International Society of the Learning Sciences

Embodied Cognition in Virtual Reality to Support Learning of Scale

Tyler Gampp, Cesar Delgado, Matthew Peterson, and Karen B. Chen
twgampp@ncsu.edu, cdelgad@ncsu.edu, mopeters@ncsu.edu, kbchen2@ncsu.edu
North Carolina State University

Abstract: This work-in-progress poster reports on the development process of a virtual environment to support embodied cognition about the scale of scientific entities from subatomic particles to galaxies. Research shows that learners struggle to comprehend the sizes of entities beyond human scale. In order to determine specific entities to use in the virtual environment, a document analysis of US K-undergraduate science education standards was undertaken. Entities, categories of entities, and ranges of sizes were identified.

Introduction

The US Next Generation Science Standards propose "scale, proportion, and quantity" as a crosscutting concept that pervades science and can aid students in making connections across topics, disciplines, and grades in order to construct a more robust understanding of science (National Research Council, 2012). While cutting-edge STEM is being conducted at extremes of scale, research shows that learners of all ages hold inaccurate ideas about the size of scientifically relevant entities (Delgado et al., 2015; Magaña et al., 2012; Tretter et al., 2006a, 2006b). Science standards require that students consider scales that exist beyond their direct everyday experience. To address this issue, our research project is developing a virtual reality (VR) in which students shrink or grow to the size of atoms or galaxies, and experience scientific entities directly and in an embodied manner through VR. This paper reports on our process of selecting entities for the Cave Automatic Virtual Environment.

Theoretical Background

The theory of embodied cognition holds that understanding the mind requires acknowledgment of its inextricable relationship to a "physical body that interacts with the world" (Wilson, 2002). Virtual reality has the power of creating vivid three-dimensional representations of entities that cannot otherwise be experienced directly. The multimodal immersive experiences of VR may enhance a learner's experiential lexicon of scientific *entities* through embodied interaction and cognition — "[a]n entity is an iconic thing, a meaningful whole on its own," which instantiates a concept (Peterson et al., 2021, p. 321). This embodied cognition may support the learning of well-developed, accurate conceptions of scale. We posit that this understanding of scale can help fulfill the promise of crosscutting concepts in supporting the development of connected understanding of science. The entities selected to populate the virtual environment will play an important role in student learning, ideally becoming scale landmarks (Tretter et al., 2006b) that serve to anchor a mental number line for scale. Entities mentioned in the standards likely appear in the curriculum, and may become landmarks in student cognition.

Methods

We conducted a document analysis of the K-12 (NGSS Lead States, 2013) and college science standards (College Board, 2009) to determine what entities are referenced. The first author, a doctoral student in science education, analyzed the standards, using a constant comparative method (Corbin & Strauss, 2008) with an *a priori* code of named entities (e.g., sea otter, amoeba). Upon analysis of the initial list, the team determined that the standards frequently referenced *categories* of entities (e.g., microorganisms, autotrophs) rather than specific instances, or phenomena that span a *range* of sizes. A category is a group of entities with a small variability in size; a range involves groups of entities or phenomena that spanned several powers of 10. We incorporated categories and ranges as emergent themes into the analysis. We again reviewed the standards, coding for categories and ranges. Some entities were not included because they were pieces of a whole (e.g., human foot, head of a pin). Some groups of entities were not included because ranges could not clearly be defined (e.g., mentions of "all objects"). We then determined the absolute size of each entity using the largest measurement in any given direction. We foresee productive discussions with colleagues from other countries with different educational standards, who may have different insights as to what entities, categories, and ranges are important in science.

Findings

The analysis of the standards yielded 251 entities, 194 categories, and 14 ranges. Examples of each are presented in Table 1, for a subset of sizes (10^{-10} to 10^{2} m). The largest named entity was the Milky Way Galaxy (10^{21} m) and the smallest was the electron (10^{-18} m). The categories spanned large portions of the scale with the smallest being subatomic particles and the largest being galaxies. Ranges were limited in quantity but also spanned the entire range; they included gamma rays on the lower bound and solar system bodies on the upper bound. The named entities are concentrated within ranges of the scale with approximately 53% of entities falling between 10^{-2} m to 10^{1} m, approximately 23% between 10^{-10} m to 10^{-9} m, and approximately 7% appearing above 10^{2} m.

Table 1
Sample Entities, Categories, and Ranges for 10^{-10} to 10^{2} m

Size, m	Named Entities	Categories	Ranges	
10^{-10} to 10^{-9}	Water Molecule		X Rays	Electron and Scanning Probe Microscopes
10^{-9} to 10^{-8}	Chromosome	Cell components		
10^{-8} to 10^{-7}	Plasmodesmata		Ultraviolet/Visible Light	
10^{-7} to 10^{-6}	HIV virus	Viruses		Optical Microscope
10^{-6} to 10^{-5}	Mitochondrion, Bacteria	Cells		
10^{-5} to 10^{-4}	Animal Cell		Infrared Radiation	
10^{-4} to 10^{-3}	Amoeba	Insects		Visible
10^{-3} to 10^{-2}	Drosophila (Fruit Fly)			
10^{-2} to 10^{-1}	Bumble Bee		Microwaves	
10^{-1} to 10^{0}	Chipmunk	Mammals		
10^{0} to 10^{1}	Sea Otter			
10^{1} to 10^{2}	Box Elder	Vehicles	Radio Waves	

Discussion and Implications

Document analysis of US science education standards suggested a set of entities, categories, and ranges that can be used purposefully in a virtual environment to support embodied cognition and learning about scale. The emergent finding that categories of entities and ranges of entities or phenomena are prevalent in the standards widens the variety of entities to be conceptualized in terms of scale. Exemplars from categories can be selected based on our experience with science curriculum and their feasibility in the virtual environment. Ranges might correspond to multimodal cues; for example, entities in ranges below the reach of optical microscopy might be rendered in grayscale. Preliminary research with a prototype virtual environment shows that undergraduates and teachers find it helpful in developing their conceptions of scale.

References

College Board (2009). *College Board Standards for College Success: Science.* College Board.

Corbin, J., & Strauss, A. (2008). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Thousand Oaks, CA: Sage Publications.

Delgado, C., Stevens, S. Y., Shin, N., & Krajcik, J. S. (2015). A middle school instructional unit for size and scale contextualized in nanotechnology. *Nanotechnology Reviews 4*(1), 51-69

National Research Council (NRC). (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, D.C.: The National Academies Press, 2012.

NGSS Lead States. (2013). *Next Generation Science Standards*. Washington, DC: The National Academies Press.

Magaña, A., Brophy, S., & Bryan, L. (2012). An integrated knowledge framework to characterize and scaffold size and scale cognition (FS2C). *International Journal of Science Education*, *34*(14), 2181–2203.

Peterson, M., Delgado, C., Tang, K., Bordas, C., & Norville, K. (2021). A taxonomy of cognitive image functions for science curriculum materials: Identifying and creating 'performative' visual displays. *International Journal of Science Education*, *43*(2), 314-343. https://doi.org/10.1080/09500693.2020.1868609

Tretter, T., Jones, M. G., & Minogue, J. (2006a). Accuracy of scale conceptions in science: Mental maneuverings across many orders of spatial magnitude. *Journal of Research in Science Teaching*, *43*(10), 1061–1085.

Tretter, T., Jones, M. G., Andre, T., Negishi, A., & Minogue, J. (2006b). Conceptual boundaries and distances: Students' and experts' concepts of the scale of scientific phenomena. *Journal of Research in Science Teaching*, *43*(3), 282–319. https://doi.org/10.1002/tea.20123

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, *9*(4), 625–636.

