**TEACHING LARGE-SCALE TEMPORAL AND SPATIAL MAGNITUDES REQUIRED IN PLANETARY SCIENCE CLASSES USING COGNITIVE PRINCIPLES.** I. Resnick[1] A. Davatzes[2], and T.F. Shipley[1], [1]Dept. of Psychology, Temple University, 1701 N. 13th Street, Philadelphia, PA 19122, [2]Dept. of Earth and Environmental Science, Temple University, 1901 N. 13th Street Philadelphia PA 19122 (ilyse.resnick@temple.edu).

**Introduction:** Students struggle understanding a critical component of planetary science: the extreme magnitude implicit in time [1] and space [2]. Indeed, having a strong understanding of extreme magnitudes is necessary for being a scientifically literate consumer of information more generally [3]. The American Association for the Advancement of Science (AAAS) Project 2061 and the Benchmarks for Science Literacy have both identified "size and scale" as fundamental and unifying themes in science education [4]. Difficulty in understanding extreme magnitude may arise due to disconnect between the linear nature of magnitude and how magnitude is cognitively represented [5]. The aim of this abstract is to outline research from cognitive science on how people represent magnitude and how this representation relates to planetary science, as well as discuss potential barriers with common educational practices and demonstrate how cognitive science findings can be incorporated into educational practices.

**Representation of Magnitude:** People represent temporal and spatial magnitude information using a hierarchical combination of metric and categorical information [6]. For example, scientists conceptualize geologic time as the Geologic Time Scale (GTS); a series of hierarchically nested divisions of time based on categorical divisions (such as changes in fossil records) at absolute metric dates.

In the absence of knowing exact magnitude information, people use other category boundaries to help constrain their estimates [6]. Without information at lower-levels, people's estimations default to higher-level categories. Variation in estimation occurs because of imprecision in category boundaries. For example, knowing dinosaurs appeared in the Triassic Period would help constrain one's estimation to 50 million years; if one could only recall dinosaurs appeared in the Mesozoic Era, their estimation would instead range 180 million years. While Earth's GTS has over one hundred hierarchically nested divisions of time, students' conceptualization of geologic time contains only two: geologically "recent" and geologically "far away" [1]. Thus, estimations of unknown events may default to a category spanning over two billion years. This may become even more difficult in a planetary science class, where distinct geologic time scales, with different event boundaries, are used for each of the planets.

The number and placement of category boundaries will also systematically distort magnitude recall. Category boundaries are points of change, and are perceptually salient [7]. People recall those objects/events at boundaries more clearly than those in between [8]. Further, the number of event categories one can remember is congruent with their magnitude estimations. There will be a bias to allocate larger magnitudes for those regions populated with relatively more objects/events and allocate smaller magnitudes for those regions populated with relatively fewer objects/events.

The extreme magnitudes of planetary science are also un-familiar to students [1; 2]. People possess a compressed cognitive representation of magnitude; they accurately estimate familiar magnitudes but variation in estimation increases as a function of magnitude [9]. Following Weber's Law, it is easier to discriminate between the difference of 5 and 10 then the difference of 105 and 110. Thus, it may be hard to discriminate between events and distances at extreme magnitudes (3.5 billion and 4.8 billion are both "far away").

**Educational Implications:** Educational practices must often rely on analogies to teach concepts at extreme scales because they cannot be directly experienced [10]. Analogy refers to relating two different concepts (a base concept and a target concept) based on shared features. *Base concept* refers to the known idea; *target concept* refers to the idea being learned. For example, the football field is often used for making scale representations of geologic time [11] and the solar system [10]. Analogies are useful because they allow for understanding of an unfamiliar concept through familiar concepts.

*Potential Barriers:* There are obstacles using analogy in scale comprehension. Analogies can fail to bring about conceptual change, and even mislead students' understanding of a concept making misconceptions hard to identify and resolve [12]. A reason analogies may fail is the base and target concepts are not adequately aligned. For example, a common analogy is aligning extreme magnitude (the target concept) with base concepts such as toilet paper, volume of a stadium, stacks of buildings, etc. However, the magnitude of these base concepts may also be unfamiliar, making aligning the important magnitude information difficult. A common strategy to overcome this potential issue is to begin with a familiar magnitude (e.g., clock, road trip). However, the difference between human and extreme scales may be too big to adequately align the similar principles of both concepts.

Another reason analogies may fail is because of salient features of the base or target concepts that are not functional to the analogy. Not all features are equally relevant; however some attributes may be more accessible then others [13]. Such as aligning the geologic time to a calendar may lead students to incorrectly believe the GTS is comprised of equal temporal units.

*Recommendations:* One way to overcome barriers to alignment is to make comparisons between base and target concepts that are very similar to each other, beginning with a familiar base concept [14]. The more commonalities that exist between base and target concept, particularly when commonalities are highlighted, the more salient corresponding relations will be.

The progressive alignment approach to analogical learning is useful for when the target concept is very different from the base concept [14], such as is the case with comparing human and extreme scales. Rather than go directly from the base concept to the target concept, the progressive alignment model advocates making intermediate analogies, as necessary, to bridge the two concepts. For example, Resnick and colleagues [5] found aligning a personal time line to a meter, and then increasing the time stepwise to include a human lifespan, American history, recorded history, human evolution, Cenozoic, Phanerozoic, Proterozoic, Archean, and then all of the GTS was successful in teaching the magnitude of geologic time in an introductory-level undergraduate geoscience course (primarily non-majors) at a large urban university. Ongoing research in our lab has found an analogous version for distances also fosters a linear representation of astronomical distances. The progressive alignment of scales may alleviate the conceptual dissimilarity between human and extreme scales by providing more alignment across smaller increases of scale. Progressive alignment also provides the additional benefit of having multiple opportunities to make similar analogies; students get practice making the relevant comparisons.

Incorporating the way people naturally represent magnitude (as discussed above) will also be important in constructing a functional analogy. The more organizational structure a person has for the material the better their memory is for recall [15]. Where people have more conceptual categories they are more accurate. Analogies that emphasize hierarchical information may provide more structure to make more accurate estimations. The richer these hierarchical categories are with salient category boundaries, the more understanding one should have for the magnitude between them.

The hierarchical alignment approach to analogical learning is one way to create more hierarchically nested category boundaries of scale information [5]. Hierarchical alignment is based on the progressive alignment model, in that it progressively aligns concepts. For each progressive step, hierarchial alignment also hierarchically organizes all previous analogies in relation to the current concept. For learning scale information, students work their way stepwise through increasing amounts of magnitude, as well as locate where all the previous magnitude lines are located now relative to the increased magnitude. The hierarchical organization highlights how each scale is related to one another. Instructions on how to implement the hierarchical alignment model as a classroom activity can be accessed at: http://serc.carleton.edu/NAGTWorkshops/time/activities/60898.html.

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**Additional Information:** This research was supported in part by a grant to the Spatial Intelligence and Learning Center, funded by the National Science Foundation (grant # SBE-0541957 and SBE-1041707).