Probing students’ estimates of astronomical sizes and distances

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Abstract. Despite intensive educational efforts, it is generally known that many students still hold numerous astronomical misconceptions by the time they leave secondary school. While the identification of these misconceptions has been widely studied, much less research is devoted to retracing their origin. This work is motivated by the notion that many misconceptions may stem from erroneous estimates of astronomical sizes and distances. As this research is still in its early stages, several types of questions are explored for the assessment of students’ estimates during two rounds of pilot interviews. The findings of these pilot studies are discussed here.

Introduction

By making observations and interacting with the world, children gain so-called intuitive or naïve knowledge. This knowledge contributes to the construction of mental models, which are thought to be present in all individuals. The debate on whether children form a rather coherent framework or theory of intuitive knowledge or whether it is instead rather fragmented is still ongoing. However, regardless of their structure, it is very clear that pieces of intuitive knowledge are often at odds with most recent scientific viewpoints. In such cases, they are usually referred to as misconceptions. Also in astronomy, various student misconceptions have been documented in literature, see e.g. Bailey & Slater [1].

More specifically, several researchers have investigated students’ estimates of astronomical sizes and distances. While a general conclusion is that most people find it very difficult to make these estimates, more specific results often differ between authors. For example, Sadler [2] showed that most participants tend to underestimate the distance between the Earth and the Sun, while Mant [3] reports that half of his participants instead overestimated that distance. As Miller & Brewer [4] suggest, such discrepancies are likely to be due to differences in the assessment methods used. For example, results from multiple-choice questions are always affected by the set of provided options. Also, questions about actual physical distances in terms of miles or kilometres are hardly ideal and limit the validity of the results, as they confound the students’ intuitive perception of distances with their ability to understand and interpret large numbers. In this work, we therefore attempt to evaluate the reliability and effectiveness of different assessment questions during two rounds of pilot interviews, focusing on a small number of distances and sizes.

Estimating astronomical sizes and distances: participants and interview method

The distances of interest in this work were those between the Earth and the Moon (EM), between the Sun and the Earth (SE), between the Sun and Neptune (SN) and between the Sun and the nearest next star (SS). We chose to only probe estimates about these distances relative to each other, that is, about the ratios SS/SN, SN/SE and SE/EM. Not only does this approach alleviate the issues with large numbers of everyday distance units, it has also been shown that conceptions of relative scale are generally more accurate than those of absolute scale [5]. In addition to distances also the relative sizes of the Moon (M), the Earth (E) and the Sun (S), i.e. S/E and E/M, were probed.

In the first pilot study, 17 students were interviewed. All distance-related questions were formulated in terms of the travel time of an imaginary spacecraft, and all size-related questions referred to a Solar System to scale. In this format, the travel time for one distance or the rescaled size of one object would be given, and the others should be estimated. All questions were asked twice; first by starting out from the largest distance (size) and working towards the smallest one, and thereafter by working the other way around. In the former case, the students were shown a concrete visualisation of their answer after every question, with which they could either agree or disagree and reconsider. The answers to these two pairs of questions were surprisingly varying and inconsistent. However, it was unclear whether this resulted from difficulties inherent to the type of questions or from the inconsistency of the mental models themselves. Additionally, in the first pilot study, students were given a series of tasks on Number Line Estimations (NLE, see e.g. [6]). All students performed well on this task, demonstrating their ability to interpret the visualizations.

In the second pilot study, where 16 students were interviewed, we retained one set of questions on travel time, but additionally repeated them by directly asking the numerical values of the fractions SS/SN, SN/SE and so on. All questions were now asked starting from the largest distance (size) and working towards the smallest one. The NLE tasks were no longer included, instead students were asked to indicate how certain they were about their answers. By making these refinements to the interview procedure, we aimed to better differentiate between (in)consistent estimates resulting from guessing or from mental models.

Results and discussion

The results of the two pilot studies indicate that students in general overestimated the size ratios and underestimated the distance ratios. The amount by which they over- or underestimated became larger as the physical ratio grew, while at the same time their answers also became increasingly inconsistent. Finally, questions referring to pure fractions would lead to higher estimates than questions referring to travel time, for all fractions.

The results also indicate that students have great difficulty estimating astronomical scales in and beyond our Solar System. In addition, the answers are substantially impacted by how exactly a question is posed, which results in inconsistencies over different question types. This confirms the previous result of Miller & Brewer [4]. Also, student answers may not always reflect their true mental model of a situation, as the confrontation with a concrete visualisation regularly makes them doubt and reconsider. In the next phase of our study, we aim to convert this interview procedure into an online, interactive survey and administer it on a larger scale.

References

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