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RESEARCH ARTICLE

Do details bug you? Effects of perceptual richness in learning about biological change

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Summary

People often have difficulty in understanding processes of biological change, and they typically reject drastic life cycle changes such as metamorphosis, except for animals with which they are familiar. Even after a lesson about metamorphosis, people often do not generalize to animals not seen during the lesson. This might be partially due to the perceptual richness of the diagrams typically used during lessons on metamorphosis, which serves to emphasize the individual animal rather than a class of animals. In two studies, we examined whether the perceptual richness of a diagram influences adults' learning and transfer of knowledge about metamorphosis. One study was conducted in a laboratory setting, and the other was online. In both studies, adults who saw the bland diagram during the lesson accurately transferred more than adults who saw the rich diagram during the lesson.

KEYWORDS
biological reasoning, diagrams, perceptual richness, prior knowledge, transfer

1 | INTRODUCTION

Animals, even ones of the same species, differ from one another, and they can undergo drastic changes throughout their lives. Understanding these ideas is crucial for understanding biological phenomena such as metamorphosis and natural selection. However, many studies have shown that children and adults have difficulty in understanding that organisms of the same species can look different from one another and that they can change throughout their lifespan (Emmons & Kelemen, 2015; Rosengren, Gelman, Kalish, & McCormick, 1991). Both children and adults often reject drastic life cycle changes such as metamorphosis, which occurs in butterflies and most other insects (Rosengren et al., 1991). Even after people learn about drastic life cycle changes, they often fail to transfer this knowledge (Herrmann, French, DeHart, & Rosengren, 2013). For example, although many adults recognize that butterflies undergo metamorphosis, few realize that most insects undergo this type of change.

Previous research suggests that certain cognitive constraints may make it difficult to learn about drastic life cycle changes such as metamorphosis (French, Menendez, Herrmann, Evans, & Rosengren, 2018). We propose that an additional possible impediment to knowledge transfer about metamorphosis could be the instructional materials used when teaching this concept. Lessons on metamorphosis often use colorful life cycle diagrams that depict individuals with great perceptual detail (e.g., photos or realistic images of animals). The present study investigated whether manipulating the perceptual richness of diagrams used during metamorphosis lessons influences learners' understanding of metamorphosis and their acceptance of life cycle changes. We first describe previous research on how people understand biological changes, and we then review the literature on how diagrams influence learning and generalization.

1.1 | Understanding of biological change

People's difficulties in learning about drastic life cycle changes may arise from underlying cognitive constraints, such as *psychological essentialism* (Gelman & Rhodes, 2012). Psychological essentialism is the idea that categories (such as animal species) have underlying "essences" that give rise to their characteristics. An essentialist perspective on categories might imply that category members are unchanging, and thus might make people resistant to accepting metamorphosis as a plausible change (Rosengren et al., 1991).

People tend to accept that animals can change in *size* over their lives, but they tend to reject more drastic types of change, especially for unfamiliar animals (French et al., 2018). This pattern of responses—termed the "growth bias"—appears to be strongest among three- and four-year-old children and to decrease with age. Young children's responses suggest they believe the juvenile and adult forms of an animal will be identical, except the older version will be bigger. This pattern of growth (in which the organism changes only in size) is biologically inaccurate, as the features and proportions of animals also differ in their juvenile and adult forms (Lorenz, 1971). French et al. (2018) argue that this bias is the "default" means for reasoning about life cycle changes for unfamiliar species, because the rejection of drastic life cycle changes is most pronounced for unfamiliar animals. From this perspective, metamorphosis may be challenging to understand because it violates how people normally think of animal growth.

Although the growth bias may explain why metamorphosis is difficult to learn, it does not explain why learners do not transfer knowledge about metamorphosis learned about one animal (e.g., butterflies) to other related animals (e.g., other insects). One possible explanation involves the instructional materials normally used in teaching metamorphosis. Metamorphosis is typically taught in classrooms using life cycle diagrams that show the most relevant stages in an organism's life. These diagrams are usually perceptually rich, with drawings or photographs that depict many details about the animal's appearance at each stage. In addition, the diagrams often include irrelevant details in the background, such as plants or other animals. Perceptually rich representations have been shown to lead to poorer transfer than perceptually bland, abstract representations in domains such as arithmetic (Fyfe, McNeil, & Borjas, 2015; Kaminski & Sloutsky, 2013; Kaminski, Sloutsky, & Heckler, 2008) and physiology (Mayer, Griffith, Jurkowitz, & Rothman, 2008; Park, Moreno, Seufert, & Brünken, 2011). However, no research, to date, has examined whether perceptual richness influences learning and transfer of knowledge about life cycle changes.

1.2 | Effects of perceptual richness

The perceptual richness of diagrams may influence the learning and transfer of information. Many studies have focused on extraneous information, or "seductive details," which are potentially interesting or distracting features that are irrelevant to the concept being taught (Garner, Alexander, Gillingham, Kulikowich, & Brown, 1991). Such information may hinder learning because learners' attention is drawn to these details, shifting cognitive resources to processing those details, rather than the lesson-relevant information. In a meta-analysis examining 39 studies of the effects of seductive details on learning and transfer in a variety of domains, Rey (2012) found that extraneous details impaired both learning (i.e., retention of lesson information) and transfer (i.e., generalizing from the lesson). However, only eight of the studies included in the meta-analysis explored seductive details in images; the majority dealt with text that contained irrelevant details.

Additional studies that did not fall within the scope of Rey's (2012) meta-analysis also support the idea that seductive details in diagrams can inhibit learning and transfer. For example, in a study of 6–8-year-old children learning to read simple bar graphs, children learned more and transferred better when the lessons involved graphs that were free of extraneous details (Kaminski & Sloutsky, 2013). Likewise, adults who learned about the circulatory system with a schematic diagram learned more than those who learned about it with a detailed, anatomically correct diagram (Butcher, 2006).

Rey's (2012) meta-analysis, as well as some other recent studies (see Eitel & Kühl, 2019), has highlighted some variables that moderate the negative effects of seductive details. These include the domain (with larger negative effects in science compared to history) and learner characteristics (with learners with greater working memory capacity being less affected by seductive details).

1.3 | Abstract versus concrete representations

Although shifting cognitive resources may explain the negative effects of seductive details in some cases, it is also important to consider the potential effects of the level of abstraction of the representations. Perceptually rich materials may impair transfer because they depict a specific, concrete example of a category. These materials might lead learners to incorrectly infer that new information applies only to the depicted exemplar. Interpreting diagrams as specific, in this way, could impair transfer because learners may not attempt to generalize the concept to other cases. In one study of this issue, adults who were taught about modular arithmetic with abstract images showed better transfer than those who were taught using concrete images (Kaminski et al., 2008). Abstract representations—which also happen to be more perceptually bland—might appear more generic or prototypical, and they might, therefore, support generalization (Rips, 1975; Rosch, 1973). In contrast with the conclusions of Rey's (2012) meta-analysis, which showed that both learning and transfer are hindered by the presence of "seductive details," this literature suggests that people can *learn* well with both concrete and abstract representations, but that abstract representations promote better *transfer*.

Some findings, however, cast doubt on the superiority of abstract representations. Siler and Willows (2014) found that a lesson on modular arithmetic that included concrete but *relevant* details led to better performance than a comparable lesson that used abstract representations. In addition, lessons on modular arithmetic that involved starting with the concrete representations and progressively introducing more abstract representations (termed concreteness fading) led to better learning and transfer than lessons that used only abstract representations (McNeil & Fyfe, 2012). This work suggests that concreteness is not always detrimental, particularly if it is relevant or if it helps students grasp the problem or the structure of the domain. Having concrete representations might be especially beneficial for learning about life cycles, as the additional perceptual information might help students identify the animal used in the lesson. Thus, details that help identify the animal are not irrelevant. Therefore, we wanted to explore whether including these details would also lead to differences in transfer. This study provides the first test, to our knowledge, of the influence of perceptual richness on reasoning about life cycle changes.

The key issue might not be the representation itself, but whether students are able to transfer knowledge obtained from a concrete example provided in a lesson to an abstract model that lends itself to generalization. Abstract visual representations may ease this process because they are already fairly decontextualized. However, abstract visual representations are not the only way to promote generalization. Visual representations used in lessons are not always used alone—they are often accompanied by verbal information that also conveys the to-be-learned information. Slight modifications to the verbal information might also increase the likelihood that students will generalize.

Some evidence suggests that students learn and generalize information better when abstract visual representations are accompanied by specific (or concrete) labels or verbal descriptions (Son & Goldstone, 2009). Other research showed that using general labels (e.g., “AB”) rather than specific labels (e.g., “blue-red”) to describe a concrete representation of a pattern enhanced children's ability to transfer the rule to new patterns (Fyfe, McNeil, & Rittle-Johnson, 2015). Moreover, children who adopted the abstract language had better performance. This suggests that the verbal information conveyed in the lesson can play a critical role in how participants interpret the visual representation. To control for this effect, we used specific labels in our lesson. We also explored whether participants spontaneously generated general labels to describe the diagram. Participants' spontaneous use of general labels might be an indicator of their own abstraction process, which should be related to their ability to transfer the material from the lesson.

1.4 | Individual differences in prior knowledge

Regardless of whether seductive details or concreteness is driving the results, research has shown that the influence of perceptual richness is not uniform across learners. One learner characteristic that has been widely studied is prior knowledge. For example, Cooper, Sidney, and Alibali (2017) found that rich illustrations of trigonometry problems impaired performance for participants with low prior mathematics knowledge, as measured by standardized math scores, but not for participants with high prior knowledge. Goldstone and Sakamoto (2003) found that participants who initially scored low on a task about complex adaptive systems transferred better with abstract representations, but participants who scored high were either unaffected by the representation or benefitted from the concrete representation. Thus, prior knowledge may moderate the influence of perceptual richness of diagrams on learning and transfer.

Prior knowledge also plays a critical role in learning new concepts (e.g., Kaplan & Murphy, 2000; Murphy & Allopenna, 1994), including learning about life cycle changes. For example, French et al. (2018) found that adults were more likely to endorse changes other than growth for familiar animals than for unfamiliar animals. However, there is also evidence that intuitive theories of biology persist, regardless of level of expertise. Coley, Arenson, Xu, and Tanner (2017) found that undergraduate biology majors showed patterns of essentialist reasoning about biological phenomena that were similar to those shown by non-biology majors. In addition, Shtulman and Harrington (2016) found that adults—even professional scientists—continued to rely on their intuitive theories when under time pressure. Transferring knowledge of metamorphosis might depend, not only on how the learners interact with the diagram, but also on their prior knowledge about biological change.

2 | STUDY 1

We examined the effects of perceptual richness in life cycle diagrams on adults' learning and transfer about metamorphosis. By *perceptual richness*, we mean the addition of color and other details that make the diagram more complex, which might also help people identify the animals displayed more easily. It is worth noting that the details included in the perceptually rich diagram, as will be described in the method section, are relevant to the lesson. The details and color would help differentiate the exemplar in the lesson (i.e., the ladybug) from other beetles. Given that the added perceptual information is relevant, our study is a strong test of whether adding relevant perceptual details to a visualization influences learning and generalization. If participants learn more with bland diagrams, this could not be attributed to participants who saw the rich diagram focusing on irrelevant details, since the additional details are relevant. If participants learn more with rich diagrams, it would suggest that adding perceptual information is not always detrimental.

In addition, although there has been some work on how perceptual richness influences learning and generalization in the domain of biology (Butcher, 2006; Goldstone & Sakamoto, 2003; Son & Goldstone, 2009), none of these past studies assessed how far people generalize from a lesson, or whether they overgeneralize their knowledge. The prior work in biology has focused on contexts in which people *should* generalize what they learned previously. Knowing that people can generalize even complex information is important, but it is also important to determine how far people generalize from a lesson. For example, if students learn that caterpillars turn into butterflies, they should not generalize this fact to fish or dogs.

In our study, we teach participants that ladybugs undergo metamorphosis (a concept that people rarely generalize, Herrmann et al., 2013). We then test them on whether other animals undergo metamorphosis. These animals include other ladybugs (learning items), other insects (transfer items), and other non-insect animals (overextension). In our lesson, we never specify to which group participants should generalize. This allows us to determine whether people generalize without constraints, or, more likely, whether they generalize at the appropriate category level (i.e., insects).

Based on the literature, we made distinct predictions for learning and transfer. Given the findings of Kaminski et al. (2008), we expected that both rich and bland life cycle diagrams would support *learning* about metamorphosis for the insect used in the lesson (i.e., the ladybug). We further predicted that the bland life cycle diagram would better support *transfer*; that is, individuals who received a lesson with a bland diagram would be more likely to *transfer* their knowledge to other insects than learners who received the comparable lesson with a rich diagram (Kaminski et al., 2008; Rey, 2012). In line with previous studies, we expected the effect of perceptual richness on transfer to be moderated by prior knowledge, with the advantages of bland diagrams being greater for those with low prior knowledge of biological change (Goldstone & Sakamoto, 2003). Given prior research suggesting that general biological knowledge, as proxied by college major, does not influence intuitive reasoning (Coley et al., 2017), we expected that perceptual richness would not interact with college major (i.e., Biology or non-Biology).

3 | METHOD

3.1 | Participants

Participants were 133 undergraduate students (86 women, 42 men, and 5 who declined to report gender) enrolled in an Introduction to Psychology course at a large Midwestern university. They completed the study during one session in a laboratory setting. Of the 133 students, 97 identified as White, six as Black or African American, one as American Indian or Alaska Native, 21 as Asian or Asian American, and five as some other race or ethnicity; three participants declined to report race or ethnicity. Forty-one students reported majoring in a Biology-related field (including biochemistry, nursing, zoology, pharmacy, genetics, and other majors that required extensive biology coursework), 87 students reported majoring in a non-Biology field, and five students did not report major. All participants received extra credit in their psychology course for participation. All participants provided informed consent.

3.2 | Overview of design

The study used a pretest-intervention-posttest design. The pretest was designed to assess participants' endorsements of different types of changes (size change, color change, drastic change or metamorphosis, species change). We asked about each type of change with two different questions (lifespan questions and offspring questions), described below. The intervention was a lesson about the ladybug life cycle. We selected the ladybug because it is familiar to most people. However, when we informally asked a classroom of undergraduate students whether ladybugs went through metamorphosis, very few of the students said that they believed that ladybugs did so, and quite a few students were unsure. Participants were randomly assigned to receive the lesson with either the rich or bland diagram. The posttest was a longer version of the pretest, with twice as many animals.

3.3 | Materials

All of our stimuli, diagrams, and lessons can be found at https://osf.io/f459n/. We asked participants two types of questions: (a) *lifespan* questions, “When the one on the left grows up, could it look like the one on the right?”, and (b) *offspring* questions, “Could the one on the left have a baby that looks like the one on the right?” The questions were displayed beneath images of the animals. For the lifespan questions, the juvenile (for insects, larva) form of the animal was presented on the left, and on the right there was a target picture (depending on the type of change depicted) that was larger in size. For the offspring questions, the adult form was presented on the left, and on the right there was a target picture that was smaller in size. Participants answered all of the questions of each type (lifespan or offspring) in a block, with block order counterbalanced across participants.

For each animal in the pretest and posttest, we created images that showed four different types of change: size change, color change, metamorphosis, and species change (adapted from Herrmann et al., 2013). For animals that undergo metamorphosis, size change trials depicted animals that differed *only* in size. To create these trials, we took the same picture and enlarged it or shrank it (depending on whether it was for a lifespan or offspring question trial). Size changes were always correct for lifespan questions, because all the juvenile forms presented in the lifespan questions in our study grow and get bigger. For animals that undergo metamorphosis, size changes were incorrect for offspring questions because the juvenile version is a larva, rather than a smaller version of the adult. For animals that do not undergo metamorphosis, the presented juvenile form looked similar but had different proportions than the adult form (e.g., a dog and a puppy). For animals that do not go through metamorphosis, this represented a correct type of change (Lorenz, 1971). For color change trials, the animals differed in size and color (we took the same picture, enlarged it, and changed the color). These trials have been used in prior research to examine how much an animal has to change for people to reject the change (French et al., 2018). Given that this was not the purpose of our study, the color change trials will not be discussed at length. Metamorphosis trials involved a drastic change from the juvenile to the adult form. Metamorphosis trials were always correct for insects and amphibians (for both lifespan and offspring questions), and incorrect for the other animals. Species change is a non-biologically-possible drastic change in the form of the animal; species change trials were always incorrect. All of the depicted changes involved a difference in size, because prior research suggests that people reject biological changes that are not accompanied by a change in size (Rosengren et al., 1991). We asked about each type of change for both the lifespan and offspring question for each animal (eight questions total per animal).

The pretest included five animals (butterfly, ladybug, beetle, fish, and dog) and the posttest included 10 animals (ladybug, Asian beetle, firefly, stag beetle, ant, butterfly, praying mantis, fish, frog, and dog). Of these animals, only the fish and the dog do not undergo metamorphosis. Sample items can be seen in Figure 1, and sample stimuli can be seen in Figure 2. In each stimulus, the base animal was presented on the left side of the computer screen and the changed form was presented on the right. Participants saw all types of change for all animals, but the order in which the different types of change were presented was randomized for each animal (but was the same for all participants). On the posttest, the animals were presented starting with those most similar to the animal in the lesson (the ladybug), and moving farther away as trials progressed (ladybugs, then other beetles, then other insects, and then vertebrates). This progressive alignment sequence was used to facilitate transfer (Thompson & Opfer, 2010).

We divided the posttest items into three groups: learning items, transfer items, and overextension items. *Learning items* were the ladybug items (because the ladybug was the animal used in the lesson). *Transfer items* were all of the non-ladybug insects. These items required generalization from the lesson. Finally, *overextension items* were non-insects for which generalization was not appropriate (the fish and the dog).

The lesson was presented via a brief video about the life cycle of the ladybug. The only visual shown in the video was a life cycle diagram, and the only difference between the rich and the bland conditions was the specific diagram used in the video. The diagram was always present during the lesson. The voiceover was identical in the two conditions. The diagrams are presented in Figure 3 and the full script for the lesson is in Appendix A. Both the bland and rich diagrams depicted four stages of the ladybug life cycle. The rich diagram was in color and depicted many features of the animal at each stage. The bland drawing was black and white and included fewer features (see Figure 3). At points in the video that focused on a single stage, a yellow circle appeared around the relevant portion of the diagram but did not obstruct the rest of the diagram. The video used specific labels for each stage ("egg," "larva," "pupa," "adult ladybug"). The lesson

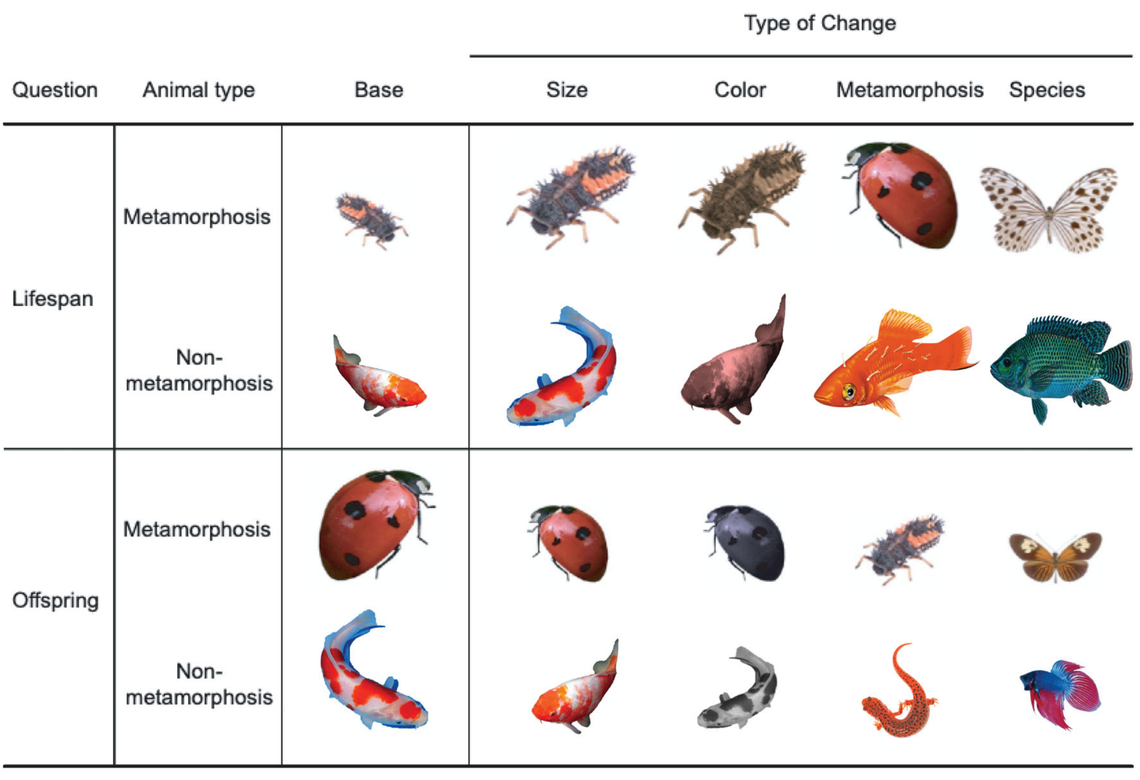

FIGURE 1 Sample stimuli pairs for animals that undergo and do not undergo metamorphosis. The figures represent the four stimuli pairs that were presented to participants. Each base was presented with each of the four types of change. The base was always presented on the left, and the second image was always presented on the right

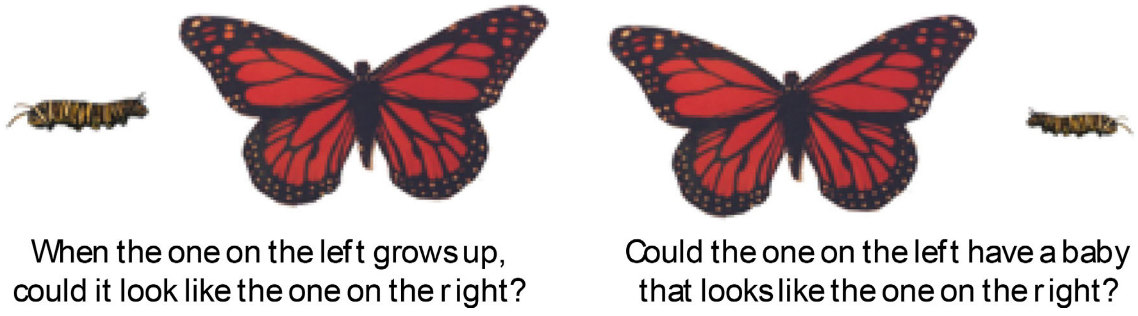

FIGURE 2 Sample stimuli. The image on the left shows a sample question for the lifespan items, and the image on the right shows a sample question for the offspring items. Both images show the metamorphosis items for a butterfly

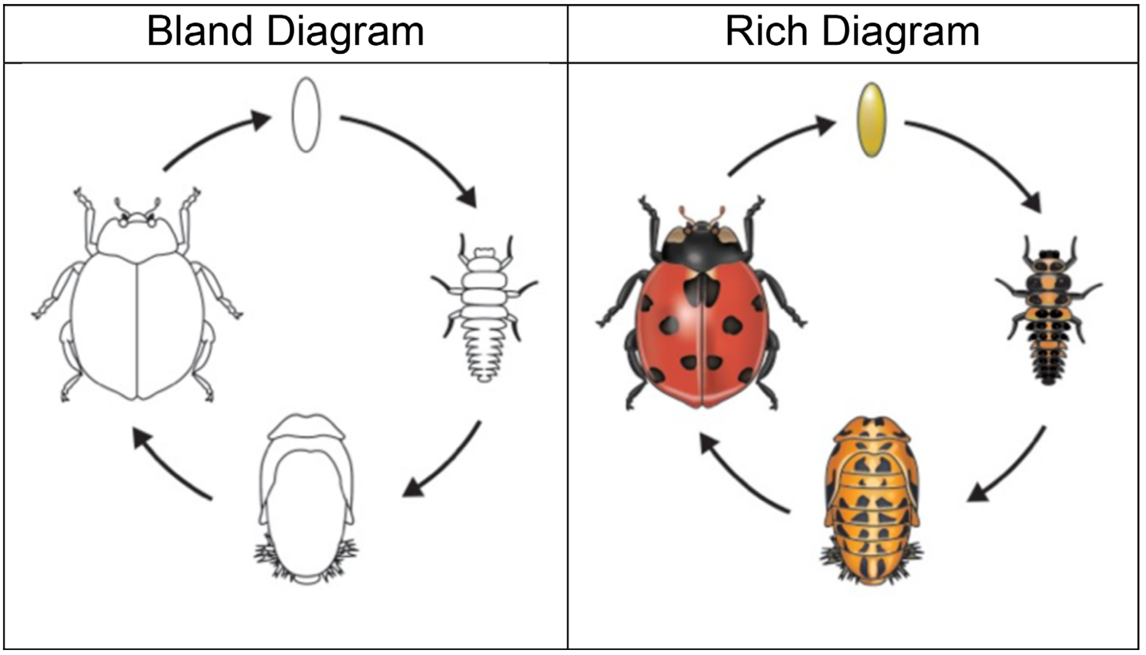

FIGURE 3 Diagrams used during the lesson. On the left is the perceptually bland diagram, which has no color and few details within the drawings at each stage. On the right is the perceptually rich diagram, which contains color and many details within the drawings at each stage. Figures available at https://osf.io/hfg38/ under a CC-BY4.0 license (Menendez, 2019)

included the statement that "many animals go through metamorphosis" but did not explicitly mention that all insects and amphibians go through this process. This allowed us to examine whether participants transferred the information from the lesson only to ladybugs, to other insects, or to all animals.

3.4 | Procedure

Participants were randomly assigned to either the rich or the bland condition. All participants were told that the purpose of the experiment was to test their knowledge about the life cycles of different animals, and that the task was modeled after a task used with children "so [the participant] might find it easy." Participants were randomly assigned to complete the *lifespan* or the *offspring* questions first in the pretest, and this assigned order was maintained for the posttest. During the pretest and posttest, one pair of images displaying one of the types of change was shown at a time. One of three trained experimenters read the questions aloud. Participants were asked to answer "yes" or "no" for each question, and they were not able to go back to a previous question once it was answered. After completing the pretest, participants viewed the video lesson with either the rich or the bland diagram, depending on their assigned condition. Following the lesson, we asked participants to provide a label for each of the diagram stages (egg, larva, pupa, and adult). Participants then completed the posttest in the same way they completed the pretest. Finally, participants provided demographic information, including gender, race/ethnicity, year in school, and major.

4 | RESULTS

First, we analyze performance on the pretest, to establish whether our sample exhibited a similar pattern of responses as did participants in previous studies. Second, we analyze participants' recall of the labels used during the lesson. Next, we present the results for the learning items. We then present the results for the transfer items. Finally, we present the results for overextensions (endorsement of metamorphosis for animals that do not go through this process). We did not find a main effect of question order (i.e., lifespan first, offspring first) for any of the dependent variables, so we do not include this variable in any of the models presented below. De-identified data and our analysis script can be found at https://osf.io/f459n/.

4.1 | Pretest performance

We used a repeated measures ANOVA to examine the proportion of endorsements that participants made for each type of change at pretest. We included type of change, whether the animal undergoes metamorphosis (yes or no; henceforth, *animal type*), question type (i.e., lifespan or offspring), whether the participant was a biology major (yes or no), and all the respective interactions as predictors. Thus, the analysis was a 4 (type of change) × 2 (question type) × 2 (animal type) × 2 (college major) repeated measures ANOVA, with college major as a between-subjects factor. The sphericity assumption was not met, so we used Greenhouse–Geisser corrections.

We found a main effect of animal type; participants endorsed a greater proportion of changes, overall, for animals that undergo metamorphosis (M = .47, SE = 0.01) than for animals that do not (M = 0.39, SE = 0.01), $F(1, 125) = 60.81$, $p < .001$, $\eta^2 = .327$. We also found a main effect of type of change, $F(1.99, 248.34) = 381.86$, $p < .001$, $\eta^2 = .753$. Similar to the findings of French et al. (2018), pairwise comparisons revealed that participants endorsed size change (M = 0.84, SE = 0.01) on a greater proportion of trials than color change (M = 0.53, SE = 0.03), color change on a greater proportion of trials than metamorphosis (M = 0.27, SE = 0.01), and metamorphosis on a greater proportion of trials than species change (M = 0.09, SE = 0.01), p's < .001.

This main effect was qualified by an animal type by type of change interaction, $F(2.57, 321.22) = 68.85$, $p < .001$, $\eta^2 = .287$. We examined the simple effects by looking at the 95% confidence intervals. Participants endorsed change in size for a greater proportion of non-metamorphosis animals (M = 0.90, SD = 0.02, 95% CI = 0.86, 0.93) than for animals that go through metamorphosis (M = 0.79, SE = 0.02, 95% CI = 0.75, 0.83), $p < .05$. Participants endorsed color change for a similar proportion of non-metamorphosis animals (M = 0.53, SD = 0.03, 95% CI = 0.47, 0.58) and animals that go through metamorphosis (M = 0.53, SE = 0.03, 95% CI = 0.47, 0.59), $p > .05$. As one would expect, participants endorsed metamorphosis for a lesser proportion of non-metamorphosis animals (M = 0.11, SE = 0.01, 95% CI = 0.08, 0.13) than of animals that go through metamorphosis (M = 0.43, SE = 0.02, 95% CI = 0.39, 0.47), $p < .05$. It is worth noting, however, that participants were not at ceiling in their endorsement of metamorphosis for metamorphosis animals. This result replicates prior research, showing that adults do not always endorse metamorphosis when appropriate to do so. Participants endorsed species change for a smaller proportion of non-metamorphosis animals (M = 0.04, SE = 0.01, 95% CI = 0.02, 0.06) than of metamorphosis animals (M = 0.13, SE = 0.01, 95% CI = 0.10, 0.16), $p < .05$; however, endorsement of species change was quite low overall. Based on the pretest data, it appears that participants endorse changes in size and color for most animals, and they simply add metamorphosis to the set of possible changes for those animals that they know undergo metamorphosis.

There was also a main effect of question type, such that participants endorsed the depicted change on a greater proportion of lifespan questions (M = 0.45, SE = 0.01) than offspring questions (M = 0.41, SE = 0.01), $F(1, 125) = 12.47$, $p = .001$, $\eta^2 = .091$. There was also a type of change by question type interaction, $F(2.17, 271.20) = 8.95$, $p < .001$, $\eta^2 = .067$. Participants endorsed metamorphosis on a greater proportion of lifespan questions (M = 0.32, SE = 0.02, 95% CI = 0.29, 0.36) than offspring questions (M = 0.21, SE = 0.01, 95% CI = 0.19, 0.24), $p < .05$. Participants also endorsed species change on a greater proportion of lifespan questions (M = 0.12, SE = 0.01, 95% CI = 0.09, 0.15) than offspring questions (M = 0.05, SE = 0.01, 95% CI = 0.03, 0.08), $p < .05$. However, these findings might be an artifact of the way we constructed the items. The species change items for the lifespan question for insects showed a larva on the left side and the adult form of a different insect on the right. Just from seeing a larva, it is difficult to know how the adult form of an insect will look, so participants may have endorsed any adult insect if they believed the larva would undergo metamorphosis. In the offspring questions, however, the animal on the left was an adult insect and the one on the right was also an adult insect. So, participants only needed to know that an insect would not turn into a different insect (arguably an easier task), potentially leading to low levels of endorsement for these questions.

The type of change by question type interaction was further moderated by an interaction with animal type, $F(2.75, 343.84) = 27.68$, $p < .001$, $\eta^2 = .181$. As seen in Figure 4, across most types of change, participants endorsed a greater proportion of lifespan questions than offspring questions. However, for color changes among animals that do not undergo metamorphosis, participants endorsed a greater proportion of offspring questions than lifespan questions.

There was no effect of biology major, nor did biology major interact with any of the other variables. Thus, general biological knowledge did not seem to influence participants' understanding of biological change.

4.2 | Lesson

After viewing the video lesson, participants were asked to recall the name of each stage in the ladybug's life cycle. Two participants were dropped from all of the following analyses because they did not view

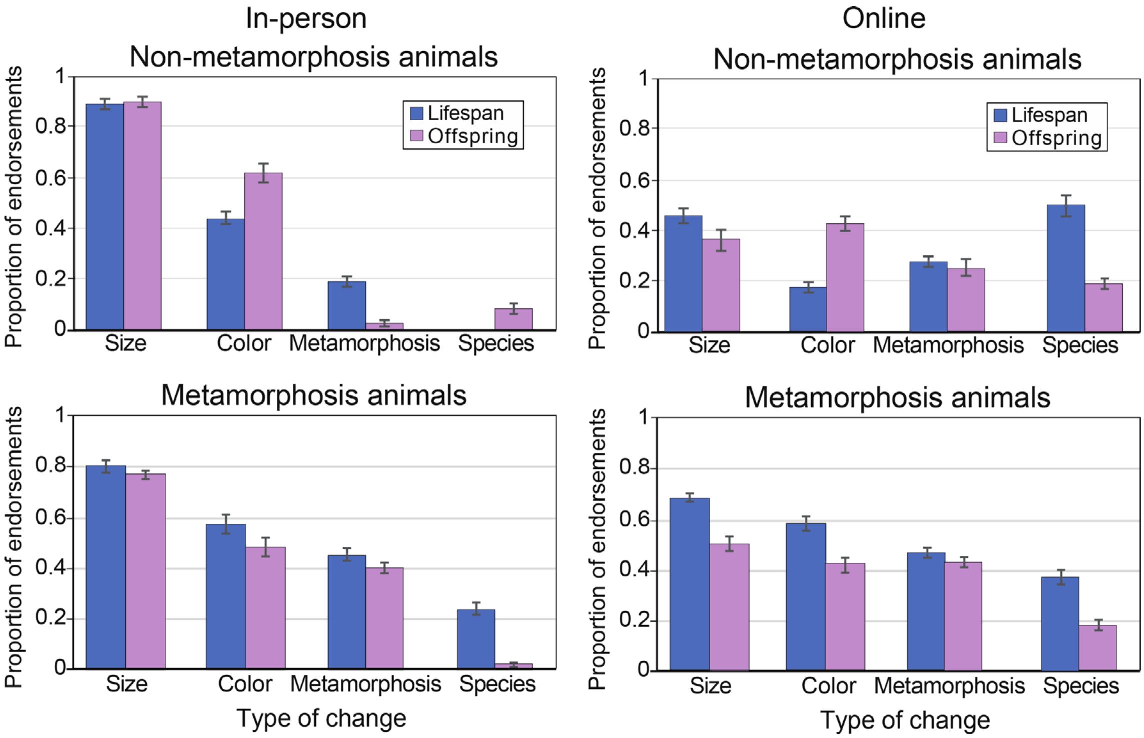

FIGURE 4 Proportion of endorsements for each type of change by animal and question type. Error bars represent the within-subjects 95% confidence interval. The panel on the left presents the results for the in-person study (Study 1). The panel on the right presents the results for the online study (Study 2)

the video lesson, due to a technical error. We counted participants' answers as correct if they said "egg," "larva," and "pupa" for the first, second, and third stages, respectively. For the final stage, we accepted a variety of responses including: ladybug, adult, adult ladybug, adult stage, adulthood, and beetle. We used a linear regression to predict the number of labels that participants remembered from their college major, diagram condition, pretest score, and their interactions. Biology majors (M = 3.58, SD = 0.81) provided more correct labels than non-biology majors (M = 3.16, SD = 1.02), $F(1, 118) = 6.53$, $p = .012$, $\eta^2 = .052$. No other effects were significant.

Given that participants could use a variety of labels for the final question, we examined whether participants used a specific term (e.g., "ladybug") or a more abstract or general term (e.g., "adult" or "beetle"). Recall that some researchers believe that perceptually bland diagrams lead to better transfer because they are more abstract (Son & Goldstone, 2009). Analyzing the labels used by participants might provide insight into whether participants think about the exemplar in the lesson in an abstract or a concrete way. However, there was no evidence that the bland diagram led more participants to use general labels, $\chi^2(1, N = 123) = 0.0005$, $p = .982$. Among participants who saw the bland diagram, 23 participants provided a general label and 37 provided a specific label. Among participants who saw the rich diagram, 23 provided a general label and 41 provided a specific label. These data suggest that participants who saw the bland diagram did not think of the animals in a more abstract way than participants who saw the rich diagram.

4.3 | Learning

To test whether participants learned that ladybugs undergo metamorphosis, we examined the difference in the probability that participants endorsed the metamorphosis items for the ladybug questions at pretest and posttest. We used a generalized linear mixed-effects model to predict participants' probability of endorsing metamorphosis from test time (pretest vs. posttest), diagram condition, college major, question type, and number of correct labels provided after the lesson. We also included the three-way interaction of test time, diagram condition, and college major and the respective lower-order interactions. We included by-subject random intercepts and two by-subject random slopes (one for test time and one for question type). The model summary is presented in Table 1.

We predicted that both the bland and rich diagrams would lead to learning. As expected, we found that participants had a higher probability of endorsing metamorphosis at posttest than at pretest. Participants endorsed metamorphosis for ladybugs an average of 0.69 times (SD = 1.22) at pretest and 3.72 times (SD = 0.81) at posttest (out of four possible [two ladybugs × 2 questions]). We did not find an effect of diagram condition or an interaction between diagram condition and test time. Thus, as predicted, both diagrams led to similar amounts of learning. Participants were also more likely to endorse metamorphosis for the lifespan questions (M = 0.41 endorsements, SD = 0.72) than for the offspring questions (M = 0.28 endorsements, SD = 0.59). No other effects were significant.

TABLE 1 Predictors of adults' endorsement of metamorphosis for ladybug (learning) items

	Study 1			Study 2		
Predictor	OR	χ^2	*p* value	OR	χ^2	*p* value
Time (Pre vs Posttest)	**>1,000**[a]	**57.16**	**<.001**	**12.49**	**10.91**	**<.001**
Rich diagram	1.81	0.11	.742	0.50	1.29	.257
Biology major	1.08	0.002	.968	0.89	0.04	.845
Labels	1.28	0.10	.746	**2.80**	**16.72**	**<.001**
Lifespan question	**108.01**	**3.88**	**.049**	0.75	0.49	.481
Time * Rich diagram	2.68	0.08	.780	0.91	0.004	.948
Time * Biology major	0.57	0.03	.871	1.41	0.07	.796
Rich diagram * Biology major	0.68	0.01	.915	0.09	3.73	.053
Time * Rich diagram * Biology major	10.12	0.11	.734	0.13	0.56	.454
Labels * Rich diagram	0.91	0.004	.949	1.16	0.11	.738

Note: Values in bold are significant at the .05 level.
[a]114,521,260,401.51; this high value is likely due to a ceiling effect for the learning items on the posttest.

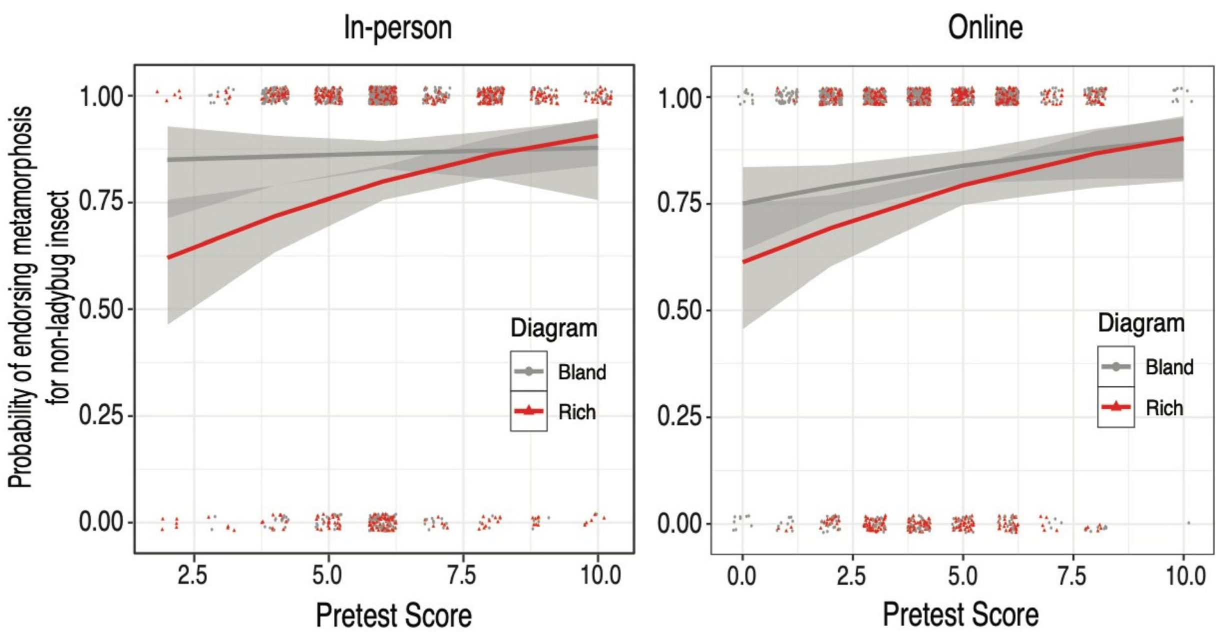

FIGURE 5 Participants' endorsements of metamorphosis for non-ladybug insects. Error bands reflect the standard error of the point estimate. Dots at the top and bottom of the graph represent responses for each participant for each item. A dot on the top (near 1) represents that a participant said "yes" to the metamorphosis item. A dot on the bottom (near 0) represents that a participant said "no" to the metamorphosis item. The x-axis shows participants' pretest scores. The left panel shows the results for the in-person study (Study 1). The right panel shows the results for the online study (Study 2)

4.4 | Transfer

Using a generalized linear mixed-effects model, we next tested whether diagram condition (coded −0.5 for bland and 0.5 for rich), pretest scores (mean-centered), college major (coded 0.5 for biology majors and −0.5 for other majors), and question type (coded −0.5 for offspring questions and 0.5 for lifespan questions) influenced endorsements of metamorphosis for non-ladybug insects. We included the three-way interaction of diagram condition, pretest, and college major, along with the respective lower-order interactions. We included by-subject random intercepts and by-subject random slopes for question type. Because participants cannot transfer what they did not learn, we controlled for participants' scores on the learning items (i.e., the ladybug items) in the models of transfer to other insects. We also included the learning by diagram condition by college major interaction in the transfer models. This follows the recommendations of Yzerbyt, Muller, and Judd (2004), who suggest that when testing the interaction between a manipulated variable (e.g., richness of the diagram) and a measured variable (e.g., pretest scores) when controlling for a covariate (e.g., amount of learning), the estimate for the interaction is unbiased only when the model includes the covariate by manipulated variable interaction.

As predicted, there was a main effect of diagram condition on participants' likelihood of endorsing metamorphosis for the non-ladybug insect (transfer) items, $\chi^2(1, N = 126) = 5.00$, $p = .025$. As shown in Figure 5, participants who received the lesson with the bland life cycle diagram ($M = 8.51$ endorsements out of 10 possible, $SD = 1.56$) were more likely to endorse metamorphosis than participants who received the lesson with the rich life cycle diagram ($M = 7.92$ endorsements, $SD = 1.47$). However, the predicted diagram condition by pretest interaction was not significant, $\chi^2(1, \text{N} = 126) = 3.53$, $p = .060$. Pretest performance was related to transfer, $\chi^2(1, \text{N} = 126) = 4.10$, $p = .043$. There was also a simple effect of learning, such that more endorsement of metamorphosis for the ladybug items was related to a higher likelihood of endorsing metamorphosis for other insects, $\chi^2(1, \text{N} = 126) = 15.93$, $p < .001$. No other effects were significant.

4.4.1 | Exploratory analysis

We also explored whether using a general label during the recall task immediately after the lesson was associated with better generalization. The literature on abstract representations (Fyfe, McNeil, & Rittle-Johnson, 2015) suggests that participants should transfer better if they used a general label. The lesson used specific labels for each stage, hence participants using general labels during the recall task might reflect participants' conceptualization of the animal in the lesson (the ladybug).

Indeed, participants who used a general label for the adult ladybug (e.g., adult, beetle, insect) during the recall phase had a higher likelihood of endorsing metamorphosis for non-ladybug insects. The model summary is presented in Table 2. Participants who used general labels after the lesson ($M = 8.48$ endorsements out of 10 possible, $SD = 1.19$) were more likely to endorse metamorphosis for the transfer items than those who did not ($M = 8.10$ endorsements out of 10 possible, $SD = 1.7$). However, even after controlling for the use of general labels, the effect of diagram richness remained significant (see Table 2). This finding suggests that the effect of perceptual richness might be distinct from the effect of abstract language.

4.5 | Overextension

Finally, we examined whether participants erroneously generalized the concept of metamorphosis to animals that do not undergo this change. To do so, we analyzed participants' endorsement of the metamorphosis and species change items for the fish and the dog. We combined these two types of change because both are drastic, non-biological changes (at least for dogs and fish). Participants rarely endorsed drastic change for dogs ($M = 0.03$, $SD = 0.17$, out of four possible). Participants more frequently endorsed drastic change for fish ($M = 0.55$, $SD = 0.74$, out of four possible); however, the rate of endorsement was still very low (only 56 participants ever endorsed one of the fish items, and only 13 endorsed more than one). We used a generalized linear mixed-effects model to examine whether participants' endorsement of drastic changes (metamorphosis and species change) for the fish depended on test time (pretest vs. posttest), diagram condition (bland vs. rich), question type (offspring vs. lifespan), and major (non-biology vs. biology). We also explored the interactions between diagram condition and test time, and diagram condition and major. We included by-subject random intercepts, by-subject random slopes for the effect of question type, and by-subject random slopes for test time. We found only that participants were more likely to endorse drastic life cycle changes on lifespan questions ($M = 0.65$,

TABLE 2 Predictors of adults' endorsement of metamorphosis for non-ladybug insect (transfer) items

	Study 1			Study 2		
Predictor	**OR**	**χ2**	***p* value**	**OR**	**χ2**	***p* value**
Rich diagram	**0.61**	**5.30**	**.021**	**0.65**	**6.00**	**.014**
Pretest score	**1.16**	**4.63**	**.031**	**1.16**	**9.35**	**.002**
Biology major	1.24	1.01	.316	1.02	0.01	.915
Lifespan question	0.90	0.40	.525	1.23	1.54	.214
Learning score	**1.77**	**19.20**	**<.001**	**1.43**	**17.55**	**<.001**
Rich diagram * Pretest	1.29	3.31	.069	1.08	0.67	.414
Rich diagram * Biology major	0.77	0.40	.529	0.63	1.67	.196
Pretest * Biology major	1.10	0.44	.506	1.01	0.02	.889
Rich diagram * Pretest * Biology major	1.55	2.42	.120	1.02	0.02	.899
Rich diagram * Learning	1.27	0.84	.359	**1.47**	**5.41**	**.020**
General label	**1.54**	**4.76**	**.029**	1.00	<0.01	.999
Rich diagram * General label	1.34	0.54	.462	1.28	0.46	.498

Note: Values in bold are significant at the .05 level.

SD = 0.68) than on offspring questions (M = 0.50, SD = 0.75), χ^2(1, N = 126) = 5.49, p = .019. The likelihood of overextension at posttest in the bland diagram condition (M = 0.60, SD = 0.70) was comparable to the likelihood of overextension at posttest in the rich diagram condition (M = 0.51, SD = 0.77), χ^2(1, N = 126) = 0.04, p = .846. There was also no interaction between diagram condition and test time, χ^2(1, N = 126) = 0.68, p = .409. Thus, participants did not indiscriminately extend the idea of metamorphosis; instead, they constrained their transfer to appropriate animals.

5 | DISCUSSION

In line with our predictions, the bland life cycle diagram enhanced participants' transfer of metamorphosis to other insects. Furthermore, the bland and rich diagrams led to comparable learning about metamorphosis for the ladybug. In addition, we saw very low levels of overextension, and these levels were comparable across conditions. This pattern of findings suggests that the higher generalization scores observed in the bland diagram condition were not due to participants in the bland condition simply endorsing every change that they were presented with. Thus, bland diagrams promoted appropriate transfer of knowledge and did not hinder learning. The bland diagram seemed to have helped participants integrate metamorphosis into their general conception of biological change.

We also found that participants who used general labels to describe the final stage of the ladybug were more likely to transfer their knowledge of metamorphosis. However, the use of general labels did not differ by diagram condition, so it could not account for the effects of perceptual richness on transfer.

6 | STUDY 2

In Study 2, we sought to replicate Study 1 using an online data collection procedure. Participants completing the study online used their own computers, tablets, or cellphones, and they completed the study in less controlled environments than did participants in Study 1. If the findings replicate, it would increase the generalizability of our findings. Allowing people to complete the study online meant that we had no control over the display conditions such as monitor size and quality of display. We considered this limitation worthwhile given the concomitant increase in external validity.

7 | METHOD

7.1 | Participants

Participants were 160 undergraduate students (46 men, 111 women, and three who did not report gender) enrolled in an "Introduction to Psychology" course at a large Midwestern university. Of the 160 students, 139 identified as White, four as Black or African American, 12 as Asian or Asian American, one as Native Hawaiian or Pacific Islander, and one as some other race or ethnicity; three did not report race or ethnicity. Fifty-eight participants reported majoring in a biology-related field, 94 participants reported majoring in a non-biology field, and eight participants did not report their majors. All participants received extra credit in their Introduction to Psychology course in exchange for their participation. All participants provided informed consent at the outset of the study.

7.2 | Materials and procedure

The stimuli were the same as in Study 1. The only difference was that participants completed the study online. The stimuli and video lessons were displayed on a survey powered by Qualtrics® (Provo, UT).

8 | RESULTS

De-identified data and our analysis script can be found in https://osf.io/f459n/.

8.1 | Pretest

We analyzed the data using the same model as in Study 1. Once again, the sphericity assumption was not met, and we used Greenhouse–Geisser corrections.

As in Study 1, at pretest, participants endorsed the depicted change on a greater proportion of trials, overall, for animals that undergo metamorphosis (M = .45, SE = 0.01) than for animals that do not (M = 0.33, SE = 0.01), F(1, 159) = 127.31, p < .001, η^2 = .445. We also replicated the main effect of type of change, F(1.74, 274.60) = 17.33, p < .001, η^2 = .098. As in Study 1, examining the confidence intervals revealed that participants endorsed size change (M = 0.50, SE = 0.02, 95% CI = .45, .54) on a greater proportion of trials than color change (M = 0.41, SE = 0.02, 95% CI = .37, .44), color change on a greater proportion of trials than metamorphosis (M = 0.35, SE = 0.01, 95% CI = .33, .39), and metamorphosis on a greater proportion of trials than species change (M = 0.31, SE = 0.02, 95% CI = .28, .36), p's < .05. We also found that participants endorsed a greater proportion of trials, overall, for lifespan questions (M = 0.44, SE = 0.01) than for offspring questions (M = 0.35, SE = 0.01), F(1, 159) = 72.48, p < .001, η^2 = .313. See Figure 4.

As in Study 1, there were significant interactions of animal type and type of change, animal type and question type, and type of change and question type, F(2.07, 328.84) = 33.03, p < .001, η^2 = .172, F(1, 159) = 36.00, p < .001, η^2 = .185, F(2.70, 429.88) = 53.36, p < .001, η^2 = .251, respectively. The three-way interaction of animal type, type of change, and question type was also significant, F(2.65, 421.30) = 37.92, p < .001, η^2 = .193. For animals that undergo metamorphosis, participants endorsed size change on a greater proportion of lifespan trials (M = 0.68, SD = 0.02, 95%

CI = 0.63, 0.72) than offspring trials (*M* = 0.50, *SD* = 0.03, 95% *CI* = 0.45, 0.55), $p < .05$. There were no differences by question type for change in color or metamorphosis, *p*'s > .05. For species change, participants endorsed this non-biological change on a greater proportion of lifespan trials (*M* = 0.37, *SD* = 0.03, 95% *CI* = 0.31, 0.43) than offspring trials (*M* = 0.18, *SD* = 0.02, 95% *CI* = 0.14, 0.22), $p < .05$. It is worth noting that the endorsement of species change (at least for the lifespan questions) was very high, relative to Study 1. None of the participants in Study 1 endorsed the species change items for the lifespan questions (*M* = 0, *SD* = 0). Given that we used the exact same images in Study 2, this might suggest that the participants in the online study did not pay full attention.

We found a similar pattern of results for animals that do not undergo metamorphosis; however, as in Study 1, for color changes among animals that do not undergo metamorphosis, participants endorsed the depicted change on a greater proportion of offspring trials than lifespan trials, $p < .05$. Also, as in Study 1, there was no effect of major, nor did major interact with any of the other variables.

8.2 | Labels

We used linear regression to examine the number of labels that participants remembered from their major, diagram condition, pretest scores, and their interactions. As in Study 1, biology majors (*M* = 3.22, *SD* = 1.28) remembered more labels than non-biology majors (*M* = 2.78, *SD* = 1.58); however, this effect was not significant in this study, $F(1, 143) = 3.05$, $p = .083$, $\eta^2 = .021$. No other effects were significant. It is worth noting that the overall level of recall was lower in this study (*M* = 2.92, *SD* = 1.49) than in Study 1 (*M* = 3.29, *SD* = 0.97). In addition, 22 participants in this study provided incorrect labels for all four stages (compared with only one participant in Study 1), suggesting that some participants did not pay full attention to the lesson.

Once again, we examined whether participants used general labels when recalling the final stage of the ladybug's life cycle. Of the participants who saw the bland diagram, 40 provided a general label and 33 provided a specific label. Of the participants who saw the rich diagram, 33 provided a general label and 43 provided a specific label. However, as in Study 1, this difference was not significant, $\chi^2(1, N = 136) = 0.43$, $p = .511$. Thus, there was no evidence that participants in the bland condition thought of the animals in a more abstract way than participants in the rich condition.

8.3 | Learning

We analyzed the data using the same model as in Study 1, but we eliminated the participants who got all four labels wrong (*N* = 22). The model summary is presented in Table 1. As in Study 1, participants had a higher probability of endorsing metamorphosis at posttest than at pretest. Participants endorsed metamorphosis for ladybugs an average of 1.59 times (*SD* = 1.31) at pretest and 3.43 times (*SD* = 1.01) at posttest (out of four possible). As in Study 1, we did not find an effect of diagram condition, or an interaction between diagram condition and test time for the learning items. Thus, as predicted, and replicating Study 1, both diagrams led to similar amounts of learning. We also found that the more labels that participants recalled, the more likely they were to endorse metamorphosis for ladybugs. No other effects were significant.

8.4 | Transfer

We analyzed the data using the same model as in Study 1, including general labels as a predictor, and we eliminated participants who got all four labels wrong. The model summary is presented in Table 2. In line with our predictions and with Study 1, there was a main effect of diagram condition on participants' likelihood of endorsing metamorphosis for the non-ladybug insect (transfer) items. Participants who received the lesson with the bland diagram (*M* = 8.07 endorsements out of 10 possible, *SD* = 1.52) were more likely to endorse metamorphosis than participants who received the lesson with a rich diagram (*M* = 7.54 endorsements out of 10 possible, *SD* = 1.87). There was also a significant effect of pretest scores, such that those who made more correct endorsements at pretest were more likely to endorse metamorphosis for the transfer items. However, contrary to our prediction, but in line with the results of Study 1, the diagram condition by pretest interaction was not significant; see Figure 5. As in Study 1, there was also an effect of learning. Participants who learned more also transferred more. Unlike Study 1, there was also a diagram condition by learning interaction. For those who received the lesson with the bland diagram, learning was unrelated to transfer, $\chi^2(1, N = 131) = 2.12$, $p = .145$. However, for those who saw the rich diagram, the better their learning, the more they generalized, $\chi^2(1, N = 131) = 19.16$, $p < .001$. Unlike Study 1, participants who used general labels for the adult ladybug did not have a higher likelihood of endorsing metamorphosis for non-ladybug insects, relative to those who used specific labels. There were no other significant effects.

8.5 | Overextension

As in Study 1, participants rarely endorsed the drastic change items for dogs (*M* = 0.05, *SD* = 0.28, out of four possible). More participants endorsed drastic changes for fish (*M* = 0.67, *SD* = 0.96, out of four possible); however, the rate of endorsement was still fairly low (59 participants ever endorsed one of the fish items, and only 23 endorsed more than one). We used a generalized linear mixed-effects model to examine whether participants' endorsement of drastic changes (metamorphosis and species change) for the fish depended on test time (pretest vs. posttest), diagram condition (bland vs. rich), question type (offspring vs. lifespan), and major (non-biology vs. biology). We also explored interactions between diagram condition and test time and diagram condition and major. We included by-subject random intercepts, by-subject random slopes for the effect of question type, and by-subject random slopes for test time. We found that participants were more likely to endorse these drastic life cycle changes at pretest than at posttest, $\chi^2(1, N = 131) = 30.93$, $p < .001$. We did not find this effect of test time in Study 1. This is likely due to participants in Study 2 endorsing drastic life cycle changes at pretest more often than participants in Study 1 (whose endorsements were low even at pretest). We also found that participants were more likely to endorse drastic life cycle changes for the lifespan questions ($M = 1.28$, $SD = 1.08$) than for the offspring questions ($M = 0.79$, $SD = 0.92$), $\chi^2(1, N = 131) = 18.63$, $p < .001$. As in Study 1, the likelihood of overextension at posttest was similar in the bland ($M = 0.56$, $SD = 0.89$) and rich conditions ($M = 0.77$, $SD = 1.02$), $\chi^2(1, N = 131) = 0.73$, $p = .395$. There was also no interaction between diagram condition and test time, $\chi^2(1, N = 131) = 0.84$, $p = .361$. Thus, as in Study 1, participants did not overextend their knowledge of metamorphosis to species that do not undergo this process. In fact, they were less likely to endorse these changes at posttest, but this effect did not vary by condition.

9 | DISCUSSION

This study largely replicated the findings of Study 1, showing once again that participants who viewed the bland diagram exhibited better transfer than those who viewed the rich diagram. Participants' use of general labels, once again, did not vary by diagram condition. Also, as in Study 1, participants rarely overextended the concept of metamorphosis to animals that do not undergo metamorphosis. The rates of overextension were comparable across the two conditions, suggesting that the bland diagram did not lead participants to endorse all possible changes but rather led to an increase in correct generalization. However, there were some concerns with whether participants in this study were paying adequate attention, as they displayed lower recall scores and higher endorsement of non-biological changes than did participants in Study 1.

10 | GENERAL DISCUSSION

In two studies, perceptually rich and bland diagrams lead to substantial learning about the concept of metamorphosis, a counter-intuitive biological process. However, in both studies, participants transferred their knowledge about metamorphosis more when they learned with a bland diagram. The pattern of data was broadly in line with our hypothesis that bland diagrams would be more beneficial for people with low prior knowledge, but neither study showed a reliable interaction of diagram condition and prior knowledge. We also found that few students overgeneralized the concept of metamorphosis to animals, like the fish, which do not undergo this process. The lack of endorsements of metamorphosis for the fish suggests that students were unlikely to overextend their knowledge of metamorphosis. The similar rates of overextension across the two diagram conditions also suggest that the benefit of the bland diagram was not due simply to participants endorsing all forms of change, but rather that they were appropriately generalizing the concept of metamorphosis to animals that they thought were likely to undergo this process (i.e., other insects). Overall, our results suggest that, even in a domain in which concrete details are relevant in order to identify the exemplar used in lessons, omitting these details while using specific labels in the lesson led to similar amounts of learning and better, appropriate transfer.

10.1 | Beneficial effects of perceptual blandness on transfer

Some researchers have argued that bland representations promote transfer because they are more abstract (Kaminski et al., 2008). Applied to the present studies, the basic idea is that the organism depicted in the bland diagram does not look exactly like a ladybug, but instead looks more like a generic or prototypical "bug." Prototypical examples are better at supporting generalizations than are non-prototypical ones (Murphy, 2002; Rips, 1975; Rosch, 1973). Conversely, the perceptually rich ladybug was highly specific, potentially leading participants to believe that the information from the lesson applied only to it, and not to other insects. We asked participants to recall the name of each stage in the diagram, primarily as an immediate recall test. However, we took advantage of this recall test to explore participants' spontaneous use of general labels. Given that the lesson used specific labels, if a participant creates their own general label, this might indicate that they are abstracting away from the specifics of the lesson. This abstraction, as one would expect, was associated with better transfer in Study 1, but the difference in participants' use of general labels was not related to diagram condition. Furthermore, even after controlling for participants' use of general labels, there was still an effect of diagram condition on transfer performance. Of course, participants' use of general labels is an imperfect indicator of how they viewed the exemplar in the lesson, but it is nevertheless suggestive that the effect of perceptual richness might extend beyond abstractness.

One possibility is that the bland diagram might have made it easier for learners to identify the underlying deep structure of the exemplar (i.e., the "insect-ness" of the ladybug). Because the bland diagram has fewer distracting features, such as spots and color, it may have been easier for learners to discern the relevant features of the diagram that are likely to generalize. In turn, the bland diagram might have promoted transfer by allowing learners to more easily identify features of the ladybug that are similar to those of the other insects presented at posttest. According to this view, perceptually bland representations promote transfer by facilitating structure mapping between exemplars and novel items (Gentner, 1983). This perspective also readily explains why we did not see greater overextension—the anatomical structure of the fish and the dog is very different from that of the ladybug and other insects. Perceptually rich diagrams might distract the learners' attention from structural features, hindering transfer. Future studies should examine whether bland representations might lead to overextension for animals that are more similar in structure, such as spiders and centipedes, but that do not go through metamorphosis.

10.2 | Prior knowledge as a moderator

We did not find that the effects of bland versus rich diagrams varied depending on prior knowledge. We expected that learners with low prior knowledge would have had a harder time discerning what information was likely to extend beyond the specific example. Given that the bland diagram omitted irrelevant information, we thought that it would allow these learners to focus on the information that was likely to transfer. Although the overall pattern of the data suggested that this might be the case, we did not find a statistically significant interaction between prior knowledge and diagram richness in either study.

It is worth noting that even at pretest, we also did not find that individuals majoring in biology differed from non-biology majors in their endorsement of metamorphosis. This is in line with prior research (Coley et al., 2017) suggesting that biology majors exhibit patterns of intuitive thinking that are similar to those of people with less biological knowledge.

10.3 | Lifespan versus offspring questions

Surprisingly, in both studies, we found differences in responses to lifespan and offspring questions. At pretest, people made more endorsements overall for lifespan questions than for offspring questions. In Study 1, participants were more likely to endorse metamorphosis for ladybugs on the lifespan questions, and across both studies, participants made more overextensions on the lifespan questions. This suggests that lifespan questions lead to more endorsements, but not necessarily more correct endorsements.

This is an asymmetry that to our knowledge has never been reported in the literature. We did not expect to find a difference between the two question types, as prior work has not reported differences (e.g., French et al., 2018). Therefore, it is possible that this is a spurious finding. However, prior research has focused primarily on children's reasoning, and the present studies focused on adults. It is possible that the distinction between lifespan changes and changes between parents and offspring emerges later in development, once people have a strong basis of biological knowledge. It may be that prior work did not find a difference between the two question types because the participants were children.

Another potential reason for this asymmetry is that the species change items always used an adult form of an animal. In the lifespan questions, this made sense, but in the offspring questions, people might have taken this as a cue to reject the item, because it is unlikely that an animal would have a "baby" that looks like an adult animal.

Although the design of our stimuli might explain why we would see differences between the question types on the species change items, it cannot fully account for the results. There were differences by question type on the other types of changes, as well, albeit smaller ones. One possibility is that people accept a wider range of changes when thinking about how an organism will look when it grows up. Conversely, people might expect that offspring will resemble their parents, and so they may be willing to accept less change when thinking about parents and offspring (Williams, 2012). Another alternative is that our lesson made people more likely to accept any changes throughout the lifespan, but not across generations. Even though the diagram abstractly depicted change across a generation (with an arrow going from the ladybug to the egg), this process was not explicitly described in the lesson. It is possible that our lesson made participants more open to changes throughout the lifespan, but failed to make participants realize that the same process (i.e., metamorphosis) that would make the juvenile forms (i.e., offspring) look different from the adult forms (i.e., parents), also leads to initial differences between parents and offspring. Future research should investigate this possibility further.

10.4 | Online versus in-person learning

Study 1 and 2 together provide important information on differences between online and in-person lessons. We found that, at pretest, participants who completed the study online endorsed the non-biological species change (such as a ladybug having a baby butterfly) more than those who completed the study in-person. This suggests that, at least initially, participants completing the study online may not have been paying adequate attention during the study. However, we also found differences in learning. Immediately after the lesson, when participants were asked to recall the name of each stage, 22 participants who completed the study online (13.75%) provided no accurate labels, while only one participant who completed the study in-person (0.75%) provided no accurate labels. Given that the video lessons were exactly the same, we believe that this difference is due to the participants watching the lesson online. The aim of Study 2 was to check whether our effects were robust to the lack of experimental control present with online samples. We did find that our main findings were robust to this threat to internal validity, but the differences observed between studies might be relevant for instructors and course designers who might be considering online or "flipped" instruction. Given the lack of random assignment to study location, we cannot make any causal claims, and we caution against taking these findings as anything more than suggestive.

10.5 | Implications

This study has some straightforward educational implications. Most importantly, our findings suggest that teachers and textbook writers should pay close attention to the visual representations used in lessons. Although perceptually rich diagrams might capture students' attention and enhance motivation (Durik & Harackiewicz, 2007), one potential cost is that students—especially those with low prior knowledge—may have a harder time discerning the deep structure of the material. Students may be less likely to apply their knowledge to novel exemplars if those exemplars differ substantially from those used in the lesson. Although this could be due to the specific diagrams used in these studies, we argue that the results likely apply to many other diagrams. Our rich diagram is actually fairly sparse, including only information that is relevant to the lesson. Even though the perceptually rich diagram included only relevant details, we still saw that removing them increased generalization. Therefore, we think it is likely that other instantiations of diagrams (such as rich diagrams that have irrelevant information, or bland diagrams that are even less detailed) will lead to similar results. As educators are often less interested in students learning isolated facts than in students generalizing from lessons, it seems that using perceptually bland diagrams might lead to the best outcomes.

However, there might also be a time and place for perceptually rich representations. Some recent work suggests that students exhibit strong transfer when first shown a rich, concrete representation that is then "faded" to a more abstract representation (Fyfe, McNeil, & Borjas, 2015). It is possible that students would have shown even greater transfer, had we shown them the rich diagram followed by the bland diagram. Conversely, teachers could also present several concrete examples followed by an abstract rule such as "all insects go through metamorphosis." Some research (e.g., Gick & Holyoak, 1980, 1983) suggests that this format might be more beneficial for learning than the single-exemplar generalization approach that we took. Future studies should examine how these different approaches compare with one another.

Our studies also have implications for the literature on folk-biological reasoning. Both studies replicate the findings of French et al. (2018) regarding what sorts of biological changes people believe to be possible. The low endorsement of metamorphosis for ladybugs at pretest highlights the counter-intuitive nature of processes like metamorphosis, as even adults who presumably know about metamorphosis in butterflies rarely believed this change to occur in ladybugs.

Previous studies had shown that giving preschool-aged children exposure to animals undergoing metamorphosis, without explicit instruction, does not lead children to generalize the concept of metamorphosis to other animals (Herrmann et al., 2013). In contrast, the current studies show that adult participants are indeed able to generalize counter-intuitive biological concepts such as metamorphosis, if provided direct instruction. Future work should investigate whether direct instruction with bland diagrams can also promote transfer of knowledge about metamorphosis in young children.

Our study also shows that general biological knowledge (as measured by college major) did not predict the extent to which students generalize counter-intuitive information. However, knowledge about the focal topic (i.e., knowledge about biological changes, measured at pretest) did predict transfer in both studies. Future research that uses a less crude measure of general biological knowledge, such as biology course work, might bring more light to this finding.

10.6 | Limitations

Some limitations of the current study should be highlighted. Our participants had presumably received lessons on metamorphosis in elementary school, and yet many of them had forgotten what they had learned. It is possible that the effects of our manipulation are short-term, and that these participants will not endorse metamorphosis for ladybugs or other insects in the future. If adults return to not endorsing metamorphosis as a possible biological change for most insects, it would suggest that there is a relatively strong tendency to reject drastic life cycle changes (French et al., 2018).

It remains an open question how the perceptual richness of life cycle diagrams would affect learners who have had no formal instruction on metamorphosis, such as children in elementary school. According to the Next Generation Science Standards, children should learn about metamorphosis by third grade (NRC, 2014). It is unclear how first- and second-grade students, who have not learned about metamorphosis in school, will learn from diagrams with differing amounts of perceptual detail. On one hand, given that children in these grades have had very little formal biology education, one could expect that they would benefit most from the bland diagram. On the other hand, some studies have found that children perform better with richer, more interesting visual representations, because they increase motivation and thereby improve learning (Durik & Harackiewicz, 2007). The effects of perceptually rich representations on motivation might be less pronounced with adults, given that they have likely had more exposure to bland diagrams (Wiley, Sarmento, Griffin, & Hinze, 2017).

Finally, this study does not pinpoint the mechanism for why bland representations promote transfer more than richer representations. Our findings do not align with the seductive details effect, as the rich diagram included only relevant details. But our results might be compatible with multiple other possibilities, such as differences in the level of abstractness and motivational factors. Future research should evaluate these and other plausible mediating factors, so as to elucidate the mechanisms through which perceptual richness influences transfer.

10.7 | Conclusion

This research demonstrates that bland diagrams can have beneficial effects for transfer, both in an online and an in-person setting. This research further suggests that bland diagrams do not lead learners to overgeneralize their new knowledge to items for which it is not appropriate. Instead, bland diagrams lead learners to endorse metamorphosis as a plausible biological change for animals that undergo this change, without reducing their endorsement of other, biologically correct types of change. These studies also suggest that the effects of perceptual richness on transfer are not due to participants thinking of the exemplar in the lesson in a more abstract way. In sum, in these studies, perceptually bland diagrams enhanced transfer without hindering learning or leading to overextension; thus, bland diagrams yielded better performance than rich diagrams, even though the rich detail was relevant to the task at hand. Lessons that involve bland representations may be optimal for student learning and transfer.

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CONFLICT OF INTEREST

There are no conflicts of interest.

DATA AVAILABILITY STATEMENT

De-identified data and our analysis script can be found in https://osf.io/f459n/ .

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APPENDIX A

"Animals change a lot throughout their lives. All animals grow. Some animals change in other ways, as well. For example, some grow hair, some change the color of their skin or their hair, and some go through metamorphosis. Metamorphosis is big change in the form of the animal's body. For example, metamorphosis may involve growing new body parts like antennae or wings. Many animals go through metamorphosis.

Let us look at ladybugs as an example. Like all other insects, ladybugs hatch from eggs. But when they first come out of the egg they do not look like the adult ladybugs you see outside. They look kind of like a worm. At this stage, we call them larvae. Larvae move around looking for food. Larvae grow and grow and when they are almost fully grown they attach themselves to a plant. They cover themselves with tough skin. At this stage, we call them pupa. Inside the pupa, the ladybug's body is rounding out and it is growing wings. After 5 days, the pupa splits open and the adult ladybug comes out. After a few hours when the ladybug dries, it is finally able to fly. After some time, the ladybug finds another ladybug to mate with. The female lays the eggs and the cycle starts again!

So that is the life cycle of a ladybug."