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CURRICULUM ARTICLE

"Force-Talk" in Evolutionary Explanation: Metaphors and Misconceptions

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Abstract The notion of "pressure" as an evolutionary "force" that "causes" evolution is a pervasive linguistic feature of biology textbooks, journal articles, and student explanatory discourse. We investigated the consequences of using a textbook and curriculum that incorporate so-called force-talk. We examined the frequency with which biology majors spontaneously used notions of evolutionary "pressures" in their explanations, students' definitions and explanations of what they meant when they used pressures, and the structure of explanatory models that incorporated evolutionary pressures and forces. We found that 12–20 percent of undergraduates spontaneously used "pressures" and/or "forces" as explanatory factors but significantly more often in trait gain scenarios than in trait loss scenarios. The majority of explanations using "force-talk" were characterized by faulty evolutionary reasoning. We discuss the conceptual similarity between faulty notions of evolutionary pressures and linguists' force-dynamic models of everyday reasoning and ultimately question the appropriateness of force-talk in evolution education.

Keywords Evolution · Education · Force-dynamic reasoning · Misconceptions · Pressure

Natural selection is an important thread within the causal fabric of a scientific worldview, tying together numerous biological disciplines and theoretical frameworks (Dobzhansky 1973; Huxley 2010). More than a century of educational efforts in evolution education have revealed a diverse array of tenacious and pervasive misconceptions about natural selection, evolution, and the nature of science (reviewed in Nehm and Schonfeld 2007). Furthermore, biology students and teachers often lack (or reject) a naturalistic scientific worldview (Evans et al. 2010), fail to adopt evolution as a conceptual organizer for the life sciences (Nehm et al. 2009), and utilize faulty evolutionary reasoning patterns (teleology, essentialism, and intentionality) characteristic of young children (Sinatra et al. 2008). One aspect of evolution education that has received comparatively less attention is the role that language and discourse practices play in the formulation of mental models of evolutionary causation (Lemke 1990; Pinker 2009).

While written and spoken language are necessary components of science learning and meaning making (Kaplan et al. 2009), the path from intended meaning(s) to subsequent interpretation of scientific terms may be remarkably circuitous (Lemke 1990). "Select," "adapt," and "fit"—so-called multivalent terms or homonyms—are ubiquitous elements of evolutionary language as a consequence of their recruitment from ordinary discourse (Goudge 1967; Ryan 1985; Wandersee 1988). The same word—"adapt," for example—typically refers to very different processes depending on its location within formal scientific vs. everyday language. To the frustration of many students, the multiple meanings of scientific terms are often subtle, implicit, and undefined (Ryan 1985).

Empirical studies of biological language have documented the remarkable diversity that single words or terms may be used to represent. Pitombo et al. (2008), for

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example, recently examined scientific discourse practices within genetics, specifically examining the utilization of gene concepts and ideas of gene function in biology textbooks. Through careful analysis of semantic context, Pitombo et al. documented more than eight different intended meanings of the term "gene function." While experts may be able to effortlessly differentiate such multiple meanings, the question remains as to whether the same may be said of students. Research in several domains, including science, mathematics, and statistics, suggests that they cannot (e.g., Wandersee 1988; Lemke 1990; Durkin and Shire 1991; Kaplan et al. 2009).

The field of evolutionary biology is not unique in having co-opted many common-use terms, such as "selection," "adaptation," "competition," "fitness," and "pressure." But such practices are not without risk. As Goudge (1967, p. 15) warns, "Practitioners, in searching for ways of expressing new facts and stating new conclusions, frequently mingle figurative and non-figurative forms of speech… What is important, of course, is not to confuse figurative expressions with those that are literal or technical. Otherwise, misconceptions easily arise." Indeed, to what extent is lexical ambiguity—coupled with the mixing of scientific and everyday discourse practices—to blame for the absence of anticipated conceptual progress following undergraduate biology coursework (e.g., Nehm and Reilly 2007)? Careful scrutiny of evolutionary language and content—and analyses of their relationships to evolutionary thinking—hold great promise for elucidating how discourse practices may facilitate or constrain student mental models of biological causation.

Our study investigates evolutionary discourse practices associated with the notion that "pressures" are evolutionary "forces" that "cause" evolutionary change. So-called force-talk (Brunnander 2007) has become a common linguistic feature and conceptual component of scientific evolutionary discourse, and we investigate the consequences of using force-talk in evolution education. Specifically, following a biology course designed around evolution as the core idea, we examine (1) the frequency with which students spontaneously use notions of evolutionary "pressures" in their evolutionary explanations, (2) students' definitions and explanations of what they mean when they use the terms "pressures" and "forces," and (3) the structure of evolutionary reasoning models that use "force-talk."

Sample and Curriculum

Our sample included 266 undergraduate students intending to pursue biology-related careers who were about to complete the second quarter of an introductory biology sequence for majors at a large public research university in the Midwestern United States. The average age of participants was 21.4, with 51 percent of the sample female. Non-Hispanic Whites comprised the majority of the sample (73 percent), with 27 percent minority (African-American, Latino/a, Asian, and Native American). The average course grade (on a 4.0 scale) was 2.57, and participation consent was >80 percent.

The course instructor used evolution as a core theme and required the use of the Campbell and Reece (2008) textbook, which employed evolutionary "pressure" and/or "force" concepts much more commonly than the other two bestsellers (Freeman 2008; Sadava et al. 2008; see Nehm et al. 2009). Campbell and Reece (2008) employed pressure-related evolutionary language on pages 480, 485, 495, 506, 523, 540, 730, 709, 804–5, 1134, 1141, 1180, and 1230. At no point in the text were such "pressures" and "forces" defined. However, Campbell and Reece (2008, p. 540) did distinguish the concepts of natural selection and evolutionary pressures: "As you read in Chapter 22, convergent evolution occurs when similar environmental pressures *and* natural selection produce similar (analogous) adaptations in organisms from different evolutionary lineages" (italics our emphasis). Interestingly, the authors differentiated "pressure" as a separate or additional causal agent from natural selection. Regardless, numerous other examples in the text similarly implicate "pressure" as a contributor or cause of evolutionary change, but at no point did the textbook explicitly explain the reason why such pressures were distinguished from (or perhaps part of) the concepts of natural selection and/or genetic drift.

Like Campbell and Reece (2008), the course instructor (who was not aware of our research questions but consented to participation in our study) included many references to selective or evolutionary pressures in her lecture notes. A document review revealed that of the 18 course lectures, 12 (66 percent) made reference to evolutionary pressures. Lecture 2 included three references to evolutionary pressures: (1) "Because the agents of natural selection are selective pressures, such as wind, rainfall, temperature—they are mindless." (2) "Examples of pressures: Water, Aridity/Humidity, Temperature…Predation." (3) "Because selective pressures can operate only on traits that are exhibited (phenotype) not that are invisible." Additionally, lecture 4 noted: "Selection is manifested as a 'pressure' that works in a particular direction the RESULTS of which (on phenotypes) are directional, disruptive, and stabilizing." Numerous other uses of pressures were found, but they expressed ideas similar to those referenced above. Thus, much like the textbook they read, the biology majors in our sample were exposed to "force-talk" as part of their evolution education.

Assessment Methods

Assessing the composition and structure of student knowledge of evolution and natural selection is a complex task known to be influenced by instrument formats, psychometric analysis models, and the contextual features of items (Nehm and Reilly 2007; Nehm and Schonfeld 2008, 2010; Nehm and Ha 2010; see also Chi et al. 1981). Specifically, assessment research in this area has demonstrated that (1) extended open response formats typically have greater fidelity to clinical oral interviews (which are considered to be the "gold standard" in education research) than multiple choice formats (Nehm and Schonfeld 2008) and (2) item contexts, such as the gain or loss of traits, reveal significantly different dimensions (i.e., explanatory elements, "misconceptions," etc.) of evolutionary knowledge (Nehm and Ha 2010).

Building upon these prior findings, we explored undergraduate biology majors' reasoning about the role of "pressure" in evolutionary explanations using a newly developed and validated set of open response items in both evolutionary gain and loss contexts (see Table 1). Responses were gathered using an online survey system conceptualized by the senior author. The system not only captures initial responses to questions in an open-text format, but it also "mines" students' responses (in real time) for designated terms or phrases of interest (such as, in the present study, *pressure/s/ed/ing* and *force/d*). Furthermore, the computer system permits follow-up questions to be asked of particular individuals based upon their initial spontaneous responses. For students who spontaneously (i.e., unprompted) used force-talk in their evolutionary explanations, we asked them to explain what they meant when they used it. Our student response data therefore consist of (1) initial and (2) follow-up responses about pressure-related text among evolutionary gain and loss scenarios. Approximately 1,000 responses (505 from evolutionary trait gain items and 497 from loss items) were gathered and analyzed from our student sample.

In order to analyze the composition and structure of students' explanations involving evolutionary forces and pressure, we first atomized responses into a comprehensive set of scientifically accurate and/or inaccurate elements, including (1) pressure concepts (pressure, force(s), selective pressure, environmental pressure, natural pressure, etc.); (2) trait (or character state) change; (3) mutation and/or variation; (4) goals, needs, use, and adapting (i.e., acclimating); (5) adaptation (i.e., a greater fit between phenotypic distribution and the environment); (6) differential survival; (7) evolution or change of the entire species; (8) biotic and/or abiotic factors such as predators/predation, competition, food, habitat, etc.; and (9) favoring or selecting.

Two researchers used an assessment rubric to blindly score all student responses for the presence or absence of these elements (as well as a holistic judgment of the scientific accuracy of each initial and follow-up response). Initial kappa agreement values were >0.75 between raters for all elements and holistic answer scores, and all coding discrepancies were subsequently resolved via deliberation with a third expert rater prior to data analysis. All statistical analyses were performed in PASW (SPSS Inc.).

Table 1 Item prompts

Trait gain	Trait loss	Follow-up questions
A species of snails (animals) is poisonous. How would biologists explain how this species evolved from an ancestral species of snails that was not poisonous?	A species of flightless birds (birds that cannot fly, such as penguins) is closely related to bird species that are able to fly. How would biologists explain how a flightless bird species originated from an ancestral bird species that could fly?	Please explain what you mean by the term "pressure/pressured/pressures/pressuring" and how it fits into your explanation.
Most living oak species (plants) produce nuts. How would biologists explain how an oak tree species with nuts evolved from an ancestral species that did not produce nuts?	Thorns are completely absent in one rose species (plants). How would biologists explain how this thornless species evolved from an ancestral rose species with thorns?	
One species of prosimians (animals) has long tarsi. How would biologists explain how this species with long tarsi evolved from an ancestral species of prosimian that had short tarsi?	In one species of *Suricata* (animals), a pollex is absent. How would biologists explain how the *Suricata* species without a pollex evolved from an ancestral species of *Suricata* with a pollex?	
Dodders, a plant species, have haustoria. How would biologists explain how the dodder species with haustoria evolved from an ancestral species that lacked haustoria?	One species of Labiatae plants is known to lack pulegone. How would biologists explain how this species evolved from a closely related ancestral plant species that had pulegone?	

Note that both gain and loss items included two familiar taxa and traits and two unfamiliar taxa and traits

Results: Student Conceptions of Evolutionary "Pressures"

Much like the Campbell and Reece (2008) textbook, undergraduate biology students used "force-talk" abundantly and in diverse ways in their evolutionary explanations (Fig. 1; Table 2). When asked what they meant when they used pressure or force-related terms in their explanations, many students explicitly noted that pressure was a biological term, as if to emphasize it was an appropriate expression of scientific discourse: "the term pressure is a biological term that causes the…species to evolve" or "A pressure is a biological term which applies to evolution of a species."

Some students considered pressures and forces to be direct causes of death, evolutionary change, or large-scale change: "An environmental pressure...acts on an organism causing it to either evolve or die." Likewise, "Pressures [are] anything that can cause a change in a species…" Some students simply explained evolutionary pressure as an "external force." Just as some responses noted that pressure was a cause of change, the lack of pressure was also envisioned as an explanation for the absence of change: "Pressure is a what promotes change and evolution. Without it no change would be required because there would be no outside force." Thus, pressure is likened to a physical force that directly causes evolutionary change (Fig. 1a, b).

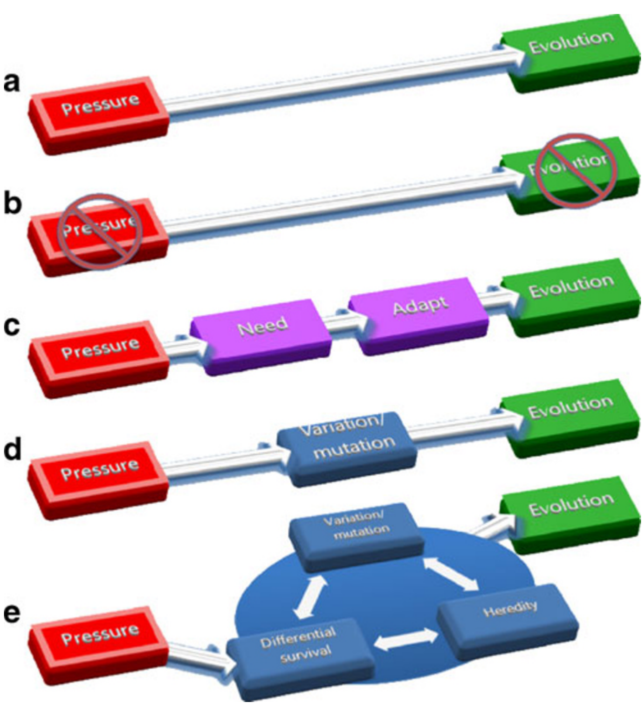

Fig. 1 Models of student conceptions of the role of pressure in evolutionary change: **a** pressure as a direct force that causes evolution; **b** pressure is absent; therefore, evolution does not occur; **c** pressure causes there to be a need to adapt, resulting in evolution; **d** pressure directly causes variation/mutation to occur, resulting in evolution; **e** pressure causes differential survival, contributing to the natural selection model, resulting in evolution

While pressure is discussed as a cause of change, it is often described in only very general or vague terms and is not differentiated from natural selection: "A pressure is something that would influence evolution within a species." In other cases, however, pressure is implicated as a cause of adaptation, acclimation, or adjustment: "Pressure[s] are factors placed on species by something other than themselves that cause species to adapt to their environment." Similarly, "A pressure is something that constantly affects an organism, forcing a change in the organism to adjust. In the example some pressure forced the animal to grow a longer tail over a long period of time." Likewise, "Pressure is something that causes an organism to either change or accommodate its surroundings. The plant was under pressure from predators so in order for survival this plant had to develop over time some type of method for survival, in this case thorns." As one student notes, "it just makes sense" that pressure causes change: "Pressure is the driving force of evolution and natural selection. It makes sense that a force against an organism would cause a change in its character."

The concept of need due to pressure is also discussed as a cause of change. Here pressure is implicated as the cause of the need for adaptation, acclimation, or adjustment: "Environmental pressures include things such as climate and habitat that would cause an animal to need to change something about itself in order to better survive." Similarly, "Pressures are situations that force evolution. The need for food forced the birds to develop the ability to fly at first but when the ability is no longer needed it slowly disappears." (see Fig. 1c).

Other students expressed a different view of pressure that was conceptually (and most likely, accurately) tied to natural selection, in particular to differential survival (Fig. 1e). This view is perhaps the most closely related to a scientific view, in which pressures apparently serve as shorthand for a long list of biotic and biotic factors that account for the differential survival of individuals: "Pressures are different things such as water density, seasons, etc." Similarly, "Environmental pressures are aspects of the environment in which an animal lives that affect its survival and its life." Other students note: "Such pressures [include] lack of water, air quality, amount of sunlight, or even an insect's involvement in the plant's method of reproduction." Likewise, "A pressure is an outside force that causes some organisms to survive more often than others. This aids in natural selection." Perhaps the clearest connection between pressures and differential survival presented by a student was: "Pressure[s] are environmental conditions that are favorable/unfavorable to certain traits, and therefore will

Table 2 Exemplar quotes of inaccurate and accurate pressure use in student explanations of evolutionary pressure

	Student responses	Model (Fig. 1)
Inaccurate use of pressure	The selective pressures on the snail, probably predation in this case, caused the change to come about slowly.	Model A
	Pressure is what promotes change and evolution. Without it, no change would be required because there would be no outside force.	Model B
	A pressure being some outside force that makes the species have to evolve and adapt in order to account for the change.	Model C
	Pressures would be certain forces of nature that results in a mutation and evolution.	Model D
Accurate use of pressure	The term pressure in this instance is referring to the threats posed by predators to their prey. The ancestral species that was lacking poison probably experienced more predation and those that exhibited the poisonous trait were more likely to survive and pass on the useful genes. When I mentioned pressures I am referring to the elements that fuel evolution and allow certain traits to be passed on to future generations. Pressures include temperature, precipitation, predation, etc.	Model E

Responses are linked to the associated model represented in Fig. 1

help/hinder the survival of different organisms with different traits."

Importantly, "force-talk" is not always correctly or reasonably connected to the core or "key concepts" of natural selection (i.e., the causes/presence of variation, heritability, differential survival; see Endler 1986; Nehm and Reilly 2007). For example, some students appear to consider pressures to be the causes of mutations: "Pressures would be certain forces of nature that results in a mutation and evolution in a species" (Fig. 1d). On the other hand, some students consider pressure to act on mutations: "Selective pressures are mindless agents of natural selection that operate on mutations that occur by random chance." And still other students refer to pressure as a favoring mechanism: "The availability of food and resources also is a pressure causing certain mutations to be favored."

The models of explanation discussed in the above sections represent the majority of student definitions of pressure in relation to evolutionary change scenarios. Models A, B, C, and D are considered conceptually problematic, as pressure is a vague and unspecified causal agent of change (Fig. 1). Of the five models we identified, only model E (Fig. 1) clearly and correctly integrates pressure with the core concepts of natural selection. It is important to note that while "pressure" is not a necessary element of evolutionary explanations, when used it should be connected to the core concepts of natural selection in some way.

Students' Evolutionary Explanations Using Pressure Concepts

Quantitative analyses were also used to determine the frequency with which undergraduate biology majors spontaneously (i.e., unprompted) used pressure-related ideas in their evolutionary explanations that we documented above. Among the 507 student answers for the trait gain items (e.g., snail poison, oak nuts, etc.), 21.5 percent included examples of "force-talk" (e.g., pressures, forces, selective pressures, etc.). Of these, 14.4 percent were judged to be inaccurate and 7.1 percent were accurate (see methods above and Fig. 1). For trait loss items (e.g., rose thorns, bird flight, etc.), 12.4 percent of the 492 responses included pressure-related concepts. Of these, 9.1 percent were inaccurate and 3.3 percent were accurate.

Overall, quantitative analyses corroborated our qualitative analyses and revealed that pressure-related ideas were relatively common in student explanations of evolutionary change, although much less so in trait loss scenarios than in trait gain scenarios (Fig. 2). Furthermore, the vast majority of evolutionary explanations were erroneous in responses to both gain and loss contexts. Thus, students not only use force-talk to explain evolutionary events, but when they do it tends to be scientifically inaccurate (i.e., Fig. 1a–d).

Discussion

While pressure-related concepts are commonly embedded within the causal discourse about evolutionary change in journal articles, textbooks, magazines, newspapers, websites, and faculty lectures (Tuch and Johnson 2008; Efferson et al. 2008; Campbell and Reece 2008; Wade 2010; PBS 2001), none of the materials that we examined explained how such ideas were related to (or differentiated from) natural selection or genetic drift. This finding motivated our study of students' causal evolutionary explanations and whether they also used such language and what they meant when they used it. This work demonstrated that (post-instruction) many undergraduate biology majors (approximately 20 percent, depending on context) spontaneously employed pressure or force-

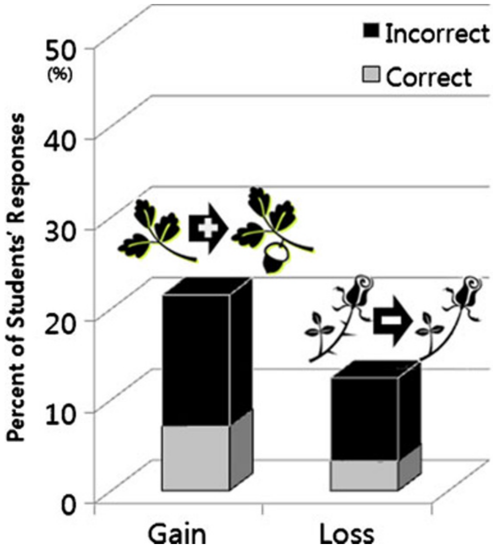

Fig. 2 Percentage of correct and incorrect pressure use in gain and loss items. Students spontaneously (i.e., unprompted) utilized pressure concepts as a component of evolutionary explanations in both gain and loss contexts. Within the context of evolutionary gain, such as the gain of acorns in oak species, 21.5% of students used pressure in their responses. In the context of evolutionary loss, such as the loss of thorns in a rose species, pressure responses constituted 12.4% of the total responses. The majority of student explanations using "pressure" were judged to be incorrect

related concepts in their evolutionary explanations, and the majority of these explanations were scientifically inaccurate and employed naïve biological ideas or "misconceptions." Thus, many students in our sample who are emerging from introductory biology coursework appear confused about what evolutionary pressures are and how they can be appropriately incorporated into causal evolutionary explanations. Whether this finding is a product of the textbook they used (Campbell and Reece); the magazines, newspapers, and websites that they read; the lectures that they attended; or the preconceptions that they held cannot be causally demonstrated in our study.

The important question remains: Why do students form misconceptions about pressure and force in evolutionary explanations? We consider force-dynamic reasoning models to be one likely explanation for the naïve conceptualization of pressure as a causal agent in evolution (Talmy 1988; Pinker 2009: Chapter 4). Cognitive scientists and linguists have demonstrated that so-called force-dynamic models are fundamental to the workings of human language and cognition; they are used to partition and conceptualize how the world works (Talmy 1988; Gunckel et al. 2009; Pinker 2009: Chapter 4). Specifically, force-dynamic reasoning is a mental model common to everyday reasoning that involves the use of causative forces in language to imply a causal relationship between agonists and antagonists in an event (Talmy 1988; Gunckel et al. 2009; Pinker 2009: Chapter 4). Talmy (1988) argued that this model of reasoning is inherent in the grammar of many languages—particularly in verbs and connectives—and is a way in which we view and explain causation (e.g., evolutionary change).

In typical force-dynamic scenarios (Pinker 2009), antagonists (e.g., wind) directly cause changes in the states (e.g., movement) of agonists (e.g., a ball). Such causal scenarios are represented visually in Fig. 3a, c (adapted from Pinker 2009: Chapter 4). In the first example, the intrinsic state of the ball (agonist) is at rest (i.e., not moving up or down the ramp), but when the wind (antagonist) blows in the direction of the ramp, it provides enough force or pressure to move the ball up the ramp (against its intrinsic state at rest). As long as the antagonist (wind) is consistently acting upon the agonist (ball), it will be held at the top of the ramp. Conversely, when the agonist (ball) is not subject to the antagonist's actions (wind), it will roll back down the ramp, at which point it will return to its intrinsic state (at rest). In each of these examples, the movement of the ball—caused by the presence or absence of the antagonist (wind or forces)—results in a change of state of the ball.

Force-dynamic reasoning in evolution is illustrated when causative power is given to pressures, forces, natural selection, or specific abiotic/biotic factors, which by simple logic cannot directly cause an actor to change. This can be seen in Fig. 3b, d, where the rose is analogous to the ball

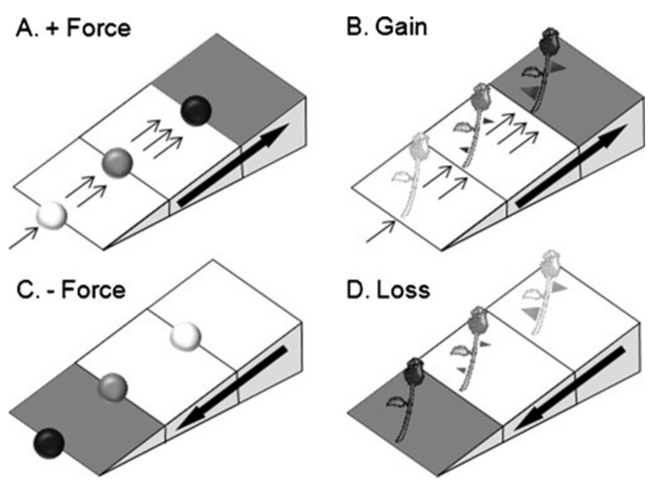

Fig. 3 Force-dynamic models of evolutionary reasoning. Generalized representations of force-dynamic reasoning are exhibited when the presence (**a**) or absence (**c**) of a force causes a change in the state of the object. When a force is present, it causes the ball to roll up the ramp, against its intrinsic tendency (being at rest). In the absence of a the force (**c**), the ball is no longer being pushed up or held on the ramp and so returns to its intrinsic state as it rolls down the ramp. This reasoning can be applied to evolutionary examples such as that shown in the gain (**b**) and loss (**d**) of a trait. In trait gain (**b**), the force is the pressure that causes the development of thorns on roses, whereas in trait loss (**d**), the absence of said pressure causes the loss of the trait (thorns)

(agonist) and pressure is analogous to wind (antagonist). There, the change of state of the agonist (ball movement) is analogous to the evolution of the specified trait (thorn evolution). Following force-dynamic reasoning, when “pressure” acts on the rose (Fig. 3b), students appear to associate the force with a necessary outcome, in this case the development or gain of thorns (analogous to movement, up the ramp). And conversely, when the rose is not subject to pressure (Fig. 3d) or when such pressure is relaxed, students appear to expect the loss of the trait (movement down the ramp, back to the intrinsic state). In these scenarios, evolution does not occur unless an antagonist is added; a force must be present to cause evolutionary features to change, or absent to cause traits to “fade away.”

Student use of force-dynamic reasoning is apparent in evolutionary explanations of trait gain such as, “Increased pressure such as predation would have caused the species of snail to evolve to be poisonous for protection.” In this explanation, the pressure is the antagonist acting directly on the snail (the agonists), causing it to “evolve” (change of intrinsic state) to become poisonous. Notably, such explanations are not multigenerational and do not involve the differential survival of individuals with heritable traits. Similarly, “The older species was able to spread their seeds another way but as the pressures in the environment changed, it became essential that it have seeds…” Here the student uses changes in pressure (the antagonist) as the cause of seed production (change of the intrinsic state) in oaks (the agonist).

Force-dynamic reasoning is also prevalent in students’ evolutionary explanations of trait loss. For example, “Different selective pressures could have forced the ancestral species to evolve a trait for thorns, so biologists could say that a thornless rose evolved from a rose with thorns because the thornless rose may not have been subject to those same pressures as was its ancestor.” In this example, difference of selective pressures (the antagonist) causes the rose (the agonist) to evolve (change intrinsic state of thorns). Likewise, “The flightless birds might [lose] their wings due to environmental pressures that don’t require wings.” Here the student designates environmental pressures (the antagonist) as the cause of wing loss (change of the intrinsic state) in birds (the agonist).

Force-dynamic reasoning was not confined to students’ initial evolutionary explanations; students also used this reasoning when defining what they meant by “pressure.” For example, in a follow-up response clarifying the use of pressure, one student stated: “An environmental pressure that acts on an organism cause[s] it to either evolve or die.” Another student stated: “Pressure [is] what promotes change and evolution. Without it no change would be required because there would be no outside force.” Similarly, “Pressure is something forced upon an organism or its environment, and in this situation, the pressure causes change or adaptation in the organism.” And “A pressure is an environmental obstacle that may cause evolution in a particular direction.” These examples suggest the use of everyday force-dynamic reasoning models, where pressure is considered to be a “force” that is directly causing a change in the organism or species, resulting in evolution.

It is important to emphasize that student explanations utilizing “force-talk” are not always incorrect or indicative of misconceptions. Theoretically, it is possible to use such “force-talk” in a scientifically accurate way. In such explanations, “pressure” may be used as a placeholder for a particular biotic/abiotic factor that is involved in differential survival (such as predation). The pressure (predation) influences the evolution of a species by removing individuals from the population, causing differential survival. This in turn leads to the inheritance of a different assemblage of traits in the population, which changes the variation available within and among populations. The output of this causal loop (natural selection) is a change in the genotypic and phenotypic frequencies in the population, leading to evolution.

Comparable examples of “force-talk” in scientific explanations may be found in the literature. Baker (2009, p. 43) addresses phenotypic change: “This changing pattern of survival has in turn acted as a selective pressure on their…parasites. Many aspects of the size, shape, colour and behaviour of the larvae and pupae of both species… appear to be adaptations to the selective pressures exerted by bird predation.” On a genetic level, Metzgar and Wills (2000, p. 584) likewise link pressure to selection: “Repetitivity itself is evolving in these sequences, and microsatellites have independently been selected for their mutability many times in response to similar selective pressures.” Laland et al. (2010) provide perhaps the clearest case of using “selective pressure” as a generic placeholder for variables that may cause differential survival or reproduction. These authors arrange so-called selection pressures in a table (p. 143) which includes many specific factors, such as “exposure to novel climates,” “dispersal and sexual selection,” “invention of cooking,” and lactose digestibility, among others.

In his bestselling evolution textbook for undergraduates, Futuyma (2009: 288) also appears to use selection pressures as generic placeholders for particular variables or processes: “The guppy experiments also show that a feature may be subjected to conflicting selection pressures (such as sexual selection and predation), and that the direction of evolution may then depend on which is stronger.” Here, pressures are likened to forces, which may have different or counteracting effects. What is notable in this formulation is that heterogeneous processes (sexual selection and predation) fall under the same umbrella term (pressure).

"Pressure as a placeholder" notions are also apparent in students' evolutionary reasoning. In such cases, students associate "pressure" with biotic/abiotic factors (predation, food, water, climate, etc.) but nevertheless do not always connect this interaction with the core concepts of natural selection, particularly differential survival/reproduction (group A). For example, "Pressures are different things such as water density, seasons, etc." and "pressures such as environmental factors (water, nutrients, climate, etc.), or surrounding populations of animals." However, other students do connect their definition of pressure as a biotic/abiotic factor with the core concepts of natural selection (group B). For example, "Pressures mean…things like weather, water density, and other factors that could affect how an organism…survives in its environment." Another student stated: "Pressures are environmental conditions that are favorable/unfavorable to certain traits, and therefore will help/hinder the survival of different organisms with different traits." Another example of this reasoning is: "Pressures are anything in the environment that could potentially threaten the survival of an organism, such as predators or natural disasters, but can also be anything ranging from the habitat to types of nutrition in the environment." Overall, it is clear that some students construct mental models of pressure that are consonant with the likely reasoning of evolutionary biologists. Nevertheless, this is an uncommon occurrence and calls into question the utility of force-talk in biology textbooks, journal articles, and university lectures.

Conclusions

1. Force-talk is an ubiquitous but ill-defined linguistic element of causal evolutionary explanation in biology textbooks, journal articles, and university lectures.
2. Post-instruction, the majority of biology majors who employed force-talk in evolutionary gain and loss scenarios displayed faulty models of evolutionary causation.
3. Faulty evolutionary explanations incorporating pressures and forces may be explained by the recruitment of everyday force-dynamic reasoning patterns into evolutionary explanations.
4. Biology faculty, teachers, textbook writers, and science journalists should carefully consider the necessity of "force-talk" given that it may elicit everyday force-dynamic reasoning models that fail to accurately explain evolutionary change.

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