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An investigation on conceptual understanding about cosmology

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Abstract. In this study, we identify patterns among students beliefs and ideas in cosmology, in order to frame meaningful and more effective teaching activities in this amazing content area. We involve a convenience sample of 432 high school students. We analyze students' responses to an open-ended questionnaire with a non-hierarchical cluster analysis using the k-means algorithm.

1. Introduction and Aims

Cosmology is a meaningful context to teach, at high school level, contemporary physics topics, such as quantum mechanics, particles' standard model, nuclear reactions. The students beliefs and ideas about cosmology have been investigated in some aspects (e.g. the works of Prather *et al.* 2002, Wallace *et al.* 2012, Coble *et al.* 2018), but a coherent picture of students conceptual understanding is yet to be provided. We aims to identify patterns between such beliefs and pre-instructional ideas about cosmology, in order to frame meaningful and more effective teaching activities in this content area.

2. Methods

On the basis of previous studies (Wallace *et al.* 2012, Bailey *et al.* 2012, Trouille *et al.* 2013) we have identified two groups of conceptual dimension: "basic" and "advanced". The first group concerns fundamental astronomical entities (CO) such as stars, galaxies, constellations, nebulae, and time and length scales of typical astronomical events and objects (AD). The second group includes birth (BB) and age (Age) of Universe; temperature and chemical composition of the Universe changing over the time (T&C); space-time expansion (EX); hypothesis about the future of the Universe, black holes, dark matter and dark energy (BHDM). Then, we designed a questionnaire with 17 open-ended questions that addressed two or more aspects of the identified dimensions. We involved in this study a convenience sample of 432 high school students (17.9 ± 0.7 years old) attending extra-curricular activities about physics topics at the authors' Department. The collected data set was independently and completely analyzed by three researchers, who defined for each question five categories fitting the students' responses and ranging from "not given or unclear response" to "scientifically correct". To check students' responses categorization we used inter-rater reliability, obtaining at the end of process a satisfactory level of 0.82. We combined the students' answers on a given aspect by using the non-hierarchical cluster analysis and the k-means algorithm, with the aim to identify

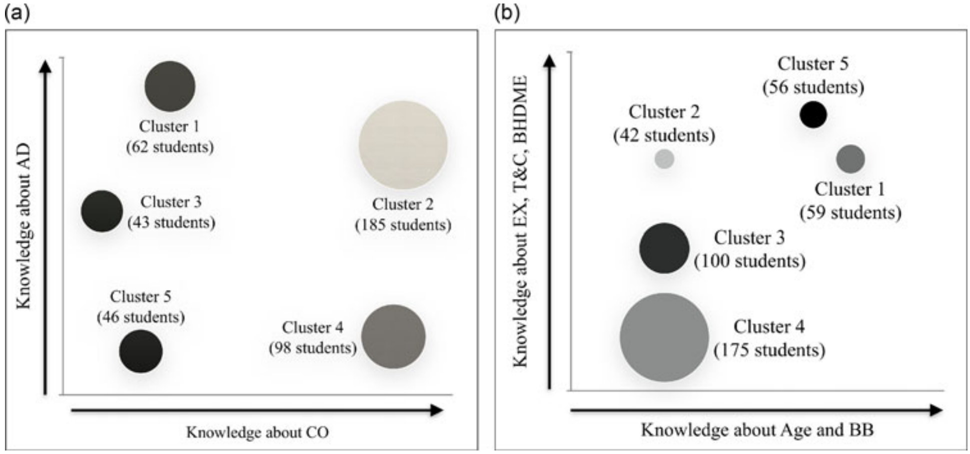

Figure 1. 2-D visual representation of the cluster distribution regarding basic dimensions (panel *a*) and advanced conceptual ones (panel *b*).

reasoning patterns corresponding to different levels of conceptual understanding about the targeted dimensions (Battaglia *et al.* 2019).

3. Results

For each dimension, we choose a five clusters solution, which reflect increasingly complex reasoning. The final interpretation of each cluster was validated by the same professional astrophysicists. In Fig. 1 we show 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. 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. Moreover, about 30% of them are unable to order from the nearest to the most distant one, compared to the Earth, a series of astronomical objects and fail to reconstruct the timeline of significant events in the universe history. 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. We note that the majority of students are in the lowest level of knowledge. Furthermore the students being in the higher knowledge levels about Age and BB show also an high levels of knowledge about expansion, temporal evolution and more advanced aspects of cosmology.

4. Conclusions

The collected students' responses suggest that cosmology is addressed during the curricular teaching and the dissemination activities in informal setting. Cluster analysis results point out that some relevant aspects are neglected, for instance how scientists support claims about theories of the Universe. Moreover, the curricular teaching seems to have a limited impact on students' ideas also about basic aspects, such as the role of gravity and does not allow a deep conceptual understanding about cosmology. To validate the identified clusters, we are in the process of administering a revised version of the questionnaire to a wider sample of students.

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