Effects of priming variability on adults learning about metamorphosis

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Abstract

Prior research on biological concepts suggests that people underestimate within-species variability and reject metamorphosis as a possible change for unfamiliar organisms. This may be due to psychological essentialism. This study investigated whether manipulating perceptions of biological variability (both within species and between species) led to increases in endorsement of metamorphosis among undergraduate students. We manipulated perceptions of variability by priming students before a lesson and by highlighting variability in the diagrams used during the lesson. Priming led to more endorsement of metamorphosis, but only among those with high prior knowledge. Our results suggest that manipulating perceptions of variability is not only possible but might be beneficial for those who have strong prior knowledge about biology.

Keywords: intuitive theories; psychological essentialism; metamorphosis

Introduction

Biological variability is a key concept in science education, and its importance is reflected in the Next Generation Science Standards (National Research Council, 2013). Differences between species are an integral part of biodiversity. Differences within the same species provide the basis for evolution through natural selection. Differences between parents and offspring are key to understanding genetic transmission. Finally, life cycle differences are integral for understanding processes like aging and metamorphosis. Despite this emphasis on variability in biology and science education, little is known about how adults understand variability in the biological domain and how understanding of one type of variability (e.g., parent-offspring variability) could influence understanding of another type (e.g., within-species variability).

In this paper, we focus on variability across the lifespan, specifically variability that arises due to metamorphosis, and we explore how thinking about biological variability (i.e., between- and within-species variability and variability between parents and offspring) might influence learning about metamorphosis.

Cognitive Constraints

Some researchers have investigated how people think about biology and have proposed several cognitive constraints that might influence biological reasoning. Constraints on biological reasoning include teleological thinking (Kelemen, 2012), anthropocentric thinking (Arenson & Coley, 2017), and psychological essentialism (Gelman & Rhodes, 2012). These constraints may be related to one another and have been linked to misconceptions in the biological domain (Coley, Arenson, Xu, & Tanner, 2017; Coley & Tanner, 2015). For the purpose of understanding biological variability, the most relevant constraint is psychological essentialism (Emmons & Kelemen, 2015; Shtulman & Schulz, 2008). We focus special attention on a subcomponent of psychological essentialism, featural stability, because it has been proposed that featural stability makes learning about metamorphosis difficult (French, Menendez, Herrmann, Evans, & Rosengren, 2018).

Psychological Essentialism. Psychological essentialism is the tendency to think of natural kinds as having an underlying essence that defines the category to which they belong (Gelman, 2004; Medin & Ortony, 1989). Many researchers have proposed that some biological concepts are difficult to grasp because they contradict psychological essentialism (Coley & Muratone, 2012; Gelman & Rhodes, 2012).

Some researchers have argued that children have an essentialist view of animal categories, which leads them to underestimate, and sometimes even reject, within-species variation (Shtulman & Schulz, 2008; although see Emmons & Kelemen, 2015). Psychological essentialism could thus hinder understanding of biological concepts such as evolution by making it difficult for people to appreciate within-species variability, which is integral for understanding natural selection (Shtulman & Calabi, 2012). In support of this view, adults who have less understanding of within-species variability also tend to have more misconceptions about evolution (Shtulman & Schulz, 2008). This finding suggests that decreasing essentialist reasoning might lead to greater acceptance of evolution.

Featural Stability Bias. The featural stability bias is the tendency to think that the features of an animal will remain stable over time (French et al., 2018), and so adult versions of animals will be identical to their juvenile forms except in size. Featural stability is incompatible with dramatic changes such as those that occur in metamorphosis. Previous work on children's understanding of biological change has shown that preschool children consider metamorphosis to be an optional change—one that animals can choose to engage in—rather than a biological process (Rosengren, Gelman, Kalish, & McCormick, 1991).

French et al. (2018) showed participants different pairs of animals, with each pair presenting the juvenile form and the adult form of an animal. Relative to the juvenile form, the adult form could vary in size, vary in color, undergo metamorphosis, or change species altogether (as a control item). Children were more likely to accept changes when all features remained the same except for size. Participants of all ages preferred change in size rather than naturalistic growth (i.e., change in the proportions of the animal) when asked to reason about unfamiliar species. This is surprising given that naturalistic growth is the type of change most animals, including humans, undergo (Lorenz, 1971). The authors suggested that featural stability is a "default" way of thinking when no other information about the type of change an animal undergoes is available**.**

Learning and generalization of metamorphosis

Even after observing animals going through life cycle changes such as metamorphosis, children and adults rarely generalize to other animals. Herrmann, French, DeHart, and Rosengren (2013) placed two displays, one with a pregnant mouse and another with a caterpillar, in a preschool classroom for 10 weeks. This ensured that the children observed both metamorphosis and naturalistic growth. After being exposed to these displays children were more likely to accept metamorphosis, but only for the species with which they had direct experience (the butterfly).

However, a study by Menendez, Rosengren, and Alibali (under review) showed that providing adults with a formal lesson on metamorphosis led them to accept metamorphosis, not only for the animal included in the lesson (i.e., a ladybug), but also for other insects. In addition, participants who saw life cycle diagrams that were perceptually simple (bland) displayed better generalization that participants who saw diagrams that were perceptually rich. This study suggests that generalization of knowledge about metamorphosis is possible, even to unfamiliar species, and that diagrams might be an effective way to help people understand biological change.

Importance of prior knowledge

One key finding of Menendez et al. (under review) was that the effectiveness of the diagram intervention varied as a function of pretest performance. Adults who had low prior knowledge benefitted more from the bland diagram than the rich diagram. This finding aligns with research on mathematics learning that shows that the effectiveness of visual representations is moderated by student characteristics such as prior knowledge (Siler & Willows, 2014). This literature suggests that visual representations may be an important aid in helping students learn about biological variability, but that their effectiveness might depend on students' content knowledge prior to the lesson.

Prior knowledge has also been found to influence categorization. Appropriate prior knowledge in the domain, however minimal, can speed up learning of new concepts (Kaplan & Murphy, 2000; Murphy & Allopenna,1994). The importance of prior knowledge can also be seen learning about metamorphosis. French et al. (2018) found that, for unfamiliar species, adults tended to accept only change in size. Evans and Rosengren (2018) argue that new information interacts with preexisting mental models of biological change to create a new mental model that has elements of the preexisting model; therefore, acceptance of metamorphosis might depend on participants' prior knowledge about what types of changes are possible in the natural world.

Current study

The goal of the present study was to investigate whether exposing adults to different types of biological variability can increase how much they learn from a lesson on metamorphosis. This could occur if exposing adults to biological variability serves to decrease their essentialist reasoning. Toward this goal, we used two different interventions. First, we used texts that a) highlighted within-species variability (potentially decreasing essentialist reasoning), b) highlighted between-species variability (potentially increasing essentialist reasoning), or c) did not highlight either form of variability (control). Second, we created two new life cycle diagrams, one that portrayed parents and offspring as identical (as is typical in life cycle diagrams) and one that portrayed parent-offspring variability.

We hypothesized that participants who received the within-species variability text would generalize the concept of metamorphosis more broadly than those in the control condition, potentially because of a reduction in essentialist reasoning, whereas those who received the between-species variability text would generalize more narrowly. This result could suggest that essentialist thinking impedes understanding of dramatic biological changes such as metamorphosis. The effectiveness of the texts might depend on them activating knowledge that learners already possess; therefore, we hypothesize that the texts will be more effective for individuals with higher prior knowledge. Further, we expected that participants who received the lesson with the diagram that highlights parent-offspring variability would transfer their knowledge about metamorphosis more widely than participants who received a lesson with a diagram the highlights parent-offspring similarity. Based on prior work by Menendez et al. (under review), we will also explore interactions between diagram type, text, and prior knowledge. In light of past work on understanding of within-species variability and evolution (Shtulman & Schulz, 2008), we will also explore if our manipulation influenced participants' beliefs about the origin of species.

Method

Participants

We recruited 240 undergraduates from an Introductory Psychology course. Participants were 156 women, 82 men, and 1 non-binary individual (one participant did not report gender). The racial/ethnic make-up of the sample was: 137 white, 8 Black or African-American, 86 Asian or Asian-American, 2 Pacific Islander or Native Hawaiian, 8 Hispanic or Latinx. Participants completed the study individually in a laboratory setting and provided written consent before the start of the study.

Design

This study used a pretest-intervention-posttest design. Participants were randomly assigned to one of the three text priming conditions (within-species variability, between-species variability, control), and one of the two diagram conditions (different-offspring, identical-offspring).

Materials

All stimuli were displayed on a computer screen. For the pretest and posttest, we created images that showed three different types of change: change in size, metamorphosis, and change in species (Herrmann et al., 2013). *Change in size* items showed an original animal and a copy that was either larger or smaller. For mammals and fish, we included instead naturalistic growth items (in which the proportions change in addition to the size), which is common in these species. The *metamorphosis* items showed the larva and the adult form of an insect or an amphibian. *Species change* items showed an original animal and an animal of a different species (e.g., a dog and a cat). This type of change was included to assess whether participants would endorse *any* type of change. For animals that do not undergo metamorphosis, we substituted a second species change item for the metamorphosis item. Given the importance of prior knowledge in participants' acceptance of metamorphosis (French et al., 2018) and the potential educational implications of this study, we used real animals rather than artificial animals. Example items can be seen in Figure 1.

Participants were asked about these types of change in two different ways that address the connections between juvenile and adult versions of each animal. In *lifespan* questions, participants were asked: "When the one on the left grows up [point to the juvenile version], could it look like the one on the right [point to the adult version]?" In *offspring* questions, participants were asked: "Could the one on the left [point to the adult version] have a baby that looks like the one on the right [point to the juvenile version]?" These questions were blocked, and the order in which the lifespan and offspring questions were asked was counterbalanced.

The pretest included five target animals (butterfly, ladybug, grey ladybug, fish, and dog), and the posttest included ten target animals (ladybug, Asian beetle, firefly, stag beetle, ant, butterfly, praying mantis, fish, frog, and dog). The order of the animals was fixed, but the order of the questions about different types of change was randomized for each animal (but not randomized for each participant).

Each prime text was a short paragraph about butterflies. The between-species variability prime compared two species of butterflies and explained how they differ:

> "Many kids learn about Monarch butterflies in school. But do you know the difference between Monarchs and Black Swallowtails? Monarchs have orange wings and Black Swallowtails are black with yellow and blue. Monarchs travel long distances, but Black Swallowtails do not migrate at all. The wings of the two butterflies are also different. Monarchs have large pointy wings, while Black Swallowtails have wings that are rounder at the bottom. These are the differences between these two types of butterflies."

The within-species variability prime explained how, even within the same species, individuals vary greatly:

> "Many kids learn about Monarch butterflies in school. But kids do not know all about Monarchs. Monarchs are known for their orange wings, but some have wings that are more red and others have wings that are more yellow. Many Monarchs migrate long distances, others short distances and some do not travel at all! The wings of monarchs are also different. Some have large pointy wings, others have large skinny wings while some have small pointy wings. While they are different, all of them are the same type of butterfly."

The prime texts were matched in number of sentences and features mentioned. Participants in the control condition saw a control text that included the same number of statements, to control the length of exposure.

> "Many kids learn about animals in school. They learn all sorts of facts about them. Kids learn about how different animals look. They learn about the life cycles of animals. They also learn where the animals live and what they eat. They learn about how animals move. Most kids think that learning about animals is fun"

The video lesson explained the life cycle of ladybugs. The only visual shown during the lesson was a life cycle diagram of a ladybug. Participants in both diagram conditions received the same lesson; the only difference was the diagram used in the video. In the *identical-offspring* condition the adult form of the ladybug was identical to the parent. In the *different-offspring* condition the adult form of the offspring had a different pattern of spots, fewer spots and different coloring than the parent. After the lesson, participants were asked to name each of the stages in the life cycle. Figure 2 shows both diagrams.

After completing the posttest, participants typed their answers to two questions to assess their beliefs about the

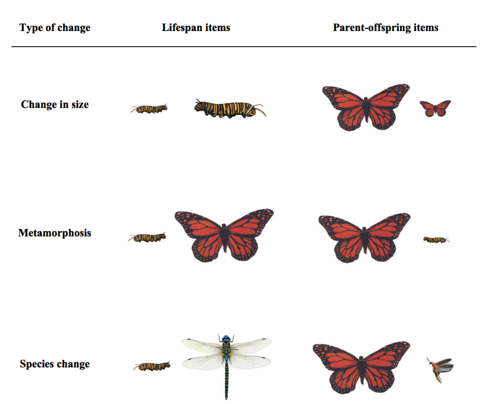

Figure 1. Examples of each type of change for both types of questions.

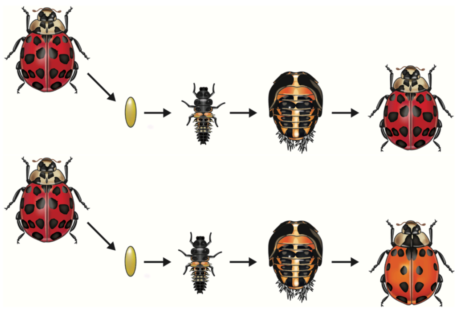

Figure 2. Diagrams used during the lesson. The top diagram is the identical-offspring diagram. The bottom diagram is the different-offspring diagram.

origin of species (e.g., "How do you think the first spider got here to Earth?"). The questions were adapted from Evans (2000; 2001). Finally, participants completed a modified version of the Essentialism Belief Scale (modified to be about animal categories; Haslam, Rothschild, & Ernst, 2000) and provided demographic information.

Procedure

Participants were randomly assigned to complete either the lifespan or offspring questions first in the pretest, and this order was maintained for the posttest. Participants saw a series of 30 images at pretest. Each image displayed only one type of change. Participants were asked to endorse (answer "yes") or reject (answer "no") each type of change, and they were not able to go back to previous questions once they had answered. Then, participants were also randomly assigned to read one of the three text prime conditions (between-species variability, within-species variability, or control). Following the texts, participants watched a video lesson with one of the two diagram conditions (different offspring or identical offspring). Participants were then asked to label each of the stages in the diagram. After the lessons, participants completed the posttest (60 images), evolution questions, and the EBS, and provided demographic information.

Results

Understanding of Metamorphosis

Our analysis focused on the number of insect items for which participants endorsed metamorphosis. We analyzed the data using a general linear model with prime condition, diagram, pretest (as a continuous variable), and their interactions as predictors. We used non-orthogonal contrasts to examine the effects of the primes, with the control condition as the reference group.

There was a three-way interaction between prime (between vs. control), diagram and pretest, $F(1, 229) = 4.54$, $p = .034$. For participants who received the lesson with the identical-offspring diagram, there was an interaction of the between versus control contrast and pretest, $F(1, 229) = 6.125$, $p = .014$. Among these participants, those with high pretest scores endorsed metamorphosis more if they had read the between-species variability prime rather than the control text, $F(1, 229) = 4.88$, $p = .028$ (Figure 3A). The opposite was found among participants with low pretest scores; these participants endorsed metamorphosis more in the control condition than in the between-species variability condition, $F(1, 229) = 5.12$, $p = .025$. For the within-species variability prime, these patterns were less pronounced. Participants with high pretest scores endorsed metamorphosis more if they received the within-species variability prime compared to control; however, this trend was not significant, $F(1, 229) = 2.83$, $p = .094$. Among those with low pretest scores, there was no difference between the within-species variability prime and the control conditions, $F(1, 229) = 1.37$, $p = .243$. For participants who received the lesson with the different-offspring diagram, there were no differences as a function of prime and pretest (Figure 3B). The results do not differ if we analyze participants' endorsement item by item using a hierarchical linear model, rather than using composite scores.

Origin of species

We coded participants' explanations for whether they mentioned evolution, creationism, or spontaneous generation (Evans, 2000). We also coded whether participants mentioned the life cycle of the animal in their answers. A single explanation could be coded into multiple categories. Twenty percent of the responses were double coded to assess reliability; agreement was above 98%.

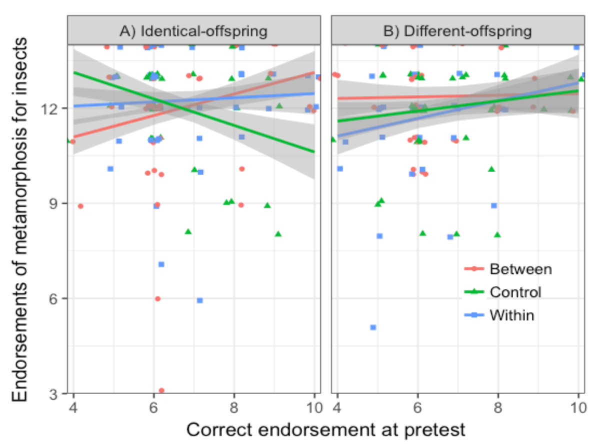

Figure 3. Participants' endorsement of metamorphosis for all insect items by pretest score. Each line represents a priming condition. Shaded regions represent the 95% confidence intervals. (A) Identical-offspring diagram. (B) Different-offspring diagram.

Overall, endorsement of evolution was very high with 82.2% of participants providing evolutionary explanations. Only 6.67% of participants gave creationist explanations, and only 5.42% referred to spontaneous generation. Many participants (37.5%) mentioned the life cycle of the animal in their explanations. We conducted three logistic regressions examining whether participants' explanations about the origin of species reflected evolution, creationism, or spontaneous generation. We included the interaction of pretest scores, priming condition, and diagram condition (with all the respective lower-level effects), and we included participants' endorsement of metamorphosis at posttest as a predictor. We did not find any significant effects for evolution or creationism (all p's > .05). However, we found that participants' endorsement of metamorphosis at posttest decreased the odds of participants' citing spontaneous generation as the origin of a species, χ^2 (1, N = 240) = 4.14, p = .042. No other effects were significant.

Discussion

In this study, we sought to manipulate psychological essentialism by highlighting different types of biological variability using text-based primes and diagrams. As hypothesized, highlighting variability led to increases in participants' acceptance of metamorphosis; however, this was only true among those who scored high at pretest. Additionally, highlighting more than one type of variability did not lead to further improvements. Contrary to our hypothesis, we did not find a difference between the between-species variability and the within-species variability primes, but the trends were stronger for participants who received the between-species variability prime.

We expected the within- and between-species variability primes to have different effects; however, this was not the case. One potential reason why the primes led to similar results could be that the between-species variability prime highlighted within-category variability for the broader category of insects. Future studies should investigate this possibility. We did find that the effect of both primes differed as a function of prior knowledge (i.e., pretest). The primes were intended to activate knowledge that people already possessed. We believe the primes were effective only among adults with high prior knowledge because they were more likely to have knowledge about within- and between-species variability. This might also be the reason why the trends were always stronger for the people who received the between-species variability prime. Adults rarely endorse within-species variability (Shtulman & Schulz, 2008), but they presumably know the difference between different species of animals.

We also found that there were not additive effects of highlighting more than one type of variability. For participants who saw the diagram that highlighted parent-offspring variability, the primes had no effect. This could suggest that simply highlighting any type of biological variability makes people more likely to accept metamorphosis. This opens up the possibility that all types of biological variability are related in people's minds, which could explain why we find similar results when we highlight between-species, within-species, or parent-offspring variability—all lead to an increased acceptance of metamorphosis.

This study has potential implications for the theory of psychological essentialism. Although some researchers have argued that there are developmental trends in essentialist reasoning (Gelman, 2004; Evans & Rosengren, 2018), essentialist reasoning has been assumed to be an individual characteristic. Indeed, essentialist reasoning about natural kinds is fairly constant, and independent of years of biological education (Coley et al., 2017). Our study suggests that essentialist reasoning can be decreased, at least for short periods of time. This decrease might be related to greater acceptance of biologically accurate but counter-intuitive information such as metamorphosis.

This work also has potential implications for science education. Mayr (1982) has argued that essentialist models of species are predominant in biology, and that these models are problematic when trying to account for sexual dimorphism, metamorphosis, and evolution. This study suggests that instruction that does not rely on an essentialist model of species might lead to better learning in the biological domain. Although our study suggests that understanding of metamorphosis might decrease endorsement of spontaneous generation, it is still an open question whether teaching children about metamorphosis and decreasing essentialist reasoning will lead to downstream effects for learning about evolution. Future research should look at children who have not learned about evolution to further examine if there is a relation between understanding metamorphosis and acceptance of evolution.

This study should be interpreted in light of its limitations. First, all the adults in our study probably had already learned about metamorphosis. Future studies should look at elementary school children who have received little biology instruction. This group would allow researchers to determine if essentialist thinking in biology is a product of how this subject is taught in the United States. Second, it is not clear how long lasting the effects of our manipulation would be. If the effects of our prime manipulation are brief, it would not be a useful intervention for biology classes.

Biological variability is a key concept in science education. Understanding how children and adults learn about variability can further our knowledge of how cognitive constraints, such as psychological essentialism, influence learning and generalization and potentially influence education. We found that highlighting variability was useful among individuals with high prior knowledge. Our findings suggest that psychological essentialism might be one reason why learning about drastic biological change is difficult. Overall, we found that highlighting any type of biological variability leads to better generalization from a biology lesson but that the effectiveness of this manipulation depends greatly on learner characteristics such as prior knowledge in the domain.

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