

ASTRONOMICAL PILLS

One-shot questions about the Universe

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ABSTRACT

In the last two years, the Public Outreach & Education office (POE) of the INAF-Osservatorio Astronomico di Brera (Milano, Italy) has carried on an extensive survey (over 1300 tests) on the instinctive ideas that junior and secondary school students (aged 13-19) use when facing astronomical concepts. Students were asked to answer nine closed-answer questions and an open-answer one. They were only allowed a few seconds to make their choices. Our goal was to take a first step into the exploration of the naïve view of the Universe developed by students in the different age ranges. In particular we explored the evolution (if any) of some misconceptions with respect to age and other educational factors. In this talk we present a critical review of our work, highlighting the following points: “lessons learned”, “what works and what doesn’t” and “what can be learned” from our personal experience.

INTRODUCTION

The Public Outreach & Education office (POE) of the INAF—Osservatorio Astronomico di Brera (Milano, Italy) began a survey on the astronomical ideas and concepts held by junior and secondary school students in 2003. Two years of data collection and over 1300 tests have enabled us to take a first step into the idea of the exploration of the Universe as developed by school-age youngsters. We now present the preliminary results of this survey, stressing some aspects of our own personal experience.

Our goal was to explore the naïve view of the Universe developed by youngsters in different age ranges, mainly focusing on the general perception of the Universe, on distance and size, and how gravity works. In particular, we looked for the evolution (if any) of some misconceptions with age and at the role of socio-educational factors. We would like to stress that we did not aim to investigate the students’ knowledge of science, but, rather, the spontaneous schemes and concepts used by youngsters when facing some basic astronomical ideas. We tried to rebuild the image of the Universe developed by youngsters over time using these schemes.

THE ORIGINS OF MISCONCEPTIONS

Why are we so interested in misconceptions? From childhood onwards, people create their own representation of the environment. These representations are based on perception, they are affected by social relationships and they are described by us-

ing informal language. This is what is known as the common-sense framework. For instance, if we rely only on our perception alone we would say that it is the Sun that moves around a still Earth.

However, schooling teaches us a very different representation of the environment. This is the rational scientific framework, based on logical abstraction, hypothetical-deductive reasoning and the use of formal language. Misconceptions are born when people try to combine common and scientific sense together. The process involves not only content knowledge, but, most importantly, thinking structures as well. New knowledge does not erase the pre-existing ideas by merely replacing them; rather, it modifies itself to fit the older conceptual scheme. This is a mostly subconscious process due to the fact that common-sense knowledge is more intuitive and more useful for solving daily problems than is the scientific sense. Furthermore, the process involves the emotional sphere: people simply like familiar ideas.

Misconceptions hamper the correct assimilation of new learning. By studying misconceptions, it is possible to understand better how people's minds work during the learning process and to improve educational strategies to provide a better assimilation of new concepts.

It is only in the last hundred years that the first analyses of children's misconceptions have been carried out following Piaget's theory about the phases of cognitive development. According to this theory, misconceptions are just a phase that depend only on the age of the child, and disappear from adults' minds at the end of cognitive development. However, modern theories provide a more complex framework. First of all, cognitive structures interact with learnt contents and produce resistant conceptual schemes which are almost completely unknown and ignored by teachers and educators. Moreover, social framework and educational level as well as age are involved in the process. This means that misconceptions do not disappear with age and, in fact, some studies highlight the fact that some misconceptions are difficult to eradicate and fairly predictable (e.g. Cavallini, 1995). This was confirmed by surveys that have been carried out to investigate teenagers' and adults' misconceptions since 1970 (e.g. Mayer, 1990).

Our work follows this line by studying misconceptions in the domain of astronomy. We think that astronomy is a useful field to highlight several misconceptions and to develop the capacity for abstraction essential for scientific knowledge.

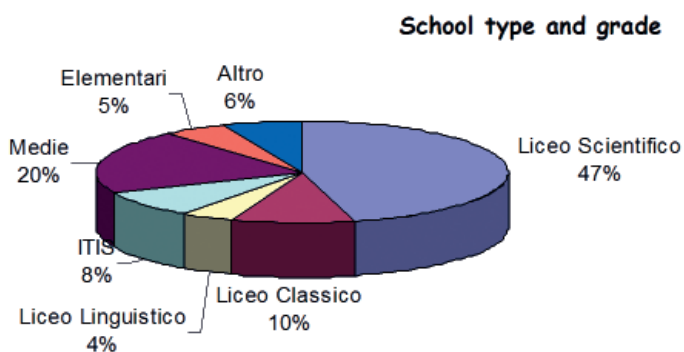
We collected more than 1300 completed tests over a period of 2 years (2003-2005), consisting of 10 questions on astronomical topics, concerning the students' percep-

SAMPLE AND TEST FEATURES

Figure 1. More than half of the schools involved were secondary schools (14-18 year-olds): 47% science-oriented, 10% literature-oriented, 8% technical-skills-oriented, 4% language-oriented. Then, junior schools (11-13 year-olds) follow with 20%.

tion of the Universe, distance and size in the Solar System, properties of light and how gravity works. The study sampled students in different age ranges (13-19 years old) and from different types of school (see Fig 1).

To study the possible evolution of misconceptions with age, we considered three groups: 13-14 years old (last year of junior school) 14-16 years old (first two years of secondary school), more than 16 years old (last three years of secondary school). We also looked for differences between males and females for each age group.



There were two versions of the test, administered at different times, so the same topics could be compared, and to see what bias (if any) is introduced by question structure. Therefore, the test consisted of closed-answer questions with multiple-choice on common- and scientific-sense and open-answer questions.

Students took the test as soon as they arrived at the observatory. We tried to put the students at ease by explaining the purpose of the test and by pointing out that it was not like a school test, starting with the fact that it was anonymous and was not going to be marked. Then, we asked them to answer questions as quickly as possible to let their spontaneous imagination come out. To allow their imaging to emerge more easily, questions were posed during informal conversations with students; moreover, in the open-answer questions we let students choose their favourite method of expression: images, words or both. We now present the results analyzed so far.

DATA ANALYSIS

Let us start with the question about the perception of the Universe. The analysis revealed the presence of similar answers, which were therefore grouped in categories. The most frequent answers were "infinity" and "objects". The older the pupils, the higher the rate of "infinity" with respect to "objects". In addition, we studied what kinds of objects and adjectives were chosen to describe the Universe and we found

that the Universe consists mainly of planets, stars and galaxies and that it is perceived as big and dark (see Fig. 2).

We also collected drawings about the Universe. Their number is small compared with the whole set of data (about 15%), but we think they are representative of the perception of the Universe because they are consistent with the results previously described. Since the drawings do not vary between age groups, we could think of three possible age-independent scenarios.

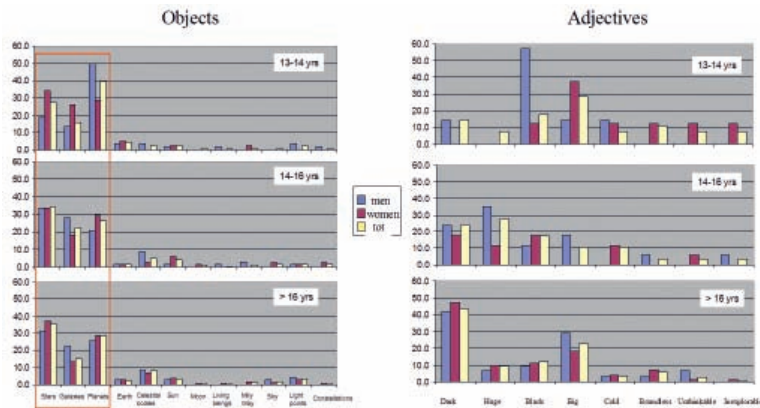


Figure 2. Objects and adjectives used to describe the Universe in the open-answer question about the Universe perception

1. The so-called “Cosmic Box” in which the Universe is perceived as a box of stars (point-like or traditional 5-pointed) and planets in a space, sometimes encircled by an edge. It’s worth noting that the Sun and stars seem to be perceived as two different types of objects.
2. The so-called “Solar System”, in which the Universe is perceived as equivalent to a Solar System with very small distances between same-sized planets. This is consistent with the literature: the Solar System as a sort of all-



Figure 3. The “Cosmic Box”. It is worth noting that the Universe is sometimes encircled by an edge and that the Sun and the stars are perceived as two different kinds of objects.

Figure 4. The “Solar System”. It is worth noting that all the bodies have the same size and that distances between them are very small.

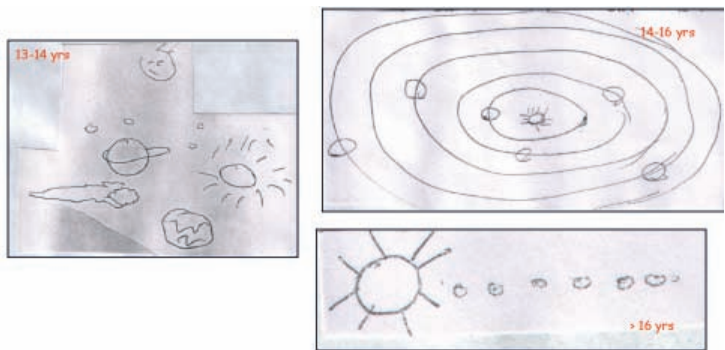
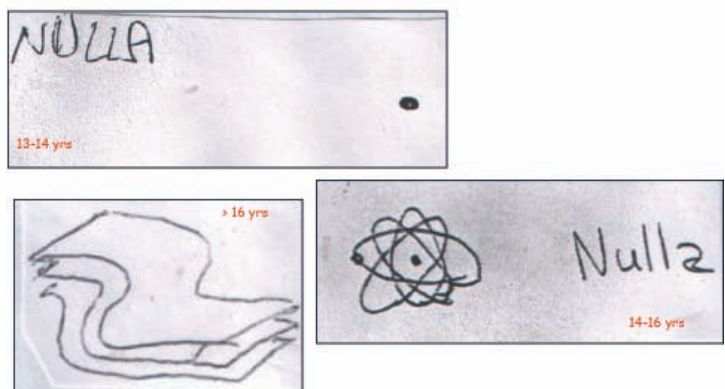


Figure 5. The “Empty Expanse”. In Italian nulla means “nothing”.



purpose astronomical box in which people put everything known about the Universe (Dussault, M., 1999, “How do visitors understand the Universe? Studies yield information on planning exhibitions and programs, *Association of Science-Technology Centers Newsletter*).

3. The so-called “Empty Expanse” in which the Universe is perceived as an empty space without any evidence of stars, planets or other features.

Then, we investigated the students’ perception of distances in the Solar System and in the Universe with an open-answer question. For the size of the Solar System, the students had the correct idea about the order of magnitude; in particular, the majority of them indicated numerical values remarkably close to the correct one. On the other hand, there was a wide range of answers concerning the size of the Universe. We found this was true particularly of the older students, while the younger ones indicated values very close to the size of the Solar System. This is consistent with the “Solar System” scenario. Furthermore, we compared these results with those of the analogous closed-answer question and we found they were very similar. Therefore, misconceptions on distances do not depend on question structure.

Other misconceptions were not as difficult as we had thought. From the analysis of the open-answer questions described so far, students seem to know nothing about hierarchy in the Universe. Nevertheless, when they were asked a properly formulated closed-answer question, almost all of them were pretty sure that the Solar System belongs to a galaxy. The difference is striking because they seemed completely unaware of the discrepancy, even when we asked them to consider their different answers.

What is the cause of this discrepancy? There could be several causes. We think the use of specific language forms in a given framework plays an important role. In particular, the presence of keywords significantly affects the answers more than the actual knowledge the students have. Furthermore, subjects do not understand when discrepancies arise in comparing common- and scientific-sense frameworks until they are forced to combine them together in a common framework.

We investigated if students knew what gravity is by using formal language, such as the language that they might find in their textbooks (see Fig.6). As shown in Fig.6-A, three of the four answers on gravity are partially right. Except for the 10% of students who answered wrongly, most people seemed to have assimilated the concept of gravity. Moreover, the older the student, the more often the correct definition of gravity was given. Therefore, formal language affects secondary school students more than junior school ones. This result is consistent with the literature (e.g. Calcidese, P., 2002, L'Universo che non c'è'. Preconcetti e misconcezioni degli studenti in età adolescenziale nell'ambito della fisica e conseguenze sulle idee riferite all'origine ed evoluzione dell'Universo, *thesis*).

A	B
<p>The gravity force is:</p> <ul style="list-style-type: none"> a) the force which makes the Sun attracts the Earth b) the force which makes us fall c) the interaction force between two massive bodies d) the energy of a falling body 	<p>Bodies are near spherical because:</p> <ul style="list-style-type: none"> a) they spin around the Sun b) the sphere is the perfect geometric shape c) they spin around themselves d1) all men stay with feet on the ground and head up d2) make up your own answer

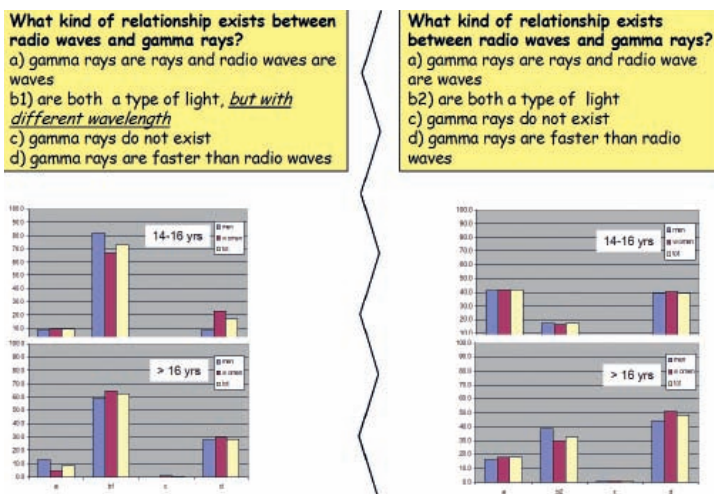
Figure 6. Formal (A) and informal (B) language used in the question about gravity.

On the other hand, another question about gravity, formulated in informal language (see Fig.6), showed the opposite result. In this case, very few people seemed to have assimilated the concept of gravity. The majority of them answered that bodies are nearly spherical because they spin around themselves. Furthermore, in an ensuing conversation, when asked whether the Earth was a perfect sphere, students immediately answered that it is not, because it is squeezed at the poles as a consequence of the Earth's rotation. Students were not aware of the discrepancy until they were

made to pay attention to both their answers. So, it seems necessary to conclude that the use of formal and informal language in a given framework causes differences in the resulting answers. For instance, if the framework was perceived as school-like, students would choose an answer in formal language, like that required in classes, notwithstanding its contents.

However, the two questions about gravity were too different in structure to allow a direct comparison on language bias only. We tried to isolate the language bias by omitting just one single keyword in the correct answer statement. The compared results showed a completely opposite trend, as shown in Figure 7. In the test version containing the keyword (namely wavelength), the students seemed to know the correct answer confidently, whereas without the keyword they were totally confused. Therefore, we obtained evidence that language formalism significantly affects the subjects' answers irrespective of school grade.

Figure 7. Language formalism significantly affects the subjects' answers irrespective of school grade.



LESSONS LEARNED

What have we learnt from our experience? The obtained results suggest that age and schooling do not modify the most basic ideas regarding the Universe. Moreover we did not find any significant difference between boys and girls.

Some misconceptions were demonstrated to be difficult to eradicate, while others are affected by the use of a specific language form. In addition, misconceptions are resistant to time: our results are very similar to those of surveys carried out 10-15 years ago (e.g. Cavallini, G., 1995, "La formazione dei concetti scientifici. Senso comune, scienza, apprendimento", Firenze, La nuova Italia Editrice; Mayer, M., 1990, "Conoscenza scientifica e conoscenza comune. Analisi dell'incidenza di fat-

tori scolastici ed extrascolastici nell'apprendimento della fisica", Roma, I Quaderni di Villa Falconieri, CEDE). Of course the method used to investigate common-sense knowledge could be improved, for instance, by considering smaller groups of students and by differentiating the test framework from the school framework. In fact, we had some evidence that the environment was perceived as school-like: for instance, some pupils tried to cheat by looking at their neighbour's answers. This was also probably due to the presence of their teachers or to the fact that the activity took place during school-time, even if located at Brera Observatory.

Finally, we are convinced that consistency in data collection and the method used is essential to make progress in the study of misconceptions and cognitive knowledge. In particular, it is important to enable educators to have access to sufficient data to make general theories, which are far more useful than isolated case studies based on individual surveys.

The aim of this test was to study any spontaneous schemes and concepts about the most relevant ideas of the Universe developed by youngsters. In particular, we looked for evolution of some misconceptions over age and socio-educational factors.

We paid particular attention to concepts that seemed not to change with age and school grade, such as distances in the Universe. Moreover, no significant differences emerged from the comparison of males versus females.

Using a list of the main ideas about the Universe found in a school-age public, we tried to bring their background knowledge to the surface and see if it blocks the correct assimilation of new learning. We found that the use of formal or informal language in a given framework significantly affects the subjects' answers, by introducing socio-educational and emotional factors. In particular, this result has highlighted the fact that scientific and non-scientific knowledge are not combined together in our cognitive structures and that age and school grade do not modify pre-existing ways of reasoning.

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SUMMARY