the sample reached by both the questionnaire and interviews; producing an analysis of typical "profiles of dissatisfaction" of students who are thinking to leave the physics degree course, and studying in detail the role of high school teachers in motivating students to choose physics.

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