IL NUOVO CIMENTO **44 C** (2021) 159
DOI 10.1393/ncc/i2021-21159-5

Communications: SIF Congress 2020

Students' understanding of Universe birth and evolution

A. Colantonio(1)(2) (*), I. Testa(2)(3), S. Leccia(2) and I. Marzoli(1)

(1) *School of Science and Technology, Physics Division, University of Camerino Camerino, Italy*
(2) *INAF-Astronomical Observatory of Capodimonte - Naples, Italy*
(3) *Department of Physics, University Federico II - Naples, Italy*

received 16 January 2021

Summary. — A coherent picture of high school students conceptual understanding of cosmology is yet to be provided. To this aim, we conducted a survey on a convenience sample of 432 Italian high school students. The students responses to an open-ended questionnaire were analysed with a non-hierarchical cluster analysis, using SPSS K-means algorithm. In this study we could identify patterns amongst students beliefs and ideas. Our preliminary findings may guide the design of meaningful and more effective teaching activities to improve students understanding of this content area.

1. – Introduction and aims

Recent curriculum reforms in Italy have promoted the introduction at secondary school level of up-to-date physics topics, such as quantum mechanics, particles' standard model, and cosmology. However, the implementation of such reforms has proven to be difficult, since such advanced subjects require a deep understanding of the underlying physical mechanisms and theories. Moreover, modern physics should be better integrated into physics classes and more effective approaches for teaching certain topics, such as cosmology, are needed. On the other side, cosmology provides a meaningful context to teach contemporary physics topics, such as nuclear reactions, light spectra, and dark matter. Previous results [1-5] suggest that students often begin university courses in astrophysics with pre-existing notions that may interfere with the instructional efforts. While university students' beliefs and ideas about some aspects of cosmology have been identified by prior work [1,2,4,5], a coherent picture of high school students' conceptual understanding in this content area is yet to be provided. By identifying patterns amongst such beliefs

(*) `https://orcid.org/0000-0003-3363-8548`. E-mail: `arturo.colantonio@unicam.it`

and ideas, it would be possible to frame meaningful and more effective teaching activities to improve students' understanding of this content area. Therefore, the present study was guided by the following two research questions:

- What are the students' ideas about relevant conceptual aspects of cosmology?
- To what extent does cluster analysis allow us to identify coherent patterns of understanding?

2. – Methods

2˙1. *Instrument*. – To answer our research questions, we first identified, on the basis of previous studies and accepted scientific models of the Universe, seven conceptual dimensions that we deemed as important for a meaningful understanding of cosmology [2-5]. For the sake of clarity, these dimensions can be divided into two groups of concepts: basic and advanced ones. Basic concepts concern fundamental astronomical entities such as stars, galaxies, constellations, nebulae, and the time and length scales of typical astronomical events and objects. Advanced concepts include: the birth of Universe; the age of Universe and how we can estimate it; how temperature and chemical composition of the Universe changed over time; the space-time expansion; hypotheses about the future evolution of the Universe. More advanced topics cover fundamental notions about black holes, dark matter and energy. For instance, we included in this latter group the notion that a black hole is an astronomical object characterized by its gravitational field. Then, starting from previous work [3-6], we designed a questionnaire with 17 open-ended questions that addressed two or more aspects of the identified dimensions. In table I, we summarize the correspondence between conceptual dimensions and designed questions. The questionnaire items included three types of task: written text, drawing, and ranking. The reason for including also a drawing task was to link students representations with the reasoning emerging from the written answer [7]. Ranking tasks were designed only for the age and distance of astronomical objects. The content validity of the questions was checked with three professional astrophysicists.

2˙2. *Sample*. – We involved in this study a convenience sample of 432 Italian high school students (17.9 ± 0.7 years old). The students: i) voluntarily attended extra-curricular activities about physics topics at the authors' department; ii) addressed basic

Table I. – *Distribution of questions across the conceptual dimensions of cosmology.*

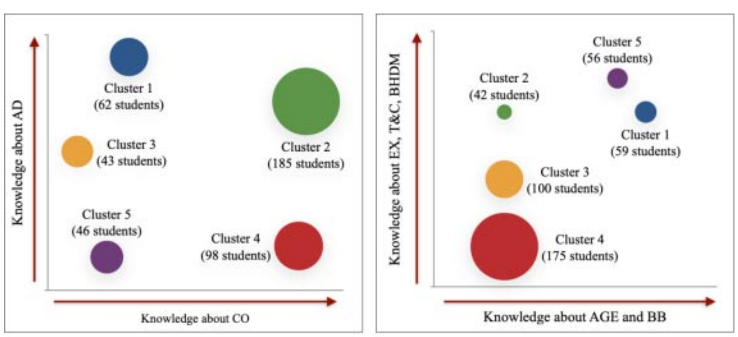
	Conceptual dimensions	Acronym	Questions
Basic	Celestial objects and their relationships	CO	Q11, Q14a,b,c,d
	Celestial objects age and distance	AD	Q12, Q13
Advanced	Universe age and its determination	AGE	Q2, Q3
	Birth of the Universe	BB	Q1, Q5, Q6, Q7
	Universe temperature and composition	T&C	Q4, Q10
	Universe expansion and future evolution	EX	Q8, Q9, Q15
	More advanced topics	BHDM	Q16a,b, Q17

elements of astronomy during their first year of high school as part of Earth Science curriculum; iii) were neither involved in specific teaching-learning sequences nor in extra-curricular activities focused on astrophysics.

2·3. *Data analysis*. – First, we categorized the students' responses using a constant comparative method [8]. Three researchers analysed independently the whole data set generating for each question a suitable number of categories to fit the students' responses. Then, we collapsed the initial categories into five hierarchical macro-categories, ranging from no given or unclear response to scientifically correct or acceptable. Two researchers reviewed again the students' responses to check the categorization. Inter-rater reliability was evaluated obtaining at the end of the process a satisfactory level of about 0.80. Because our sample was large and heterogeneous, we combined the students' responses to questions related to the same aspect using cluster analysis [9]. In such a way we could identify patterns of reasoning, which correspond to different levels of conceptual understanding about the targeted dimensions. Following the method used by Battaglia *et al.* [10], we performed a non-hierarchical cluster analysis using the SPSS K-means algorithm. The analysis was carried out in two phases. In the first one we clustered the questions related to the same dimension. In the second phase, after an interpretation of the cluster solution according to increasing levels of knowledge, we performed two different cluster analysis procedures: one for the basic and another for the advanced dimensions.

3. – Findings

The final interpretation of each cluster was validated by the same professional astrophysicists, who had already checked the questionnaire validity. For each dimension, we chose a five clusters solution, which reflects increasingly complex reasoning about the concepts related to that dimension. In fig. 1 we show a two-dimensional visual representation of our cluster solutions. In panel (a) we represent the position of each clusters with respect to the increasing levels of knowledge about the two basic dimensions. Concerning the basic conceptual dimensions (see fig. 1(a)) some 283 students have a good knowledge of CO, whereas 151 display a rather limited knowledge. Moreover, about 30% of them are unable to order from the nearest to the most distant one, compared to the Earth,



(a) (b)

Fig. 1. – Two-dimensional visual representation of the cluster distribution. The position of each cluster is represented with respect to the increasing levels of knowledge. In panel (a) we report the cluster solution regarding basic dimensions. In panel (b) we report the cluster solution regarding advanced conceptual dimensions.

a series of astronomical objects and fail to reconstruct the timeline of significant events in the Universe history. We note that there is no correlation between the knowledge of definitions of celestial objects and, between their mutual distance and the timeline of some events in the history of Universe. In panel (b) we represent the position of each clusters with respect to the increasing levels of knowledge about AGE and BB *versus* EX, T&C and BHDM. Finally, we note that although the majority of students are in the lowest level of knowledge (Cluster 4), a good knowledge of AGE and BB leads to high levels of knowledge about expansion, temporal evolution, and more advanced aspects of cosmology (Clusters 1 and 5).

4. – Conclusions

Our analysis reveals that high school students' knowledge about the Universe is rather limited. While the collected students' responses suggest that cosmology is somehow addressed during curricular teaching and dissemination activities in informal setting, the results of the cluster analysis point out that some relevant aspects are neglected: for instance, how scientists support their claims about different Universe models. Furthermore, curricular teaching seems to have a limited impact on students' ideas also about basic aspects, such as the role of gravity and other physical mechanisms underlying cosmology. In conclusion, our data suggest that typical high school teaching does not allow a deep conceptual understanding about cosmology.

As next step of our research we are developing a teaching-learning sequence, which includes paper-and-pencil as well as laboratory activities. To validate the identified clusters, we are in the process of administering a revised version of the questionnaire to a wider sample of students. Moreover, we will compare the results of clustering based on different K-means algorithms in different computational environments.

REFERENCES

[1] Lightman A. P. and Miller J. D., *Soc. Stud. Sci.*, **19** (1989) 127.
[2] Prather E. E., Slater T. F. and Offerdahl E. G., *Astron. Educ. Rev.*, **1** (2002) 28.
[3] Bailey J. M., Coble K., Cochran G., Larrieu D., Sanchez R. and Cominsky L. R., *Astron. Educ. Rev.*, **11** (2012) 010302.
[4] Trouille L. E., Coble K., Cochran G. L., Bailey J. M., Camarillo C. T., Nickerson M. D. and Cominsky L. R., *Astron. Educ. Rev.*, **12** (2013) 010110.
[5] Wallace C. S., Prather E. E. and Duncan D. K., *Astron. Educ. Rev.*, **11** (2012) 010104.
[6] Cole M., Cohen C., Wilhelm J. and Lindell R., *Phys. Rev. Phys. Educ. Res.*, **14** (2018) 010139.
[7] Tytler R., Prain V., Aranda G., Ferguson J. and Gorur R., *J. Res. Sci. Teach.*, **57** (2020) 209.
[8] Strauss A. and Corbin J., *Basics of Qualitative Research: Techniques and Procedures for Developing Ground Theory* (SAGE, London) 2018.
[9] Fazio C. and Battaglia O. R , *Int. J. Sci. Math. Educ.*, **17** (2019) 1497.
[10] Battaglia O. R., Di Paola B. and Fazio C., *Phys. Rev. Phys. Educ. Res.*, **15** (2019) 020112.