EXPONENTIAL THINKING FOR EARLY UNDERSTANDING OF THE SCALE OF THE UNIVERSE

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In the last century, science has given us knowledge of the smallest things in the universe through to the vast distances of the visible universe. Science also gives us the ways to see the scale, with the modern technologies on which our lives depend. Education should respond to these revolutionary changes in human perception. However, for many people big and small numbers are just words with very little meaning (Resnick et al., 2017). A good way to help us gain meaning is to find a simple way to operate with huge and tiny numbers using the powers of ten as a notational tool.

There is some evidence, that young children have an intrinsic logarithmic ability (Opfer et al., 2010). To exploit these abilities, we present on results of a program that introduces large number concepts through engaging activities. We aim to make the mathematics needed for describing physical reality more intuitive, more relevant and less dependent on rote learning. This work is part of a broader project called Einstein-First that aims to introduce Einsteinian concepts throughout school education (https://www.einsteinianphysics.com).

We use powers of two as a stepping stone to develop language and concepts for powers of ten. The *Powers of two* program has been tested with year 3-4 students and *Powers of ten* with year 5-6 students. Lessons in the 8 hours programs are built around activities following four general principles: a) learning from group activities, b) using models and games to explore concepts, c) using Google searches for data gathering where appropriate, and d) learning through play-acting. We present some of the activities. One successful activity was the Powers of the Universe book, created by students. Each page is a power of ten. Numbers that describe all the known physical quantities in the Universe can be fitted in this 120-page logarithmic book, in which all quantities are expressed in SI units.

The program demonstrated significant outcomes regarding understanding scale of the Universe, estimation of big and small numbers, using powers of ten as a tool for calculation and reasoning about numbers. The results of pilot trials from pre-test and post-test comparisons indicate that nearly 100% of students were able to use powers of two for describing numbers in processes such as bacteria splitting or numbers of ancestors. 78% of students preferred to use powers of ten notation over multiple zeros for big and small numbers. 98% of students widened their knowledge about the scale of the Universe. Evidence from teacher and student interviews indicates student enjoyment and appreciation of the relevance and capacity of students to extend their understanding.

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