Cognitive Psychology 92 (2017) 1–21

Contents lists available at ScienceDirect

Cognitive Psychology

journal homepage: www.elsevier.com/locate/cogpsych

Intuitive biological thought: Developmental changes and effects of biology education in late adolescence

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ARTICLE INFO

Article history:
Accepted 1 November 2016
Available online 16 November 2016

Keywords:
Intuitive biology
Science education
Conceptual change
Psychological essentialism
Anthropocentrism
Teleology

ABSTRACT

A large body of cognitive research has shown that people intuitively and effortlessly reason about the biological world in complex and systematic ways. We addressed two questions about the nature of intuitive biological reasoning: How does intuitive biological thinking change during adolescence and early adulthood? How does increasing biology education influence intuitive biological thinking? To do so, we developed a battery of measures to systematically test three components of intuitive biological thought: *anthropocentric* thinking, *teleological* thinking and *essentialist* thinking, and tested 8th graders and university students (both biology majors, and non-biology majors). Results reveal clear evidence of persistent intuitive reasoning among all populations studied, consistent but surprisingly small differences between 8th graders and college students on measures of intuitive biological thought, and consistent but again surprisingly small influence of increasing biology education on intuitive biological reasoning. Results speak to the persistence of intuitive reasoning, the importance of taking intuitive knowledge into account in science classrooms, and the necessity of interdisciplinary research to advance biology education. Further studies are necessary to investigate how cultural context and continued acquisition of expertise impact intuitive biology thinking.

1. Introduction

Cognitive scientists and educators alike acknowledge that students do not arrive at the science classroom as blank slates, but rather have developed complex and adaptive intuitive conceptual systems for understanding the world around them. As such, science education results from the interplay between students' intuitive ways of knowing and scientific concepts introduced by expert instructors, across a range of STEM disciplines, including physics (e.g., Chi, 1992; DiSessa, 1993; Vosniadou & Brewer, 1992), chemistry (Maeyer & Talanquer, 2010), and biology (Coley & Tanner, 2012, 2015; Kelemen, Rottman, & Seston, 2013; Shtulman, 2006). As such, it is critically important to understand the nature and content of intuitive understandings to inform science education. In this paper, we investigate the development of intuitive biological thought

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http://dx.doi.org/10.1016/j.cogpsych.2016.11.001
0010-0285/

in adolescence and young adulthood, and begin to explore potential impacts of increasing science education on this intuitive conceptual system.

1.1. Cognitive construals in intuitive biological thought

Humans naturally, intuitively, and effortlessly reason about biological entities, structures, processes, and phenomena in predictable ways (e.g., Atran & Medin, 2008; Berlin, 1992; Brown, 1984; Carey, 1985; Coley, Solomon, & Shafto, 2002; Inagaki & Hatano, 2006; Medin & Atran, 2004). Elsewhere, we have dubbed these regularities *cognitive construals* (Coley & Tanner, 2012, 2015). A *cognitive construal* is an intuitive, often implicit, way of thinking about the world. It might be a set of assumptions, a type of explanation, or a predisposition to a particular type of reasoning. Three such cognitive construals—*teleological thinking, essentialist thinking, and anthropocentric thinking*—recur in research on the development of intuitive biological thought. Framing intuitive biological thought in terms of these three construals is a useful way to represent a large and disparate literature. We do not claim that this list is exhaustive, nor do we claim that these construals are exclusively relevant to thinking about biology. Rather, we focus on these three construals because they have received the bulk of attention in the cognitive and developmental literature, and we have shown that they are linked to scientific misconceptions in previous work (Coley & Tanner, 2015). In the following, we briefly describe each construal, its role in intuitive biological thought, and its developmental trajectory.

1.1.1. Anthropocentric thinking

Anthropocentric thinking can involve the tendency to attribute human characteristics to non-human or inanimate objects (e.g., Piaget, 1929; Richards & Siegler, 1986), to use humans as a default analogical base for reasoning about biological species or processes (e.g., Carey, 1985; Inagaki & Hatano, 1991), or to see humans as unique and biologically discontinuous with the rest of the animal world. Although undoubtedly useful for adaptive reasoning and social cognition, anthropocentric thinking can result in misrepresentation of the place of human beings in the natural world. Such "human exceptionalism" (Gee, 2013), involves the way in which human beings are incorporated into the intuitive taxonomy of living things. According to geneticists, humans are African great apes; we share a common ancestor who lived c. 5–8 million years ago with our closest living relative: chimpanzees. However, intuitive biological taxonomies—particularly those found in industrialized western societies—tend to see humans as essentially separate from other species (Coley, 2007; Johnson, Mervis, & Boster, 1992). Likewise, undergraduate students are also slower and less accurate at classifying plants—as compared to animals—as living things (Goldberg & Thompson-Schill, 2009); this is consistent with anthropocentric thinking because it suggests that students are less likely to apply universal biological properties to organisms that are highly dissimilar to humans.

Developmental psychologists have paid little attention to the development of anthropocentric thinking past the age of 10. Although some studies document a shift from human-based analogical reasoning to category-based attribution of biological properties (e.g., Carey, 1985; Inagaki & Sugiyama, 1988), research with children reveals a persistent reluctance to classify humans with other animals (e.g., Coley, 2007; Johnson et al., 1992; Leddon, Waxman, Medin, Bang, & Washinawatok, 2012) or to attribute core biological properties, which are familiar in humans, to nonhuman organisms dissimilar to humans, particularly plants (Arenson & Coley, 2016; Richards & Siegler, 1986). As such, the degree to which anthropocentric thinking persists into young adulthood remains an open question.

1.1.2. Teleological thinking

Teleological thinking is causal reasoning in which a goal, purpose, function, or outcome of an event is taken as the cause of that event (Keil, 2006; Talanquer, 2009, 2013). Kelemen (1999) argues that teleological thinking is a central component of adults' everyday thought. For example, people appropriately make the teleological assumptions that human actions are directed toward certain goals, and that human artifacts, such as chairs and coats, are designed by their creators to fulfill some intended purpose. In intuitive biology, people likewise apply teleological thinking to explain biological entities, structures and processes, as if biological phenomena are deliberately designed to serve a purpose just as human actions and artifacts do. As Kelemen emphasizes, teleological thinking provides an important component of adults' intuitive interpretations of why events occur or why objects have the properties that they do. Although the causes, origins, and nature of teleological thinking are the subjects of considerable debate (e.g., Kelemen, 2004; Lombrozo & Carey, 2006; ojalehto, Waxman, & Medin, 2013) this construal seems to be an integral part of intuitive thinking about biology.

The developmental arc of teleological thinking involves a pattern of "pruning." Kelemen has shown that teleological thinking is widespread (or in her terms, "promiscuous") among young children and becomes increasingly selective (Kelemen, 1999, 2012). In one study, 6-year-olds favored teleological explanations for a broad range of phenomena, including properties of nonliving objects (e.g., "The rocks were pointy so that animals wouldn't sit on them and smash them") and animals (e.g., birds exist "for flying," lions exist "to go in the zoo"). College students were more selective, but still utilized teleological thinking in a biological context. Indeed, Kelemen and Rossett (2009) found that undergraduates endorsed unwarranted teleological statements about biological phenomena (e.g., "Earthworms tunnel underground to aerate the soil") 35% of the time, and that under time pressure, this figure increased to 51%. Thus, teleological thinking appears to become more narrowly applied, but does not disappear in adults.