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A fairytale creation or the beginning of everything: Students' pre-instructional conceptions about the Big Bang theory

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Summary The beginning of the universe, the Big Bang, being an important subdomain in cosmology, marks the very beginning of space and time. Therefore, it has formed the modern scientific worldview. Transferring this to students through science teaching is a frequent request in science literacy discussion (e.g., American Association for the Advancement of Science, 1993; Schecker et al., 2004).

However, it is not yet clear in science education if students' conceptions about the Big Bang vary by nationality, and therefore, if it is possible to apply the same teaching modules to students from different countries, who may have diverse social and cultural backgrounds and different curricula. These conceptions with which students enter the classroom were investigated in our study. We implemented an open-ended questionnaire survey in Germany, with questions based on recent U.S. studies. The results clearly showed, with high interrater reliabilities, widespread misconceptions like the Big Bang being an explosion of preexisting matter into empty space or the universe having a centre. Furthermore, a comparison of results from researchers in the USA, Sweden and Germany allowed us to identify differences in students' conceptions between the countries. Our findings appear to indicate that German students have slightly better pre-instructional conceptions about the Big Bang theory.

Introduction

A commonly used and important research method in the field of science education for building teaching modules in different subjects is the prior investigation of students' conceptions (Ausubel, 1968; Anderson, 2007). These must be

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taken seriously and should be used as the basis for developing teaching modules to help students move toward a better understanding of the current knowledge in science. Since it is often stated that the student's mind is not a blank slate on which new information can just be written (e.g. Bransford et al., 2000), we can help students and support them in effective learning by building upon their existing conceptions. As an example, in the U.S. teaching materials ''designed to help [···] science teachers assess their students' existing conceptions and incorporate knowledge of them into planning lessons'' are regularly published by the National Science Teachers Association (Larkin, 2012, p. 928).

On behalf of the ministers of education and cultural affairs of the German states, Schecker et al. (2004) suggested recommendations for designing physics lessons for upper secondary schools. These suggestions contain the development of a deepened understanding of the modern worldview including astrophysics and cosmology as core content of physics education in upper secondary school. Apparently, there is a need for education development concerning better approaches for teaching certain topics in modern physics such as cosmology (Schecker et al., 2004). Furthermore, the interest of young people in the domain of astrophysics and cosmology is above-average as stated in the Relevance of Science Education (ROSE) study (Schreiner and Sjøberg, 2004). One result is students' strikingly high interest in astrophysics and the universe, irrespective of their country or gender. In addition, teaching about scientific working methods and the concepts of Nature of Science (NOS) can be well illustrated by means of cosmology. For example the interaction between experimental and theoretical physics concerning the pillars of the Big Bang theory can be demonstrated, that is, how theory is adjusted according to observations or how experimental data are proving predictions already made by theory. A second example is the use of combinations of different disciplines of physics to make predictions and receive results. To discover the expansion of the universe, distances have to be measured, spectra have to be analyzed and hence the velocities of the galaxies calculated, by which they are moving away from us due to expanding space. For this optical physics, atomic physics, relativistic elements and astrophysics for stellar evolution (to gain distances e.g., for pulsating stars or supernovae) is needed. Cosmology is one of the very few areas in physics, where you cannot perform any direct experiments. Nevertheless, many discoveries have been made due to the successful interaction of various areas of physics. Furthermore, this area shows the change and provisional nature of scientific worldviews. Our knowledge is not fixed but changes constantly with new discoveries. All these various aspects therefore show the relevance of cosmology in education.

CERN — one of the world's largest international research centres focused on particle physics — also places great importance on education. Given that the Big Bang theory strongly influences the modern scientific worldview, and cosmology represents the connection between particle physics and astrophysics, CERN intends to develop a teaching module for cosmology in different languages. But what are the students' pre-instructional conceptions in that area and is it possible to use the same module in different countries?

The Big Bang has little to do with everyday life, therefore, it can be expected that a wide range of ideas will be formed. Currently, there is a lack of scientific research concerning students' pre-instructional conceptions in cosmology. The results of our study will help to fill this gap and to build a teaching module for cosmology.

Research background

The importance of students' conceptions

A student's conception is an idea of a fact, process or concept she or he has, based on experiences in everyday life, instruction, media and so on. A pre-instructional conception or preconception is ''an idea or opinion formed before enough information is available to form it correctly'' (Cambridge University Press, 2014). The study of students' conceptions and their change is a wide field of research, as demonstrated by a regularly updated bibliography containing thousands of publications (Duit, 2009). This field has developed into a focus in physics education research (Schecker, 1985; Bransford et al., 2000; Larkin, 2012). In the opening pages of his textbook on educational psychology Ausubel (1968) wrote: ''If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly'' (p. vi). Even young children cannot be considered as ''tabula rasa'', therefore, ideas cannot just be imparted; for the development of learning provisions the learner's whole cognitive organization should be known (Jung, 1978). Students entering the classroom normally have already developed deeply embedded conceptions constructed on the basis of everyday experience and informal learning, from sources such as TV, Internet, books or other printed media. Most of these conceptions are not consistent with the scientific view — one origin of many learning difficulties (Duit, 1995; Amin et al., 2014). Duit is stating further that learning chemistry and physics means to actively build knowledge upon the existing conceptions: students can only ''see'' something new through the filter of already known and familiar things. Furthermore, Duit said that there are also conceptions which are invented ''ad hoc'', when students are confronted with something new. Nevertheless, these conceptions also have to be taken seriously.

In the last decades, many studies have been conducted in that field of research in physics, mainly on the conceptions of mechanics, energy, electricity and magnetism, heat and temperature, optics and the nature of matter (e.g., Champagne et al., 1980; Gunstone and Watts, 1985; Erickson, 1979; Kristyanto and Berg, 1991; Stead and Osborne, 1980; van den Berg and Osborne, 1990; Cohen et al., 1983; McDermott and Shaffer, 1992; Ayas et al., 2010; Gómez et al., 2006). Müller et al. (2011) present a summary of German literature of students' conceptions in the different areas of physics mentioned above. Furthermore, there are cross-cultural studies such as Trumper et al. (2000), Eckstein et al. (1993), Lynch (1996), Shipstone et al. (1988) and Liu (2005). In general, students' conceptions mostly seem to be similar across countries. ''The reported cross-cultural results indicate the similarity of *types* of alternative