

Life Spirals: A Critique of Life Cycle Diagrams

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Life cycle diagrams are ubiquitous in a variety of scientific materials, ranging from introductory biology textbooks to professional publications. These diagrams typically depict stages of a particular organism's life connected by arrows, such as, for a frog: egg(s) → embryo → tadpole → tadpole with two legs → tadpole with four legs → young frog → adult frog → egg(s). In this paper, we present a critique of this sort of life cycle diagram, drawing on both metaphysics and epistemology of science. We suggest that these diagrams do not accurately represent an organism's life stages, its reproduction, or species persistence. These misrepresentations have implications for scientific reasoning, explanatory efficacy, and pedagogical efficacy. To address the shortcomings of these diagrams, we propose a new kind of diagram which we call the life spiral diagram. The life spiral diagram more accurately reflects an organism's life stages, its reproduction, and species persistence. Thus, the life spiral diagram better aids scientific reasoning, explanations of life processes, and learning.

Keywords

life cycle diagram • circularity • life stages • reproduction • species persistence • life spiral diagram

1. Introduction

Life cycle diagrams are ubiquitous in a variety of scientific materials, from introductory textbooks and online educational materials to recent publications in professional journals. These diagrams generally appear to depict stages of a particular organism's life.¹ The stages are usually connected by arrows, such as, for a frog: egg(s) → embryo → tadpole → tadpole with two legs → tadpole with four legs → young frog → adult frog → egg(s). Life cycle diagrams are used to depict not only familiar vertebrates such as frogs and people, but also fungi (Qin and Feng

1. Outside the scope of our argument are diagrams of the "life cycles" of things that aren't alive, from viruses (which are generally considered to be biological but not alive) to things which aren't biological at all such as solar panels or stars.

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2022), plants (e.g., many in Reece et al. 2019), invertebrates such as mosquitos (fig. 1), and microbial collectives such as biofilms (Lazarus et al. 2024).

In this paper, we develop a critique of the most common type of life cycle diagram, drawing on the metaphysics and epistemology of science. While there is no clear consensus about what such diagrams purport to represent, there appear to be three possibilities: the life stages of organisms (Menendez et al. 2020), organismal reproduction (Reece et al. 2019; Rye et al. 2016), or species persistence (Alexander 1968; Fauchald 1983; de Pinna 1999). We argue that these life cycle diagrams don't accurately represent any of these phenomena. This is because the diagrams suggest that the depicted organisms are immortal (see sec. 2.1). But mortality is critical for making sense of organismal life stages, of organismal reproduction, and of species persistence. We therefore propose a new sort of diagram: the *life spiral diagram*. Our proposed diagram depicts organisms as mortal, and more accurately represents an organism's life stages, its reproduction, and species persistence. In this case, the life spiral diagram is a better aid for scientific reasoning, for explanation, and for pedagogical purposes than is the most common type of life cycle diagram.

2. Critique of Life Cycle Diagrams

2.1. The Problem of Immortality

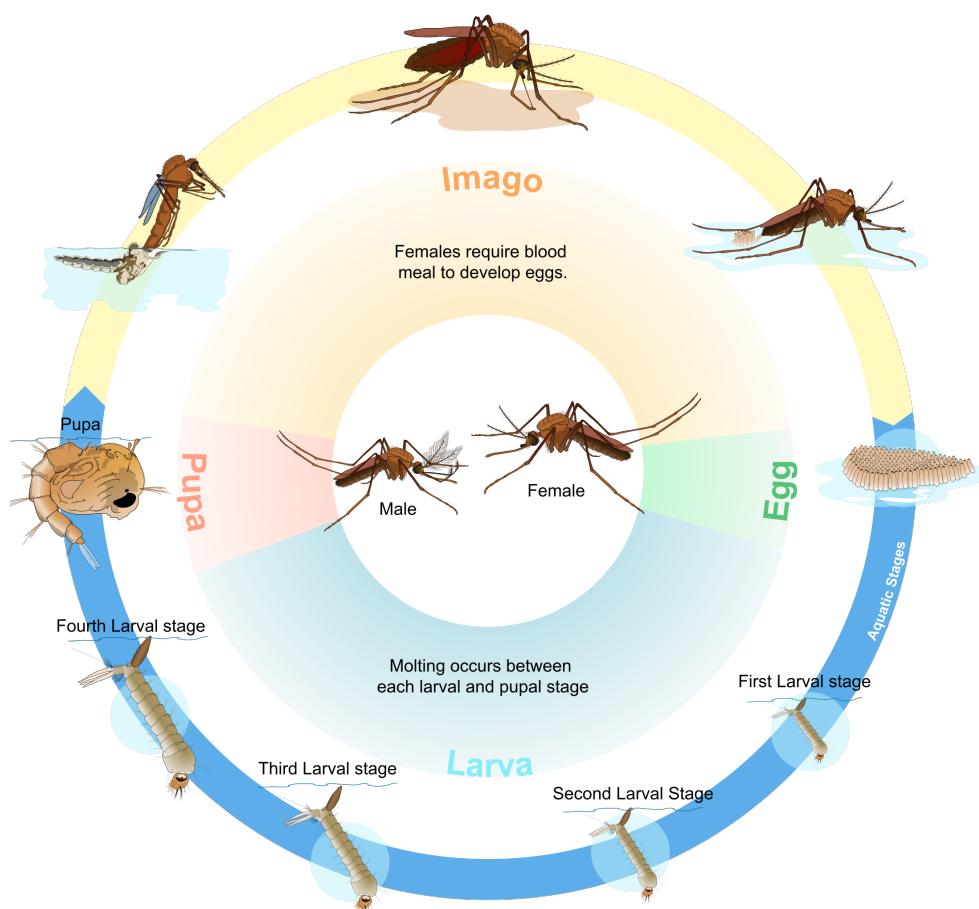


Figure 1: Typical life cycle diagram (by Mariana Ruiz Villarreal; Public Domain, <https://commons.wikimedia.org/w/index.php?curid=10071475>)

A typical life cycle diagram is found in figure 1. This diagram depicts a mosquito at different stages of development and maturity, using arrows to show development or maturation over a period of time (and suggesting the order of developmental stages and stages of maturation). Assuming that both the blue and yellow arrows symbolize the development (or maturation) over time of a particular organism, the diagram suggests that the depicted organism is immortal. This is because the adult mosquito is shown to lay the very eggs that turn into *it* in perpetuity!² In other words: rather than reproducing or dying, the diagram suggests that an adult *becomes* its eggs. This problem arises because of the closed loop created by the diagram's blue and yellow arrows. While not all life cycle diagrams employ closed loops, the vast majority do. David Menendez and colleagues surveyed several hundred life cycle diagrams from books and online sources and found that a majority are circular (81%); of those circular diagrams nearly all (99%) employ closed loops (Menendez et al. 2020). The implication of immortality leads to a number of problems, each of which takes a different form depending on what one takes life cycle diagrams to represent.³

Admittedly, the diagram is vague with regard to what the arrows represent; the particular diagram in figure 1 has no legend, and we have simply attributed a meaning to its arrows (that they symbolize the development [or maturation] over time of a particular organism). Even if the meaning we have attributed to it is not correct, however, presumably a diagram must symbolize change over time in a given entity differently than it symbolizes a change from one entity to another (of that same kind).⁴ In biology, this reflects the basic distinction between growth and reproduction. Furthermore, nothing about the symbols themselves (i.e., the arrows) suggests that different placements of the mosquito image relative to the arrows preserves this distinction. And even if the mosquito images were labeled numerically in sequential order as well as labeled with the particular life stage that they reflect, the diagram would still suggest that an adult organism gives rise to itself in perpetuity, and that it turns into its embryonic form.

2.2. Life Cycle Diagrams Purport to Represent Life Stages

Some claim that life cycle diagrams represent the important life stages of organisms: "...the primary purpose of life cycle diagrams is to show the different life stages of an organism" (Menendez et al. 2020, 4). If this is correct, then they should also show death, otherwise the mature stage is represented as continuing indefinitely.⁵ Indeed, without death, it would be difficult to make sense of what is meant by *life* stages; in other words, life, and its stages, can only be defined in contrast to death. Depicting the end of the mature life stage could be accomplished by opening what is currently shown as a closed loop in figure 1 and showing the disintegration and decomposition of the organism. The crucial insight here is that a single life – lived by a

2. This is setting aside the issue of the numerical identity of each of the bunch of (fertilized) eggs relative to a single mosquito.

3. Although linear life cycle diagrams will be briefly discussed in sec. 3, we focus on circular diagrams given that they remain the most common format for depictions of life cycles since the 1950s. For a short history of the emergence of circular life cycle diagrams, see Landin and Cozart (2024, 2–3). If linear or other open-loop life cycle diagrams do not purport to represent organismal reproduction or species persistence, and purport to represent organismal life stages only, then they are not subject to the critiques we make of typical life cycle diagrams in sec. 2.3 or sec. 2.4. However, we give some reasons for preferring life spiral diagrams over linear or other open-loop life cycle diagrams in sec. 3.2.

4. This raises the question of how to demarcate an entity's boundaries, a perennial ontological issue we cannot hope to settle here. Different ontological commitments about what is being represented may suggest the need for different diagrams, although this is not clear.

5. The death of an organism can occur at any stage of life, and thereby reflect the end of any life stage. For simplicity, we discuss it as the end of the mature life stage only.

single organism – doesn't actually "cycle." An organism comes into existence – once, carries out its life activities, and then dies – once. Strictly speaking, then, there is actually no such thing as a "life cycle"! We acknowledge that a small percentage of diagrams do display an open "cycle" or depict the end of the mature life stage (see Menendez et al. 2020), thereby avoiding the implication of immortality. The majority of life cycle diagrams, however, omit these and present a closed loop, implying the immortality of the organism in question. In so doing, they are not representative of an organism's important life stages, because the final stage is shown to continue indefinitely.

2.3. *Life Cycle Diagrams Purport to Show Reproduction*

Elsewhere, scholars have defined life cycles as centered on organismal reproduction. Here is the definition from a major biology textbook: "A life cycle is the generation-to-generation sequence of stages in the reproductive history of an organism, from conception to production of its own offspring" (Reece et al. 2019, 254). An open source, online textbook defines a life cycle as follows: "the sequence of events in the development of an organism and the production of cells that produce offspring" (Rye et al. 2016).

Both of these definitions foreground reproduction. From this perspective, life cycle diagrams are plausibly supposed to show how an organism reproduces. But by implying that organisms are immortal, most life cycle diagrams don't, in fact, show this. We set aside that gamete production, their fusion, and genetic recombination are not shown in the mosquito life cycle diagram (fig. 1), because diagrams may legitimately make omissions in the interest of simplicity. But the diagram implies that an organism is turning from an adult stage back into its egg stage in an effort to show reproduction. Yet this is *not* reproduction. While organisms may reproduce many times, they generally don't return to embryonic stages in order to do so.

This criticism is based on the assumption made above that the blue and yellow arrows in figure 1 both symbolize development (or maturation) over time. Even if a different symbol was used for reproduction than for development or maturation, and equivocation about what the arrows represent thereby avoided, the diagram would still be inaccurate because it remains false that an organism reproduces its very self.⁶ While Menendez and colleagues gesture at this problem by pointing out that life cycle diagrams fail to suggest phenotypic variation of offspring from parents (Menendez et al. 2020, 4), they don't explicitly identify the overarching problem that we do: that life cycle diagrams are not, in fact, depicting reproduction at all.

2.4. *Life Cycle Diagrams Purport to Show Species Persistence*

Finally, although much less typical than the above two interpretations, some scholars suggest that life cycle diagrams depict species persistence (Alexander 1968; Fauchald 1983; de Pinna 1999). On this interpretation, the function of life cycle diagrams is to illustrate the mechanism by which species (or populations, or lineages) endure through time: they do so through the reproduction of new member organisms. A view of life cycle diagrams understood as depicting species persistence shares important similarities with life cycle diagrams understood as depicting reproduction. Whereas the latter merely attempt to illustrate the progressive stages of reproduction, the former use reproductive stages as a means to make a broader point about

6. Our critique of life cycle diagrams does not apply to diagrams of asexually reproducing organisms because it may be argued that they do, in some sense, reproduce "themselves" given that they reproduce by cloning (see Merricks 1998). Critiquing life cycle diagrams that depict asexually reproducing organisms would require a different argument, one that rests on a commitment about whether or not cloned individuals are identical with their progenitors.

the continuation of a species through time. In other words, a focus on reproduction primarily draws attention to the level of the individual organism while a focus on species persistence draws attention to the species level.

There are two problems with life cycle diagrams insofar as they are meant to portray species persistence. The first is a version of the reproduction problem: because life cycle diagrams are often illustrated as closed loops, species are portrayed as persisting through the immortality of their member organisms, rather than by reproducing new individuals. Given that these diagrams do not actually show the reproduction of new individuals, they cannot show how species persist.

But there is another problem. Because closed-loop diagrams imply that newly reproduced individual organisms are identical to their parents (or, worse, that they *are* their parents), these diagrams are incompatible with evolutionary theory, which is crucial to understanding species persistence. Given that all individual organisms eventually die, i.e., the mature life stage does not continue indefinitely, a species cannot persist unless member organisms reproduce *new* organisms, which generally outlive their parents and may go on to reproduce more new organisms. The process of adaptation is made possible through the emergence of successive generations whose members *vary* from those of previous generations. But variation between generations cannot be depicted by a closed-loop diagram (Menendez et al. 2020). Since life cycle diagrams are often illustrated as closed loops, they cannot properly depict the means by which species persist through time. Furthermore, they suggest that species, not just organisms, are likewise immortal, since extinction does not appear to be a possibility.

3. Life Spiral Diagrams

3.1. Introducing the Life Spiral Diagram

Given these problems, we've developed a new type of diagram which we call a *life spiral diagram* (figure 2). Unlike typical life cycle diagrams, the life spiral diagram shows organismal mortality. In a life spiral diagram, a mature organism gives rise to offspring which are numerically distinct from it and which eventually die, thus avoiding the implication of organismal or species immortality typical of life cycle diagrams. Therefore, it better represents an organism's life stages, its reproduction, and species persistence.

The life spiral diagram represents organisms' mortality by depicting death with the skull and crossbones symbol. It thereby captures an important fact about the mature life stage of the organism: its end. (As noted in footnote 5, death may occur at any life stage.) The outward spiraling of the life stage progression gives a better depiction of organismal and species change over time. We used different colors to depict individual organisms which stand in parent-offspring relationships, as well as using numbers as labels for successive generations, and letters to label life stages (see fig. 2). For instance, the first-generation mature frog is labeled (1d): 1 for the generation, and *d* for the adult stage of life. Adult frogs give rise to the second generation by producing gametes which join to produce a new fertilized egg (2a), where 2 designates the second generation while *a* designates a single-celled stage of life. More letters can be added as needed whenever it is desirable to depict a greater number of intermediate organismal stages.

In addition to showing important life stages, the life spiral diagram uses different kinds of arrows to represent different relations between the pictured frogs: solid arrows for development (or maturation) over time, and dashed arrows for the production of gametes and their fusion (i.e., reproduction). Thus, it also shows organismal reproduction and species persistence; the production of new organisms is the means by which species persist. In contrast, the parent-offspring relationship is not shown in the closed-loop life cycle diagram because all life stages

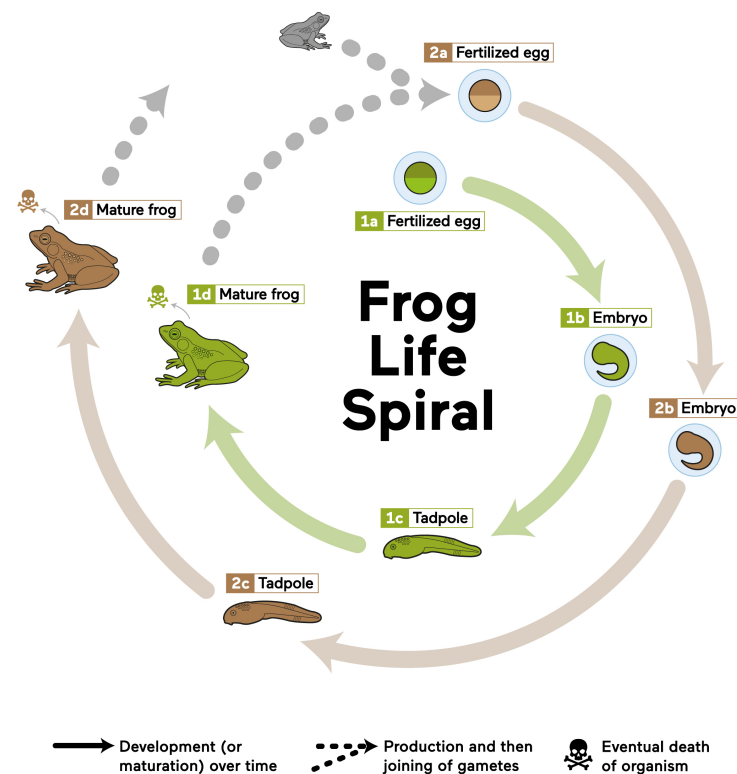


Figure 2: Example of a life spiral diagram. Created by the authors and Dave Boudreau.

are both parent *and* offspring!

3.2. Responses to Potential Objections

One might object that a more accurate and helpful depiction of life stages, reproduction, and species persistence can be illustrated without anything as fanciful as a spiral: linear diagrams, or even non-closed circular diagrams, solve some of the problems that we have identified here. Jennifer Landin and Abigail Cozart recently showed that presenting students with linear life cycle diagrams makes a substantial difference in resolving misconceptions in ecology and evolution (2024, 15–16). They found that such misconceptions commonly result from student (mis)interpretations of circular, closed-loop life cycle diagrams. Although it is true that non-closed diagrams, be they linear or circular, avoid the problem of implying organismal immortality, we maintain that the spiral diagram has other advantages. Unlike the linear diagram, the spiral diagram captures fact that life stages generally repeat *across* individual organisms (i.e., it shows reproduction and species persistence in addition to life stages); we return to this point below. Unlike a non-closed circular diagram, the spiral diagram can indicate generational turnover, a feature which, as we have noted, is essential to understanding evolution and species persistence.

Another worry about the life spiral diagram is that it might include too much detail, introducing extraneous information into the diagram. Why add a second generation of organisms when you can just draw an arrow back to the first? We hope to have convinced you in the critique above of the problems that occur in the diagrams that suggest immortality, but here's another consideration: while life cycle diagrams do appear in professional venues such as journal articles, they are most widely used in pedagogical materials such as textbooks and school lesson

plans. Given pedagogical aims, we can ask what tradeoffs between detail and explanatory clarity are legitimate. We think that life spiral diagrams not only more accurately represent whatever one takes life cycle diagrams to show, but also that they add details which may help students gain a deeper understanding of the biological world. Notably, Sisk-Hilton, Metz, and Berson already suggested that a version of a life spiral sketch can be used to teach children about trait variation across generations (2018, 31). While their explicit goal was to teach the process of natural selection, Sisk-Hilton and colleagues correctly note that this requires representations that distinguish generations (2018, 31). Here, we have diagnosed the fundamental problem in most life cycle diagrams – the implication of immortality – that underlies the failure to distinguish generations, and that leads to confusions about such biological processes. We argue for the use of life spiral diagrams, which can take either the form we or Sisk-Hilton and colleagues present.⁷ We note, however, that Sisk-Hilton and colleagues' representation suggests asexual reproduction in sexually reproducing species (crickets) – a problem which our diagram avoids.

Furthermore, diagrams that are intended as pedagogical aids shouldn't assume that students – young ones in particular – already know about the very phenomena the diagrams purport to teach. For instance, if a student doesn't already know that species persist through the reproduction of new members, they wouldn't learn it from a typical life cycle diagram. With typical life cycle diagrams the burden is put on the student to supply assumptions that *contradict* what the diagrams actually convey in order to arrive at an accurate understanding of the phenomena the diagrams purport to represent.

Menendez and colleagues write that, to their knowledge, “spatial arrangement has never been [experimentally] investigated with life cycle diagrams” in the context of educational pedagogy (2020, 12). Landin and Cozart's recent study is the first, to our knowledge, to do so (2024). Spatial arrangement (what they call “layout”) is one of the independent variables under consideration. They find that students shown a linear life cycle diagram, as compared to a circular one, were better able to answer questions about organismal survival, variation among offspring, and variation between generations. In addition, they found that diagrams depicting multiple offspring prompted more correct responses to questions about ecology and evolution. These data support the idea that small changes in diagram design can have an impact on education, as was suggested by Menendez and colleagues' review of the related literature. We therefore suggest that our life spiral design may also better support student learning, although this would require experimental study.

Despite this point about pedagogical consequences, our central critique remains that life cycle diagrams fail *on their own terms*. Scholars claim, or at least suggest, that the goals of the diagrams are to represent particular biological phenomena: life stages, reproduction, or species persistence. The closed-loop diagrams do not do that. The problem of representation is related to the pedagogical problem, however: were the diagrams to accurately represent these phenomena, they might better meet pedagogical aims. Of course, the diagrams may need to do more than represent phenomena accurately in order to do so; we leave this adjudicated. Accurate representation is a necessary but not sufficient feature of effective pedagogical aids.

Another potential objection to our critique of life cycle diagrams is that, despite scholars' claims about what life cycle diagrams show, what they really show is the fact that species' member organisms undergo *the same* life stages. In other words, perhaps life cycle diagrams aim to show

7. Sisk-Hilton and colleagues' version of the life spiral diagram differs from ours in that it takes the shape of a cylindrical helix, while ours (intuitively, though not formally) takes the shape of a conical spiral, both viewed from particular, respective angles. The evaluation of this difference is beyond the scope of our argument, and we await critical analysis or experimental investigation of this difference. We have chosen not to use the shape of a cylindrical helix in forming our diagram simply because of space considerations in fitting in our needed elements.

the repetition or regularity of life stages in a species' member organisms. But even if this were the case, the life spiral diagram does a better job than life cycle diagrams because it shows more than one generation of organisms instantiating each life stage. Showing only one member organism of a species, as life cycle diagrams typically do, fails to suggest that all members generally undergo the depicted life stages. And interpreting life cycle diagrams as depicting particular species means that nothing about its individual organisms, including repeating life stages, can be shown. These problems arise because life cycle diagrams appear to collapse the distinction between an individual organism and a species.

Said differently, a proponent of closed-loop life cycle diagrams might defend the omission of death by claiming that such an omission doesn't necessarily suggest immortality: surely those viewing diagrams, even children, can be expected to know that living beings are not immortal. To this objection we offer the following reply. Even if it were innocent to omit death, typical life cycle diagrams still depict an arrow from the mature stage back to the embryonic stage. If life cycle diagrams are a kind of phase portrait diagram, then the arrow from mature stage back to embryonic stage suggests that there are intermediate phases through which the organism passes. But that is not the case. There is no intermediate "frog-egg." Thus, understood as a phase portrait, life cycle diagrams still misrepresent their target (whatever that may be) if they include the arrow which closes the loop.

We wish to consider one final potential objection. More accurate representation is not necessarily valuable for its own sake, especially in light of the fact that some diagram omissions are deliberate and strategic (see Perini 2013; Shin, Lemon, and Mumma 2018). A defender of the 'life stages' view of life cycle diagrams, for instance, may object to our critique by claiming that the omission of death as the end of the mature life stage reflects a fair idealization. Diagrams idealize and abstract from the phenomena they represent, and the omission of detail can enhance the representational power of diagrams. If life cycle diagrams show the life stages of organisms, then the omission of death might just be such an omission. But the important roles of diagrams in general should not be forgotten. Scholars have noted that diagrams in general serve as facilitators of scientific reasoning (Perini 2013; Sheredos et al. 2013; Abrahamsen and Bechtel 2015; Kembhavi et al. 2016, 236), as explanatory tools (Abrahamsen and Bechtel 2015; Abrahamsen, Sheredos, and Bechtel 2017), and as pedagogical aids (Menendez et al. 2020; Tversky 2011; Wood and Stocklmayer 2020), among other potential purposes. Presumably, to meet these goals, life cycle diagrams should not imply immortality, for this makes them misleading. If life cycle diagrams are taken to represent life stages without showing the end of the mature stage of life, they cannot aid very well in scientific reasoning, for one may not be able to model population growth and decline without accounting for death; they cannot aid in explanations well, for one may not be able to give a coherent reason why organisms reproduce at all; and they may not serve as effective pedagogical tools, for unless one already knows or assumes that organisms die, one would not learn it from a typical life cycle diagram. Life spiral diagrams, which show mortality, are not misleading in the above ways, and can therefore better serve the general purposes of diagrams.

4. Conclusion

Life *spiral* diagrams are therefore more successful than typical life *cycle* diagrams. This conclusion follows if successful diagrams best (or better) capture the important features of the target phenomenon that they purport to represent. And life spiral diagrams capture an organism's life stages, organismal reproduction, and species persistence better than do most life cycle diagrams.

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