Review

Poor hypotheses and research waste in biology: learning from a theory crisis in psychology

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Abstract

While psychologists have extensively discussed a ‘theory crisis’, there has been no debate about such a crisis in biology. However, biologists, especially those working in the fields of ecology and evolution, have long discussed communication failures between theoreticians and empiricists. We argue such failure is one aspect of a theory crisis because misapplied and misunderstood theories lead to poor hypotheses and research waste. We review solutions for a theory crisis, comparing them with methodology-focused solutions proposed for a replication crisis. One neglected solution deserving further attention concerns the systematic mapping of theoretical models. We conclude by discussing how promoting inclusion, diversity, equity, and accessibility (IDEA) in theoretical biology could contribute to ameliorating breakdowns in the theory-empirical cycle in biology.

Drivers of research waste: a replication or theory crisis?

"*An approximate answer to the right question is worth a great deal more than a precise answer to the wrong question.*" John Tukey

The social sciences have experienced a replication crisis arising from the low replicabilities of empirical studies, particularly in psychology [1-4]. Consequently, recent rapid reforms have changed how they conduct their research [5, 6] (also see [7]). One particularly noteworthy example is their adoption of pre-registration and registered reports, which can involve pre-commitment of study aims and methods, with the latter involving peer review [8-11]. For example, starting 6 in 2015, more than 130 psychology journals accepted registered reports in 2020 [12] (see also [13]). These innovations can curtail questionable research practices, QRPs, such as selective reporting and HARKing (hypothesizing after results are known); such QRPs are ubiquitous in both social and biological sciences [14-16]. In one example, studies based on pre-registered reports supported the author's hypotheses only 40% of the time, whereas traditional non-pre-registered studies supported the authors' hypotheses over 85% [17]. Similar reforms are being adopted in biology, albeit more slowly, especially ecology and evolutionary biology [18-20].

The replication crisis and QRPs are closely tied to research waste. Research waste occurs in three ways, according to Purger and colleagues [21]. First, scientists finish a project but never publish it or terminate it early, mainly due to negative results (publication bias). Second, scientists publish their results with insufficient reporting of methods (incomplete reporting). Third, the research suffers from poor study design, data collection, or poor analysis, so even if published, results are unreliable and unusable (poor methodological design). Rather surprisingly, Purger and colleagues estimated that research could be as high as 82-89% in ecology. This estimate is very similar to estimate of 85% made by Chalmers and Glasziou for the medical sciences [22] (see also [23-27]). Given these issues are closely tied to replication crises, it is unsurprising that the reforms for the replication crisis focused on rigorous and transparent methodology and reporting practices, including open data and code [2, 28-31].

A series of articles in psychology have also pointed out a more fundamental problem contributing to insufficient replication and research waste [32-39]. To distinguish it from a ‘replication crisis’, it has been called a ‘theory crisis’ [34-36], wherein researchers frequently test vague and incorrect hypotheses/questions because the theory is often verbal (i.e., informal), so researchers can interpret it more freely (c.f., high researcher degrees of freedom [40]). Even when written formally as mathematical models, theory is often poorly described, leading to misinterpretation by empiricists and a mismatch between theoretical predictions and empirical hypotheses. This has been called an ‘interpretation crisis’ [32] (see also, ‘generalizability crisis’ [38]). As the opening quote from John Tukey suggests, testing a precise hypothesis, derived from a wrong or misinterpreted theory, seems certainly a form of research waste or, at least, research inefficiency. Additional signals of a theory crisis within a field include an overall lack of theories (and theoreticians) or the prevalence of poorly reasoned or vague theories. Yet, the lack of formalization and the prevalence of poor interpretations seem to be a substantial part of the discussion on the theory crisis in psychology (cf. [34-36]). Therefore, we use the term a ‘theory crisis’ to include both:

1) a lack of testable, formal theories within a field and 2) misinterpretations of sufficiently developed theories by empirical researchers.

To our knowledge, theory crises have not been discussed and linked to research waste in biological research (cf. [19]). Yet, there has been much debate about communication gaps and failures between theoreticians and empiricists, especially in ecology and evolutionary biology [41-49] (also see [50]; hereafter, we use ‘theoretical models’ or ‘model’ as a formalized version of ‘theory’, i.e., mathematical or computational models). Such debates indicate a theory crisis (at least within our definition) may have long existed and remains unresolved in biology. For example, in a 2022 paper [45], Servedio reported survey results from theoreticians in ecology and evolution on how their models are used in empirical work. Models were misinterpreted and used incorrectly 19% of the time, while 36% of the time, they were cited in a non-specific manner. That is, the rest of the time (45%), empiricists cited models correctly, relating their work to specific theoretical results. Whether 45% is good or bad, there is much to improve for what both 91% of theoreticians and 80% of empiricists agreed upon – the importance of a tight feedback loop between theoretical and empirical work in biology [49] (see also [41]). Nonetheless, given these statistics, it is worth asking whether biology currently suffers from a theory crisis and if so, how it might be remedied.

Therefore, our aims are four-fold. First, we investigate communication breakdown between theoreticians and empiricists through the lens of a theory crisis to illustrate how such breakdowns could contribute to both research waste and a replication crisis. Next, we review proposed solutions for the theory crisis, including theory-empirical communication failures from the social and biological sciences. We then highlight a critical gap in a scientific cycle — the lack of systematic mapping of models — which, when addressed, can facilitate communication between theoreticians and empiricists. Finally, we shift our focus to two issues: the low numbers of pure theoreticians in biology and their diversity with respect to identity, geography, and academic training. We describe two solutions to ameliorate both problems, which could help not only create diverse science teams between theoreticians and empiricists but also turn more people into theoreticians and liaisons between the two groups.

Theory before replication: questionable research practices and research waste in relation to theory

As alluded to above, a replication crisis is often attributed to methodological or reporting shortcomings concerning data collection and analysis. In contrast, a theory crisis is due to misunderstanding, miscommunication, or misapplication of theory (i.e., epistemic failure rather than methodological) [35, 36]. Like many other fields, including psychology, biology heavily relies on inferential statistics, especially null hypothesis significance testing, NHST [51, 52]. In doing so, researchers often derive their hypotheses or predictions from existing theory (i.e., an alternative hypothesis within the framework of NHST). Then, they statistically operationalize their hypothesis, using, for example, independent *t*-tests or generalized linear mixed-effects models to reject the null or accept the alternative.

In psychology, several authors have recently pointed out that this statistical translation is problematic because many theories and hypotheses are verbal, so interpretations of the theories can become unconstrained or subjective and, therefore, ungeneralizable

[32, 34-38]. In biology, such translation issues can certainly happen or even be prevalent based on our experience. Yet, many theories have mathematical or computational formalizations, i.e. models that provide *directional* or *quantitative predictions*, thanks to a long tradition of theoretical biology (especially in ecology and evolution, e.g., [43]). Then, the main issue in biology appears to be that empiricists often misinterpret or misapply theory [45].

A case study of this is the so-called ‘modern coexistence theory’ (MCT) [5, 53, 54], which, as pointed out by Terry and Armitage [55], is less a predictive, testable theory but rather an analytical framework for partitioning growth rates into various coexistence-promoting mechanisms. The theory itself presents few quantitative predictions but rather offers a useful analytical method for concentrating many informal verbal hypotheses concerning ecological coexistence under a simple, formal umbrella. Empirical users of this theory are therefore free from the burden of directly confronting any theoretical predictions with data yet can also claim the status of carrying out ‘theoretically motivated’ research. As a result, many empirical papers using the MCT framework lack quantitative or even directional hypotheses concerning the effects of some factor on species coexistence, potentially reducing replicability (though this has yet to be quantified). Arguably, the major prediction made by MCT concerning the outsized roles of spatial and temporal environmental variation on species coexistence is probably the most mathematically difficult part of the theory for empiricists to understand and test.

Such barriers are not unique to MCT but occur in all fields where training in the writing and interpretation of formal theory is not a central theme in the scientific curriculum [47]. Mathematical barriers can instead drive biologists toward imprecise or vague verbal theories – which is the main cause of the theory crisis in psychology [35, 36]. Even among empiricists fluent in mathematics, theoretical models are often deliberately oversimplified for the sake of clarity and analytical tractability, meaning that further development and analysis of context-dependent expansions of a theoretical paper's results may be required to yield a useful, testable hypothesis. This, of course, requires at least a cursory understanding of the natural histories and physicochemical factors determining the behavior of one's chosen study system.

Turning now to evolutionary biology, an interesting example concerns the 'extrinsic mortality hypothesis', proposed in 1957 by G. C. Williams [56]. In his verbal theory, Williams argued that high extrinsic mortality rates should select for increased rates of growth, reproduction, and aging and, therefore, a shorter maximum lifespan. This verbal theory inspired a large number of empirical studies (reviewed in [57]; see also [58-62]). However, a more formal analysis of these predictions has subsequently predicted that under alternative, biologically reasonable assumptions, extrinsic mortality can both increase or decrease the rate of aging, while extrinsic mortality and aging can be disassociated (summarized in [63]). Therefore, it is important to review relevant mathematical models and understand which set of assumptions is most relevant to one's study system.

Given these examples, we suggest that a theory crisis can lead to three types of questionable research practices, QRPs (see Figure 1). These three 'new' extensions of QRPs are counterparts to well-known issues of empirical studies: HARKing (hypothesizing after results are known), *p*-hacking (or 'data dredging'), and cherry-picking (of results to report). The first we will call ‘H-BUTing’ (/hei-tʃ-but-ing/) or ‘Hypothesizing Before Understanding Theory’. H-BUTing happens because a theory is not formalized, or even if it is formalized, it is difficult to understand. H-BUTing is also called ‘premature hypothesis testing’ [37]. It is premature because researchers either do not understand a theory itself or they do not understand if their study systems are suitable for testing the theory. We call the second QRP hypothesis hacking or *h*-hacking, where liberal interpretations and translations of theory or models will lead to hypotheses that fit researchers’ beliefs prior to studies or too vague (i.e., qualitative and nondirectional) hypotheses more likely to return significant results. Generating surprising (highly unrealistic) hypotheses can be a part of *h*-hacking because supporting a surprising hypothesis can lead to a high-profile journal publication (cf. [64]; see also [65]). The third is hypothesis cherry-picking (termed by Krämer [32]), where researchers deliberately ignore alternative, theoretically valid hypotheses that do not support their initial beliefs or most favorable interpretation of their results.

Similarly, we can add ‘poor conceptual design’ alongside poor methodological design, publication bias, and incomplete reporting as the primary contributors to research waste. Epistemological issues (e.g., conceptual issues) are upstream of methodological issues (Figure 1). Therefore, solving downstream issues, such as incomplete reporting, does not fix upstream issues, such as improper use of theory. More specifically, poor conceptualization can compromise the internal validity of a study, for example, via inappropriate experimental design or measurement (for difficulties in measuring theoretical constraints, see [66]). At the same time, it can also threaten external validity (generalizability), for example, through the biases in the selection of study systems, as certain theory is more easily tested in particular organisms or locations [38] (see also, "Western, Educated, Industrial, Rich, and Democracies", WEIRD [1, 67] and "Social background, Trappability, Rearing history, Acclimation and habituation, Natural changes in responsiveness, Genetic make-up, and Experience", STRANGE [68]). Therefore, addressing a theory crisis may be more important than easing a replication crisis.

Proposed solutions: more development, education, and collaboration

Proposed solutions can be grouped into three kinds. First, researchers can do more work to understand and operationalize theory before conducting a study with hypothesis testing (also referred to as a 'confirmatory' study). Scheel and colleagues argue that premature hypothesis testing is rampant in psychology, but researchers should conduct more non-confirmatory studies (sometimes referred to as 'exploratory' or 'discovery-oriented' studies; [36], cf. [37]). Non-confirmatory studies can resolve issues of H-BUTing (hypothesizing before understanding theory) because they will identify whether and when a model is relevant to their biological system by understanding model assumptions and parameter space (e.g., a model assuming semelparous organisms without non-overlapping generations) [37]. A non-confirmatory exploration is often warranted before embarking on confirmatory work, especially at the start of post-graduate research programs. An alternative approach that we find to be valuable is to reproduce the results of a theoretical study on our own (typically on a computer). Once this is accomplished, the models can be further modified and played with to more thoroughly understand its scope and assumptions.

Second, universities can offer undergraduate and postgraduate courses on how to understand theoretical and mathematical/computational models and, more broadly, the role of theory in the scientific process — thereby promoting the training of pure theoreticians and theoretically proficient empiricists (i.e., liaisons). Some psychologists have shared their experiences on the effectiveness of such courses [33, 39] (see also [41]). For example, Borsboom, and van der Maas teach a 'theory construction' course where, in addition to lectures on the methodology, students create computer simulation models which can explain a phenomenon well but also see a model is limited as it creates non-sensical values under some settings [33]. We agree that such a hands-on course would be eye-opening and useful training. In the biological sciences, however, theoreticians are almost always a minority group who teach courses that a minority of students attend, and often at levels more advanced than the average biosciences student is proficient. Thus, although education is important and effective, it cannot break the status quo of early separation between theoreticians (who often arrive at biology with math or physics degrees) and empiricists (who tend to avoid most math and physics classes beyond prerequisites). This is also because understanding math takes time, and interventions should start much earlier than university education. Furthermore, we have noticed a trend in the fields of ecology and evolution wherein advertisements for pure theoreticians seem to be declining, whereas appointments in 'quantitative biology' are on the rise. We speculate that this may reflect a more general growing trend of interest in the more lucrative fields of data science and bioinformatics, which compete with the theoretical sciences over a shared pool of students. Nevertheless, online education and technologies can overcome the shortage of theoreticians (more discussed later).

Thirdly, theoreticians and empiricists can collaborate more. Recently, Ou and colleagues have described how theoreticians can write more accessible papers by being mindful of what parts of their analyses are the most difficult for empiricists to understand [42]. Likewise, Grainger and colleagues have produced an excellent guide for empiricists with tips on understanding and testing formal theory [41]. Notably, these two papers largely overlap in their author lists, which comprise a mixture of empiricists, theoreticians, and liaisons in ecology and evolutionary biology. Though the primary means by which theoreticians and empiricists interact is indirectly through citation of one another's publications, direct collaboration might be a more effective means for reducing barriers in understanding, though the relative scarcity of theoreticians in most biological fields can limit such direct interactions. Interestingly, a group of psychologists have successfully attempted an exercise called the 'Many Modelers Hackathon' where a few theoreticians worked with many empiricists to formalize verbal theories during a 3-hour workshop [69]. This Many Modelers event was successfully run as part of a 2021 conference for the Society for the Improvement of Psychological Science (SIPS) – a model for the Society for Open, Reliable, and Transparent Ecology and Evolutionary Biology (SORTEE). A Many-Modelers Hackathon holds tremendous potential in ecology and evolution, and our field has a long history of formalizing theories and designing complex experiments in which they are tested (more on the potential of this type of hackathon later).

A gap in the scientific cycle and a proposed solution: systematic mapping of theoretical models

In Figure 2, we illustrate a scientific cycle where researchers seek to understand a phenomenon and develop a theory via two pathways: empirical research and theoretical development. The last three decades have seen a revolution in empirical research with a rise in research synthesis, especially meta-analysis [70, 71]. Meta-analyses (often a part of systematic reviews) have gradually been superseding traditional narrative reviews because meta-analyses can bring about many unique benefits, which are impossible with narrative reviews [72]. For example, meta-analyses, embedded in a systematic review, can provide an unbiased synthesis, compared to potentially biased experts' opinions, concerning trends in the literature. Meta-analyses as a quantitative synthesis can more objectively identify general patterns and knowledge gaps, explain inconsistencies among empirical studies, and generate ideas that can fledge into theories [73].

Unlike empirical meta-analyses, the synthesis of theory is primarily narrative rather than systematic, representing a gap in the scientific cycle (Fig. 2) [74] (cf. [75]). While it is unclear how a quantitative synthesis of theoretical literature might be carried out, a systematic qualitative synthesis is still possible. Such syntheses might encompass a systematic review or a systematic map (sometimes, known as a scoping review; see [76, 77]). Although often confused, systematic reviews and maps have different objectives [78, 79]. The former answers a specific question, often relating to "What works?" (e.g., does an intervention have an effect?), but the latter addresses a more general question, such as "What has already been studied and where do gaps remain?" [80]. Therefore, a systematic map is a structured collection of studies, more relevant to qualitatively summarizing models. Systematic maps can find general patterns and knowledge gaps in a related collection of models. Further, such a map of models can also identify gaps in empirical observations, for example, by examining how parameter values in theoretical models are defined (e.g., whether they are based on results of empirical studies or simply best guesses that require further empirical validation). Although their number is limited and often (mis-)labelled as a systematic review, systematic maps of models seem to exist in medicine and biology.

One noteworthy systematic map has been made for the field of life history theory. Many empiricists have tested hypotheses concerning covariation between life history traits such as growth rate and age of reproduction with behavioral and physiological traits, theorized to arise from trade-offs between investment in current and future reproduction, known as ‘pace-of-life syndromes’ [81]. Thus, Mathot and Frankenhuis (an empiricist-theoretician duo) attempted to map theoretical models on this topic, but they only identified two unique models [82]. More importantly, however, these models both present ways in which covariances could arise between life history and other traits without the current-future-reproduction trade-offs; that is, many previous empirical studies may have presented data supporting a hypothesis that did not have full theoretical support to begin with, possibly committing H-BUTing and hypothesis cherry picking (Figure 1).

This example may give the impression that such mapping activities are futile, as theoretical papers are rare for most questions in biology. But this is topic-dependent. A systematic map of theory relating to antimicrobial resistance, for example, identified 273 studies of mathematical models made at the population level [83] (see also [84]); this map elucidated theoretical gaps, such as the scarcity of models on transmission between humans and animals and the consideration of environmental factors. Similarly, another systematic map collated 698 studies of agent-based models of infectious disease transmission published from 2006 to 2015 [85]. Recently, Achter and colleagues have published an opinion article promoting systematic maps (and reviews) of agent-based models so that new models do not ‘re-invent the wheel’ but rather build upon previous models in environmental sciences [74]. They argue that such a systematic map can lead to further refinement and the development of a theory. We concur and join their call for systematic maps of mathematical and computational models. Importantly, systematically mapping models could guard against hypothesis cherry-picking and *h*-hacking (Figure 1). This is because a map gives a comprehensive catalog of current theoretical models, which can direct the development of a set of testable hypotheses, hopefully reducing the incidence of cherry-picking hypotheses or liberal interpretations of theories.

Notably, bibliometric analysis (e.g., analysis of articles’ citation impacts and connections to other articles via citations and collaborations) exists for models of antibiotic resistance [86] in addition to the systematic map mentioned above [83]. Some of us (SN and ML) have recently proposed a new way of synthesizing literature, named ‘research weaving’, which combines systematic mapping and bibliometrics [80]. As outlined above, systematic mapping summarizes the current state of knowledge and evidence, identifying areas with research gaps and clusters (i.e., an abundance of research papers). As a complementary approach, bibliometrics enables researchers to see how pieces of evidence are connected. Such analysis can reveal the structure and development of a field and how influential particular works have been (research weaving examples, see [87, 88]). Therefore, a research weaving of theoretical models holds much potential, for example, for collaboration work between theoreticians and empiricists because both can contribute to such an activity (cf. [74]) and can lead to the synthesis of both theoretical and empirical results (Figure 2).

Furthermore, some bibliometric analyses (i.e., geographic and collaboration-network analyses) can reveal the lack of inclusion, diversity, equity, and access (IDEA; more often referred to as EDI or DEI) in a field of study. Therefore, this aspect can potentially be harnessed to identify the areas of biology and dimensions of IDEA that might benefit from targeted collaboration outside the historical trends in the field. Next, we posit a hypothesis that achieving IDEA could help ameliorate a theory crisis regarding the shortage of good theories (and theoreticians) and misinterpretations and misapplications of theories.

Ideas to create a tight theory-empirical feedback loop by achieving IDEA: inclusion, diversity, equity, and access

Several articles have pointed out the shortfall of IDEA in the theoretical biology community [41, 89, 90]. Evidence suggests theoreticians are an impactful and privileged group that lacks diversity (e.g., [91]). Yet the lack of diversity may be due to the number of people in the community being much smaller than that of empiricists (see [92]). Therefore, increasing the pool of theoreticians with IDEA goals in mind could ameliorate both the theory crisis and the lack of diversity. Of relevance, in recent years, many academic societies in biology have put forward statements and created special committees for IDEA so that they encourage historically under-represented and marginalized groups of people not only to join societies but also to represent societies in leadership roles, with some noticeable success (cf. [93]).

Ecology and evolution have large, old, and influential societies such as the Ecological Society of America, the British Ecological Society, the Society for the Study of Evolution, the Society for Molecular Biology and Evolution, and the European Society for Evolutionary Biology. We believe that these societies should make one of their missions to facilitate the training of more theoreticians, especially those from historically under-represented groups (e.g., women [94] and the Global South [95]). Theoretical work is not only impactful, but it also provides mathematical and computational skills that are highly transferable. Theoretical work also facilitates a potentially flexible and family-friendly lifestyle compared to empirical work, as a pen and paper or a laptop can be enough to get the work done. Therefore, theoretical work can help break down academic inequity by allowing researchers to remain at or return to their home institutions that may not be able to financially support large lab or field-based research programs. At the same time, addressing the scarcity of theoreticians is an urgent issue because researchers now regularly collect and analyze massive, complex datasets with only a small pool of theories to generate *a priori* hypotheses (living in a data-rich-theory-poor world, e.g., [96]). Such an overabundance of data should make us re-think the importance of theory and theoreticians, especially because the cycle of theory construction and empirical work (Figure 2) has repeatedly been proven effective and efficient. Therefore, a theory crisis can entail another meaning that is more pressing in the future – the extreme shortage of theories and theoreticians. But how could we kill two birds – addressing the theory crisis and IDEA – with one stone? We outline two paths forward, building upon the proposed solutions above.

One approach is to encourage societies to create free training videos on how to understand and build theoretical models (e.g., on a YouTube channel). A potential model for a video series has been created by Richard McElrath, a mathematical-theoretician-turned-Bayesian-statistical-modeler. His YouTube channel lists a 20-free-video series based on his book “Statistical Rethinking”, with which he attempts to democratize the knowledge of Bayesian statistics and causal inference for biologists [97]. Further, distributed remote seminar series on theoretical biology can also attract a large viewership, as demonstrated by the International Initiative for Theoretical Ecology’s online live series and YouTube archive (https://iite.info/seminar/).

Another inspirational example of remote education comes from a non-profit, *e-Education*. Founded by Atsuyoshi Saisho, the company has revolutionized high school education in Bangladesh – where the shortage of teachers has been a serious issue – through its use of video instruction. Based on his experience of video education provided in an extracurricular school in Japan, he created a lecture series featuring the most charismatic teachers in Bangladesh. Saisho believed such video education was best because one could stop and repeat lectures until understanding was demonstrably achieved, and students could work at their own pace through video lectures by the best teachers in the country [98]. This program became an instant sensation when, upon the initial introduction of these video materials, including mathematics, 18 rural students passed exams to enter universities, such as the University of Dhaka (the country’s best tertiary institution). These students came from a Bangladeshi village where only one person had ever previously attended university

– the local media touted it as “a miracle of Haimchar village”. The program has now spread to 14 countries across 5 continents (https://eedu.jp/).

A second strategy is for societies to include hackathon-like activities in their conference schedules. More specifically, they could organize Many-Modeler-like hackathons where theoreticians and empiricists interface to formalize theories or create testable hypotheses, as discussed above [69]. It is important to note that people may believe that computer programming skills are a prerequisite for participation in a hackathon, but the term is now widely used for any event that is structured around team-based creative problem-solving. For example, any event with the goal of developing new guidelines, policies, or solutions to academic, environmental, or societal issues can be called a hackathon (this is the definition the Society for the Improvement of Psychological Science, SIPS, uses). A good example of such a non-programming hackathon is assembling 100 ecology and evolution journal editors to develop shared guidelines for accepting registered reports (which SN co-organized previously; outcomes including [99-101]). Along with hackathons, a new style of conferences could add ‘unstructured discussion’ events where participants are prompted to discuss or debate ideas and issues without any pre-specified task to achieve (contrasting to a hackathon). The IDEA benefits of hackathons and unconferences include opportunities to work with a diverse group, including senior and junior colleagues. These new conference activities have been embraced by several learned societies such as the Society for the Improvement of Psychological Science (SIPS), the Society for Open, Reliable, and Transparent Ecology and Evolutionary Biology (SORTEE), and the Association for Interdisciplinary Meta-science and Open

Science (AIMOS) with successful outcomes such as publications and new interdisciplinary collaborations.

For example, we (SN and ML) have organized several hackathons and unconferences at SORTEE annual online meetings; one of the activities has already resulted in a publication [102] (other examples of SORTEE conference publications; [103-105]). This publication introduces the idea of 'MeRIT' (Methods Reporting with Initials for Transparency) – how to acknowledge the methodological contributions of authors in more detail (www.merit.help), complementing widely adopted CRediT (Contributor Roles Taxonomy; [106]). We created MeRIT to facilitate team science where providing appropriate credits to each team member can become an issue [107, 108]. What ecology and evolutionary biology now need is a diverse team science with theoreticians and empiricists – and Many Modeler hackathons can kickstart such teams. Of course, this kind of team is needed for a systematic mapping of theoretical models, as introduced above.

Less waste and more IDEA for the future of biology

Here, by reviewing articles both in psychology and biology, we have described how biology is also potentially prone to a theory crisis, which contributes to replication crises and research waste. We have also looked at current and potential solutions, notably, systematic mapping of theoretical models, to help resolve the theory crisis (Figure 3). Despite past attempts to fix theory-empirical communication breakdowns, dramatic success has yet to be achieved in creating a tight feedback loop between theory and experimentation (cf. [41]). We contend that pursuing IDEA can, at least partially, ameliorate such breakdowns and presented two concrete ideas – engaging educational videos and many-modeler-like-hackathon events at conferences – that academic societies are encouraged to act upon. We encourage you and your scientific community to generate more ideas and action them to improve both theory-empirical communication and IDEA. Finally, we eagerly anticipate a future where research waste is a relic of the past and diverse team science prevails and tackles both big questions in ecology and evolution and pressing ecological and environmental issues human beings have been and will be facing. We believe that biology will get there if biologists can replicate "a miracle of Haimchar village" again and again.

Declarations

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Author contributions

Conceptualization: All

Visualization: ML

Writing the first draft: SN

Writing – review & editing: All

Figures

Figure 1.

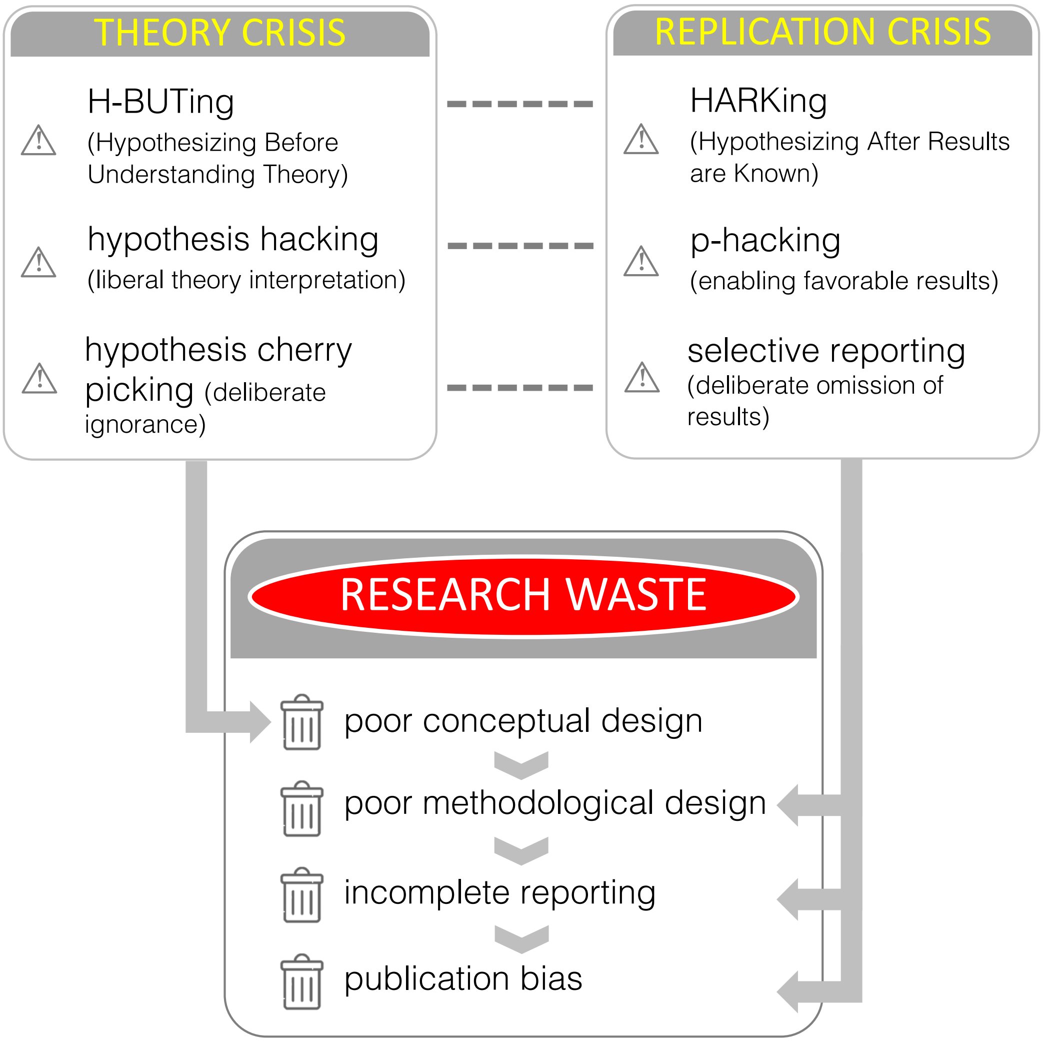

Fig. 1. Questionable research practices, QRPs, arising from a theory crisis (via epistemological issues) and replication crisis (via methodological issues) and how they relate to research waste. QRPs concerning the theory crisis relate to poor conceptual design, which comes upstream of the other 3 items of research waste related to QRPs resulting from a replication crisis. Note that selective reporting and incomplete reporting may sound similar, but the former indicates deliberate selection of positive results while the latter represents the lack of culture in providing all the results and associated outcomes, including associated data and code.

Figure 2.

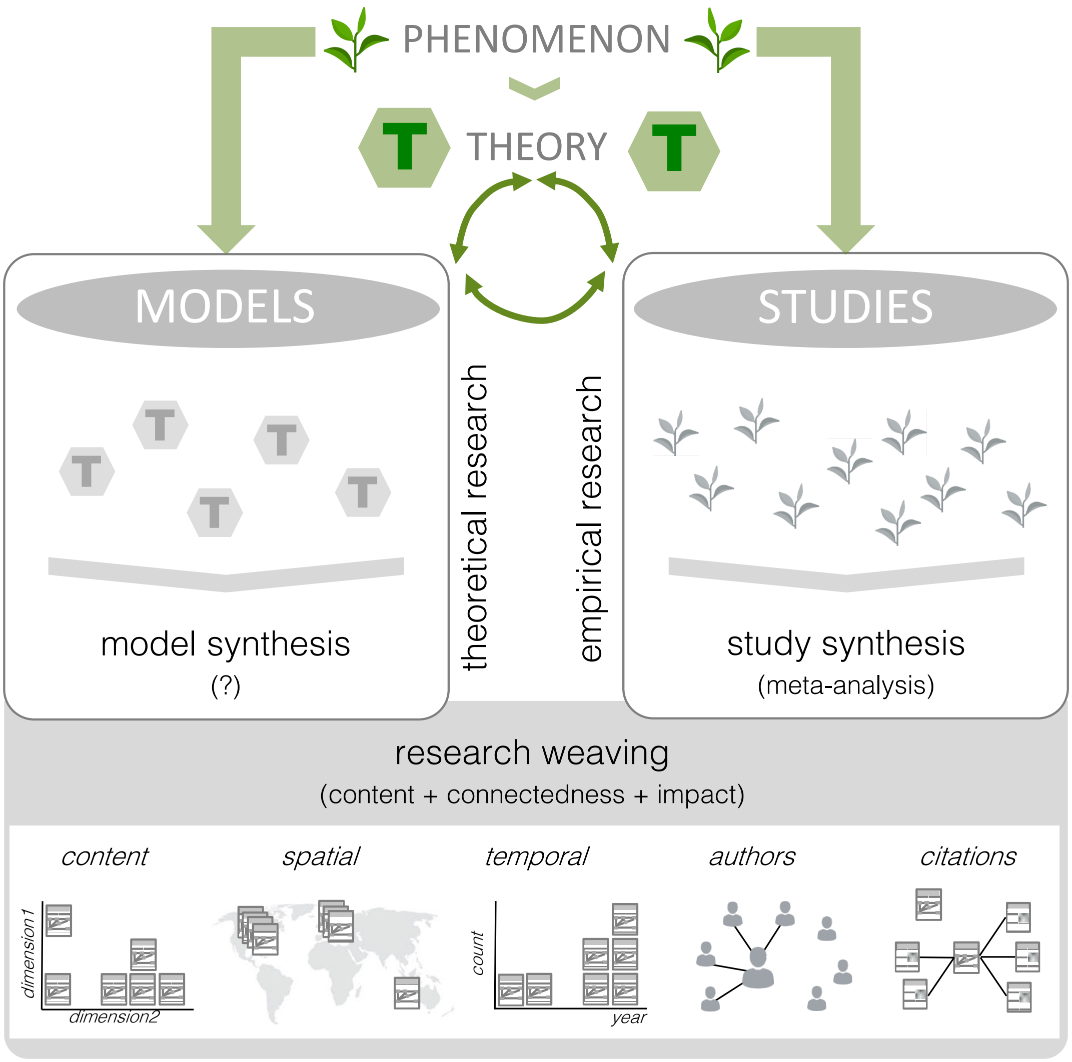

Fig. 2. A depiction of a scientific cycle. Researchers seek to understand a phenomenon and develop a theory while engaging with theoretical research or empirical research. While meta-analysis has revolutionized empirical synthesis, the synthesis of theories (models) is primarily narrative. Research weaving (systematic mapping and bibliometrics) could help not only synthesize theoretical models but also summarize both types of research on a topic.

Figure 3.

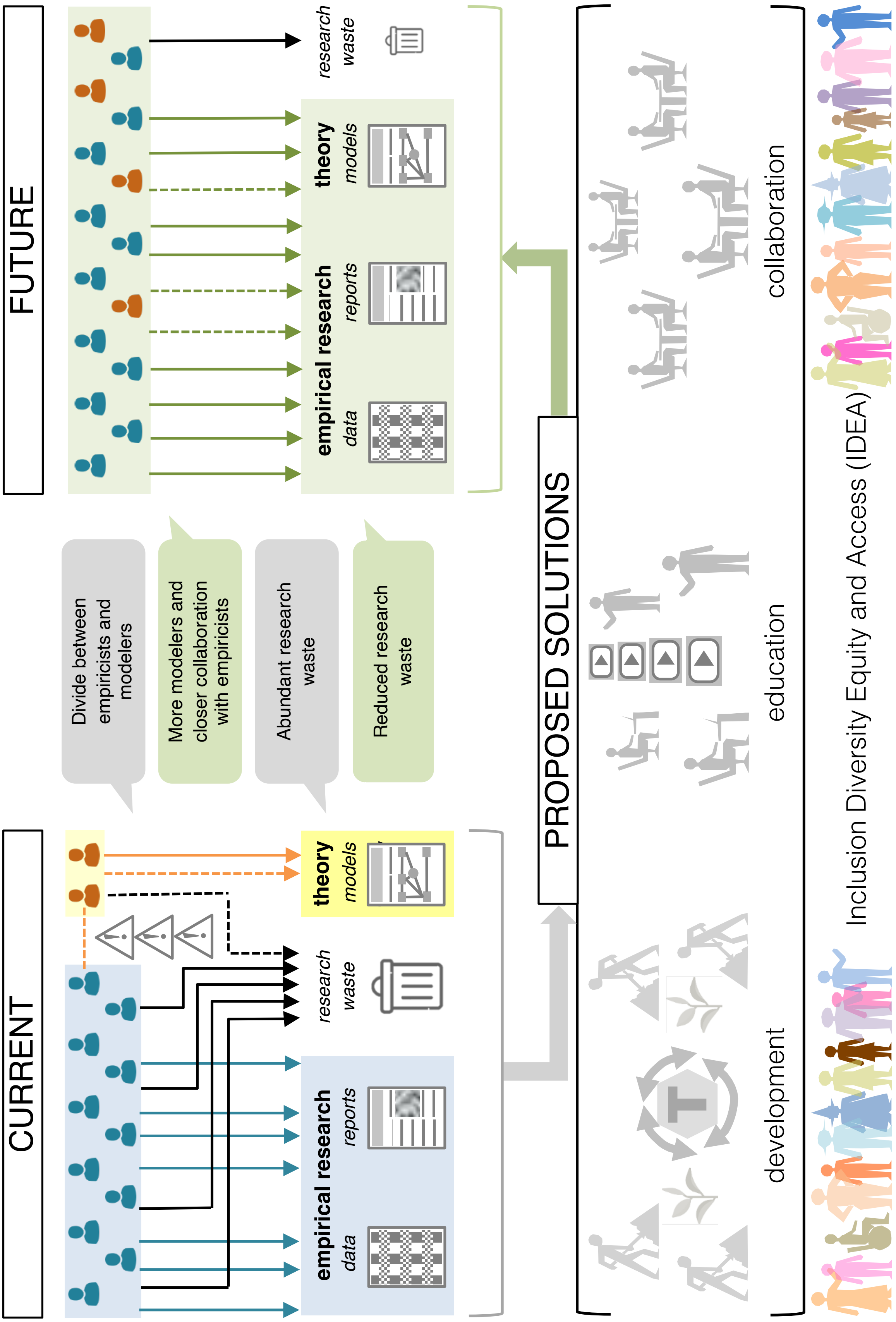
CURRENT
empirical research
data
reports
research waste
theory
models
Divide between empiricists and modelers
More modelers and closer collaboration with empiricists
Abundant research waste
Reduced research waste
FUTURE
empirical research
data
reports
theory
models
research waste
PROPOSED SOLUTIONS
development
education
collaboration
Inclusion Diversity Equity and Access (IDEA)

Fig. 3. The current and future of empirical and theoretical research. Currently, due to miscommunications between theoreticians (minority) and empiricists (majority), resulting in research waste. Via the proposed solutions, development, education and collaboration, the future research community will have more theoreticians working with empiricists, especially if learned societies can embrace the theory crisis and promote the integration of theoretical and empirical work through IDEA. Solid lines represent no direct collaborations, while dotted lines indicate direct collaborations (the upper panels). While research waste may be an unavoidable part of the scientific process, more research efficacy can be attainable.

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