1 *Review*

2 **Poor hypotheses and research waste in biology: learning from a**

3 **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

64 unusable (poor methodological design). Rather surprisingly, Purger and colleagues

65 estimated that research waste could be as high as 82-89% in ecology. This estimate is

66 very similar to the estimate of 85% made by Chalmers and Glasziou for the medical

67 sciences [22] (see also [23-27]). Given these issues are closely tied to replication

68 crises, it is unsurprising that the reforms for the replication crisis focused on rigorous

69 and transparent methodology and reporting practices, including open data and code

70 [2, 28-31].

71

72 A series of articles in psychology have also pointed out a more fundamental problem

73 contributing to insufficient replication and research waste [32-39]. To distinguish it

74 from a 'replication crisis', it has been called a 'theory crisis' [34-36], wherein

75 researchers frequently test vague and incorrect hypotheses/questions because the

76 theory is often verbal (i.e., informal), so researchers can interpret it more freely (c.f.,

77 high researcher degrees of freedom [40]). Even when written formally as

78 mathematical models, a theory is often poorly described, leading to misinterpretation

79 by empiricists and a mismatch between theoretical predictions and empirical

80 hypotheses. This has been called an 'interpretation crisis' [32] (see also,

81 'generalizability crisis' [38]). As the opening quote from John Tukey suggests, testing

82 a precise hypothesis, derived from a wrong or misinterpreted theory, seems certainly a

83 form of research waste or, at least, research inefficiency. Additional signals of a

84 theory crisis within a field include an overall lack of theories (and theoreticians) or the

85 prevalence of poorly reasoned or vague theories. Yet, the lack of formalization and

86 the prevalence of poor interpretations seem to be a substantial part of the discussion

87 on the theory crisis in psychology (cf. [34-36]). Therefore, we use the term a 'theory

88 crisis' to include both: 1) a lack of testable, formal theories within a field and 2)

89 misinterpretations of sufficiently developed theories by empirical researchers.

90

91 To our knowledge, theory crises have not been discussed and linked to research waste

92 in biological research (cf. [19]). Yet, there has been much debate about

93 communication gaps and failures between theoreticians and empiricists, especially in

94 ecology and evolutionary biology [41-49] (also see [50]; hereafter, we use 'theoretical

95 models' or 'model' as a formalized version of 'theory', i.e., mathematical or

96 computational models). Such debates indicate a theory crisis (at least within our

97 definition) may have long existed and remains unresolved in biology. For example, in

98 a 2022 paper [45], Servedio reported survey results from theoreticians in ecology and

99 evolution on how their models are used in empirical work. Models were

100 misinterpreted and used incorrectly 19% of the time, while 36% of the time, they were

101 cited in a non-specific manner. That is, the rest of the time (45%), empiricists cited

102 models correctly, relating their work to specific theoretical results. Whether 45% is

103 good or bad, there is much to improve for what both 91% of theoreticians and 80% of

104 empiricists agreed upon – the importance of a tight feedback loop between theoretical

105 and empirical work in biology [49] (see also [41]). Nonetheless, given these statistics,

106 it is worth asking whether biology currently suffers from a theory crisis and if so, how

107 it might be remedied.

108

109 Therefore, our aims are four-fold. First, we investigate communication breakdown

110 between theoreticians and empiricists through the lens of a theory crisis to illustrate

111 how such breakdowns could contribute to both research waste and a replication crisis.

112 Next, we review proposed solutions for the theory crisis, including theory-empirical

113 communication failures from the social and biological sciences. We then highlight a

114 critical gap in a scientific cycle — the lack of systematic mapping of models —

115 which, when addressed, can facilitate communication between theoreticians and

116 empiricists. Finally, we shift our focus to two issues: the low numbers of pure

117 theoreticians in biology and their diversity with respect to identity, geography, and

118 academic training. We describe two solutions to ameliorate both problems, which

119 could help not only create diverse science teams between theoreticians and empiricists

120 but also turn more people into theoreticians and liaisons between the two groups.

121

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

124 As alluded to above, a replication crisis is often attributed to methodological or

125 reporting shortcomings concerning data collection and analysis. In contrast, a theory

126 crisis is due to misunderstanding, miscommunication, or misapplication of theory

127 (i.e., epistemic failure rather than methodological) [35, 36]. Like many other fields,

128 including psychology, biology heavily relies on inferential statistics, especially null

129 hypothesis significance testing, NHST [51, 52]. In doing so, researchers often derive

130 their hypotheses or predictions from existing theory (i.e., an alternative hypothesis

131 within the framework of NHST). Then, they statistically operationalize their

132 hypothesis, using, for example, independent t-tests or generalized linear mixed-effects

133 models to reject the null or accept the alternative.

134

135 In psychology, several authors have recently pointed out that this statistical translation

136 is problematic because many theories and hypotheses are verbal, so interpretations of

137 the theories can become unconstrained or subjective and, therefore, ungeneralizable

138 [32, 34-38]. In biology, such translation issues can certainly happen or even be

139 prevalent based on our experience. Yet, many theories have mathematical or

140 computational formalizations, i.e. models that provide *directional* or *quantitative*

141 *predictions*, thanks to a long tradition of theoretical biology (especially in ecology and

142 evolution, e.g., [43]). Then, the main issue in biology appears to be that empiricists

143 often misinterpret or misapply theory [45].

144

145 A case study of this is the so-called 'modern coexistence theory' (MCT) [5, 53, 54],

146 which, as pointed out by Terry and Armitage [55], is less a predictive, testable theory

147 but rather an analytical framework for partitioning growth rates into various

148 coexistence-promoting mechanisms. The theory itself presents few quantitative

149 predictions but rather offers a useful analytical method for concentrating many

150 informal verbal hypotheses concerning ecological coexistence under a simple, formal

151 umbrella. Empirical users of this theory are therefore free from the burden of directly

152 confronting any theoretical predictions with data yet can also claim the status of

153 carrying out 'theoretically motivated' research. As a result, many empirical papers

154 using the MCT framework lack quantitative or even directional hypotheses

155 concerning the effects of some factor on species coexistence, potentially reducing

156 replicability (though this has yet to be quantified). Arguably, the major prediction

157 made by MCT concerning the outsized roles of spatial and temporal environmental

158 variation on species coexistence is probably the most mathematically difficult part of

159 the theory for empiricists to understand and test.

160

161 Such barriers are not unique to MCT but occur in all fields where training in the

162 writing and interpretation of formal theory is not a central theme in the scientific

163 curriculum [47]. Mathematical barriers can instead drive biologists toward imprecise

164 or vague verbal theories – which is the main cause of the theory crisis in psychology

165 [35, 36]. Even among empiricists fluent in mathematics, theoretical models are often

166 deliberately oversimplified for the sake of clarity and analytical tractability, meaning

167 that further development and analysis of context-dependent expansions of a

168 theoretical paper's results may be required to yield a useful, testable hypothesis. This,

169 of course, requires at least a cursory understanding of the natural histories and

170 physicochemical factors determining the behavior of one's chosen study system.

171

172 Turning now to evolutionary biology, an interesting example concerns the 'extrinsic

173 mortality hypothesis', proposed in 1957 by G. C. Williams [56]. In his verbal theory,

174 Williams argued that high extrinsic mortality rates should select for increased rates of

175 growth, reproduction, and aging and, therefore, a shorter maximum lifespan. This

176 verbal theory inspired a large number of empirical studies (reviewed in [57]; see also

177 [58-62]). However, a more formal analysis of these predictions has subsequently

178 predicted that under alternative, biologically reasonable assumptions, extrinsic

179 mortality can both increase or decrease the rate of aging, while extrinsic mortality and

180 aging can be disassociated (summarized in [63]). Therefore, it is important to review

181 relevant mathematical models and understand which set of assumptions is most

182 relevant to one's study system.

183

184 Given these examples, we suggest that a theory crisis can lead to three types of

185 questionable research practices, QRPs (see Figure 1). These three 'new' extensions of

186 QRPs are counterparts to well-known issues of empirical studies: HARKing

187 (hypothesizing after results are known), *p*-hacking (or 'data dredging'), and cherry-

188   picking (of results to report). The first we will call 'H-BUTing' (/hei-tʃ-but-ing/) or

189   'Hypothesizing Before Understanding Theory'. H-BUTing happens because a theory

190   is not formalized, or even if it is formalized, it is difficult to understand. H-BUTing is

191   also called 'premature hypothesis testing' [37]. It is premature because researchers

192   either do not understand a theory itself or they do not understand if their study

193   systems are suitable for testing the theory. We call the second QRP hypothesis

194   hacking or *h*-hacking, where liberal interpretations and translations of theory or

195   models will lead to hypotheses that fit researchers' beliefs prior to studies or too

196   vague (i.e., qualitative and nondirectional) hypotheses more likely to return

197   significant results. Generating surprising (highly unrealistic) hypotheses can be a part

198   of *h*-hacking because supporting a surprising hypothesis can lead to a high-profile

199   journal publication (cf. [64]; see also [65]). The third is hypothesis cherry-picking

200   (termed by Krämer [32]), where researchers deliberately ignore alternative,

201   theoretically valid hypotheses that do not support their initial beliefs or most favorable

202   interpretation of their results.

203

204   Similarly, we can add 'poor conceptual design' alongside poor methodological

205   design, publication bias, and incomplete reporting as the primary contributors to

206   research waste. Epistemological issues (e.g., conceptual issues) are upstream of

207   methodological issues (Figure 1). Therefore, solving downstream issues, such as

208   incomplete reporting, does not fix upstream issues, such as improper use of theory.

209   More specifically, poor conceptualization can compromise the internal validity of a

210   study, for example, via inappropriate experimental design or measurement (for

211   difficulties in measuring theoretical constraints, see [66]). At the same time, it can

212   also threaten external validity (generalizability), for example, through the biases in the

213   selection of study systems, as certain theory is more easily tested in particular

214   organisms or locations [38] (see also, "Western, Educated, Industrial, Rich, and

215   Democracies", WEIRD [1, 67] and "Social background, Trappability, Rearing history,

216   Acclimation and habituation, Natural changes in responsiveness, Genetic make-up,

217   and Experience", STRANGE [68]). Therefore, addressing a theory crisis may be more

218   important than easing a replication crisis.

219

220   Proposed solutions: more development, education, and collaboration

221   Proposed solutions can be grouped into three kinds. First, researchers can do more

222   work to understand and operationalize theory before conducting a study with

223   hypothesis testing (also referred to as a 'confirmatory' study). Scheel and colleagues

224   argue that premature hypothesis testing is rampant in psychology, but researchers

225   should conduct more non-confirmatory studies (sometimes referred to as

226   'exploratory' or 'discovery-oriented' studies; [36], cf. [37]). Non-confirmatory studies

227   can resolve issues of H-BUTing (hypothesizing before understanding theory) because

228   they will identify whether and when a model is relevant to their biological system by

229   understanding model assumptions and parameter space (e.g., a model assuming

230   semelparous organisms without non-overlapping generations) [37]. A non-

231   confirmatory exploration is often warranted before embarking on confirmatory work,

232   especially at the start of post-graduate research programs. An alternative approach

233   that we find to be valuable is to reproduce the results of a theoretical study on our

234   own (typically on a computer). Once this is accomplished, the models can be further

235   modified and played with to more thoroughly understand its scope and assumptions.

236

237 Second, universities can offer undergraduate and postgraduate courses on how to

238 understand theoretical and mathematical/computational models and, more broadly, the

239 role of theory in the scientific process — thereby promoting the training of pure

240 theoreticians and theoretically proficient empiricists (i.e., liaisons). Some

241 psychologists have shared their experiences on the effectiveness of such courses [33,

242 39] (see also [41]). For example, Borsboom, and van der Maas teach a 'theory

243 construction' course where, in addition to lectures on the methodology, students

244 create computer simulation models which can explain a phenomenon well but also see

245 a model is limited as it creates non-sensical values under some settings [33]. We agree

246 that such a hands-on course would be eye-opening and useful training. In the

247 biological sciences, however, theoreticians are almost always a minority group who

248 teach courses that a minority of students attend, and often at levels more advanced

249 than the average biosciences student is proficient. Thus, although education is

250 important and effective, it cannot break the status quo of early separation between

251 theoreticians (who often arrive at biology with math or physics degrees) and

252 empiricists (who tend to avoid most math and physics classes beyond prerequisites).

253 This is also because understanding math takes time, and interventions should start

254 much earlier than university education. Furthermore, we have noticed a trend in the

255 fields of ecology and evolution wherein advertisements for pure theoreticians seem to

256 be declining, whereas appointments in 'quantitative biology' are on the rise. We

257 speculate that this may reflect a more general growing trend of interest in the more

258 lucrative fields of data science and bioinformatics, which compete with the theoretical

259 sciences over a shared pool of students. Nevertheless, online education and

260 technologies can overcome the shortage of theoreticians (more discussed later).

261

262   Thirdly, theoreticians and empiricists can collaborate more. Recently, Ou and

263   colleagues have described how theoreticians can write more accessible papers by

264   being mindful of what parts of their analyses are the most difficult for empiricists to

265   understand [42]. Likewise, Grainger and colleagues have produced an excellent guide

266   for empiricists with tips on understanding and testing formal theory [41]. Notably,

267   these two papers largely overlap in their author lists, which comprise a mixture of

268   empiricists, theoreticians, and liaisons in ecology and evolutionary biology. Though

269   the primary means by which theoreticians and empiricists interact is indirectly

270   through citation of one another's publications, direct collaboration might be a more

271   effective means for reducing barriers in understanding, though the relative scarcity of

272   theoreticians in most biological fields can limit such direct interactions. Interestingly,

273   a group of psychologists have successfully attempted an exercise called the 'Many

274   Modelers Hackathon' where a few theoreticians worked with many empiricists to

275   formalize verbal theories during a 3-hour workshop [69]. This Many Modelers event

276   was successfully run as part of a 2021 conference for the Society for the Improvement

277   of Psychological Science (SIPS) – a model for the Society for Open, Reliable, and

278   Transparent Ecology and Evolutionary Biology (SORTEE). A Many-Modelers

279   Hackathon holds tremendous potential in ecology and evolution, and our field has a

280   long history of formalizing theories and designing complex experiments in which they

281   are tested (more on the potential of this type of hackathon later).

282

283   A gap in the scientific cycle and a proposed solution: systematic

284   mapping of theoretical models

285   In Figure 2, we illustrate a scientific cycle where researchers seek to understand a

286   phenomenon and develop a theory via two pathways: empirical research and

287 theoretical development. The last three decades have seen a revolution in empirical

288 research with a rise in research synthesis, especially meta-analysis [70, 71]. Meta-

289 analyses (often a part of systematic reviews) have gradually been superseding

290 traditional narrative reviews because meta-analyses can bring about many unique

291 benefits, which are impossible with narrative reviews [72]. For example, meta-

292 analyses, embedded in a systematic review, can provide an unbiased synthesis,

293 compared to potentially biased experts' opinions, concerning trends in the literature.

294 Meta-analyses as a quantitative synthesis can more objectively identify general

295 patterns and knowledge gaps, explain inconsistencies among empirical studies, and

296 generate ideas that can fledge into theories [73].

297

298 Unlike empirical meta-analyses, the synthesis of theory is primarily narrative rather

299 than systematic, representing a gap in the scientific cycle (Fig. 2) [74] (cf. [75]).

300 While it is unclear how a quantitative synthesis of theoretical literature might be

301 carried out, a systematic qualitative synthesis is still possible. Such syntheses might

302 encompass a systematic review or a systematic map (sometimes, known as a scoping

303 review; see [76, 77]). Although often confused, systematic reviews and maps have

304 different objectives [78, 79]. The former answers a specific question, often relating to

305 "What works?" (e.g., does an intervention have an effect?), but the latter addresses a

306 more general question, such as "What has already been studied and where do gaps

307 remain?" [80]. Therefore, a systematic map is a structured collection of studies, more

308 relevant to qualitatively summarizing models. Systematic maps can find general

309 patterns and knowledge gaps in a related collection of models. Further, such a map of

310 models can also identify gaps in empirical observations, for example, by examining

311 how parameter values in theoretical models are defined (e.g., whether they are based

312 on results of empirical studies or simply best guesses that require further empirical

313 validation). Although their number is limited and often (mis-)labelled as a systematic

314 review, systematic maps of models seem to exist in medicine and biology.

315

316 One noteworthy systematic map has been made for the field of life history theory.

317 Many empiricists have tested hypotheses concerning covariation between life history

318 traits such as growth rate and age of reproduction with behavioral and physiological

319 traits, theorized to arise from trade-offs between investment in current and future

320 reproduction, known as 'pace-of-life syndromes' [81]. Thus, Mathot and Frankenhuis

321 (an empiricist-theoretician duo) attempted to map theoretical models on this topic, but

322 they only identified two unique models [82]. More importantly, however, these

323 models both present ways in which covariances could arise between life history and

324 other traits without the current-future-reproduction trade-offs; that is, many previous

325 empirical studies may have presented data supporting a hypothesis that did not have

326 full theoretical support to begin with, possibly committing H-BUTing and hypothesis

327 cherry picking (Figure 1).

328

329 This example may give the impression that such mapping activities are futile, as

330 theoretical papers are rare for most questions in biology. But this is topic-dependent.

331 A systematic map of theory relating to antimicrobial resistance, for example,

332 identified 273 studies of mathematical models made at the population level [83] (see

333 also [84]); this map elucidated theoretical gaps, such as the scarcity of models on

334 transmission between humans and animals and the consideration of environmental

335 factors. Similarly, another systematic map collated 698 studies of agent-based models

336 of infectious disease transmission published from 2006 to 2015 [85]. Recently, Achter

337 and colleagues have published an opinion article promoting systematic maps (and

338 reviews) of agent-based models so that new models do not 're-invent the wheel' but

339 rather build upon previous models in environmental sciences [74]. They argue that

340 such a systematic map can lead to further refinement and the development of a theory.

341 We concur and join their call for systematic maps of mathematical and computational

342 models. Importantly, systematically mapping models could guard against hypothesis

343 cherry-picking and *h*-hacking (Figure 1). This is because a map gives a

344 comprehensive catalog of current theoretical models, which can direct the

345 development of a set of testable hypotheses, hopefully reducing the incidence of

346 cherry-picking hypotheses or liberal interpretations of theories.

347

348 Notably, bibliometric analysis (e.g., analysis of articles' citation impacts and

349 connections to other articles via citations and collaborations) exists for models of

350 antibiotic resistance [86] in addition to the systematic map mentioned above [83].

351 Some of us (SN and ML) have recently proposed a new way of synthesizing

352 literature, named 'research weaving', which combines systematic mapping and

353 bibliometrics [80]. As outlined above, systematic mapping summarizes the current

354 state of knowledge and evidence, identifying areas with research gaps and clusters

355 (i.e., an abundance of research papers). As a complementary approach, bibliometrics

356 enables researchers to see how pieces of evidence are connected. Such analysis can

357 reveal the structure and development of a field and how influential particular works

358 have been (research weaving examples, see [87, 88]). Therefore, a research weaving

359 of theoretical models holds much potential, for example, for collaboration work

360 between theoreticians and empiricists because both can contribute to such an activity

361 (cf. [74]) and can lead to the synthesis of both theoretical and empirical results

362 (Figure 2).

363

364 Furthermore, some bibliometric analyses (i.e., geographic and collaboration-network

365 analyses) can reveal the lack of inclusion, diversity, equity, and access (IDEA; more

366 often referred to as EDI or DEI) in a field of study. Therefore, this aspect can

367 potentially be harnessed to identify the areas of biology and dimensions of IDEA that

368 might benefit from targeted collaboration outside the historical trends in the field.

369 Next, we posit a hypothesis that achieving IDEA could help ameliorate a theory crisis

370 regarding the shortage of good theories (and theoreticians) and misinterpretations and

371 misapplications of theories.

372

373 **Ideas to create a tight theory-empirical feedback loop by achieving**

374 **IDEA: inclusion, diversity, equity, and access**

375 Several articles have pointed out the shortfall of IDEA in the theoretical biology

376 community [41, 89, 90]. Evidence suggests theoreticians are an impactful and

377 privileged group that lacks diversity (e.g., [91]). Yet the lack of diversity may be due

378 to the number of people in the community being much smaller than that of empiricists

379 (see [92]). Therefore, increasing the pool of theoreticians with IDEA goals in mind

380 could ameliorate both the theory crisis and the lack of diversity. Of relevance, in

381 recent years, many academic societies in biology have put forward statements and

382 created special committees for IDEA so that they encourage historically under-

383 represented and marginalized groups of people not only to join societies but also to

384 represent societies in leadership roles, with some noticeable success (cf. [93]).

385

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

434　– the local media touted it as "a miracle of Haimchar village". The program has now

435　spread to 14 countries across 5 continents (https://eedu.jp/).

436

437　A second strategy is for societies to include hackathon-like activities in their

438　conference schedules. More specifically, they could organize Many-Modeler-like

439　hackathons where theoreticians and empiricists interface to formalize theories or

440　create testable hypotheses, as discussed above [69]. It is important to note that people

441　may believe that computer programming skills are a prerequisite for participation in a

442　hackathon, but the term is now widely used for any event that is structured around

443　team-based creative problem-solving. For example, any event with the goal of

444　developing new guidelines, policies, or solutions to academic, environmental, or

445　societal issues can be called a hackathon (this is the definition the Society for the

446　Improvement of Psychological Science, SIPS, uses). A good example of such a non-

447　programming hackathon is assembling 100 ecology and evolution journal editors to

448　develop shared guidelines for accepting registered reports (which SN co-organized

449　previously; outcomes including [99-101]). Along with hackathons, a new style of

450　conferences could add 'unstructured discussion' events where participants are

451　prompted to discuss or debate ideas and issues without any pre-specified task to

452　achieve (contrasting to a hackathon). The IDEA benefits of hackathons and

453　unconferences include opportunities to work with a diverse group, including senior

454　and junior colleagues. These new conference activities have been embraced by several

455　learned societies such as the Society for the Improvement of Psychological Science

456　(SIPS), the Society for Open, Reliable, and Transparent Ecology and Evolutionary

457　Biology (SORTEE), and the Association for Interdisciplinary Meta-science and Open

458 Science (AIMOS) with successful outcomes such as publications and new

459 interdisciplinary collaborations.

460

461 For example, we (SN and ML) have organized several hackathons and unconferences

462 at SORTEE annual online meetings; one of the activities has already resulted in a

463 publication [102] (other examples of SORTEE conference publications; [103-105]).

464 This publication introduces the idea of 'MeRIT' (Methods Reporting with Initials for

465 Transparency) – how to acknowledge the methodological contributions of authors in

466 more detail (www.merit.help), complementing widely adopted CRediT (Contributor

467 Roles Taxonomy; [106]). We created MeRIT to facilitate team science where

468 providing appropriate credits to each team member can become an issue [107, 108].

469 What ecology and evolutionary biology now need is a diverse team science with

470 theoreticians and empiricists – and Many Modeler hackathons can kickstart such

471 teams. Of course, this kind of team is needed for a systematic mapping of theoretical

472 models, as introduced above.

473

Less waste and more IDEA for the future of biology

475 Here, by reviewing articles both in psychology and biology, we have described how

476 biology is also potentially prone to a theory crisis, which contributes to replication

477 crises and research waste. We have also looked at current and potential solutions,

478 notably, systematic mapping of theoretical models, to help resolve the theory crisis

479 (Figure 3). Despite past attempts to fix theory-empirical communication breakdowns,

480 dramatic success has yet to be achieved in creating a tight feedback loop between

481 theory and experimentation (cf. [41]). We contend that pursuing IDEA can, at least

482 partially, ameliorate such breakdowns and presented two concrete ideas – engaging

483 educational videos and many-modeler-like-hackathon events at conferences – that

484 academic societies are encouraged to act upon. We encourage you and your scientific

485 community to generate more ideas and action them to improve both theory-empirical

486 communication and IDEA. Finally, we eagerly anticipate a future where research

487 waste is a relic of the past and diverse team science prevails and tackles both big

488 questions in ecology and evolution and pressing ecological and environmental issues

489 human beings have been and will be facing. We believe that biology will get there if

490 biologists can replicate "a miracle of Haimchar village" again and again.

491

492

501 **Availability of Data and Materials**

502 Not Applicable

503 **Competing interests**

504 SN and ML are founding members of SORTEE (Society for Open, Reliable,

505 Transparent Ecology and Evolutionary biology)

506 **Author contributions**

507 Conceptualization: All

508 Visualization: ML

509 Writing the first draft: SN

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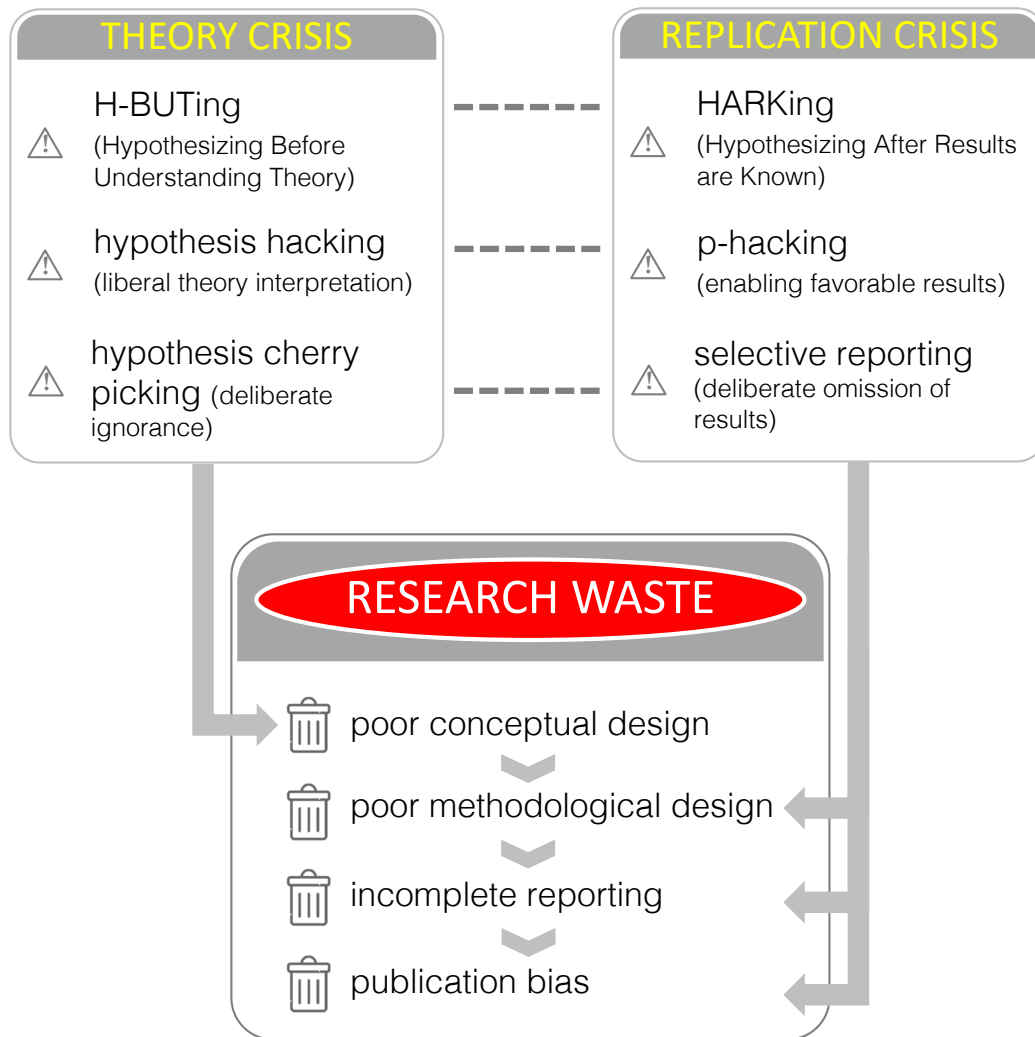
517

518 **Figures**

519 **Figure 1.**

520

521 **Fig. 1.** Questionable research practices, QRPs, arising from a theory crisis (via

522 epistemological issues) and replication crisis (via methodological issues) and how

523 they relate to research waste. QRPs concerning the theory crisis relate to poor

524 conceptual design, which comes upstream of the other 3 items of research waste

525 related to QRPs resulting from a replication crisis. Note that selective reporting and

526 incomplete reporting may sound similar, but the former indicates deliberate selection

527 of positive results while the latter represents the lack of culture in providing all the

528 results and associated outcomes, including associated data and code.

529 **Figure 2.**

530
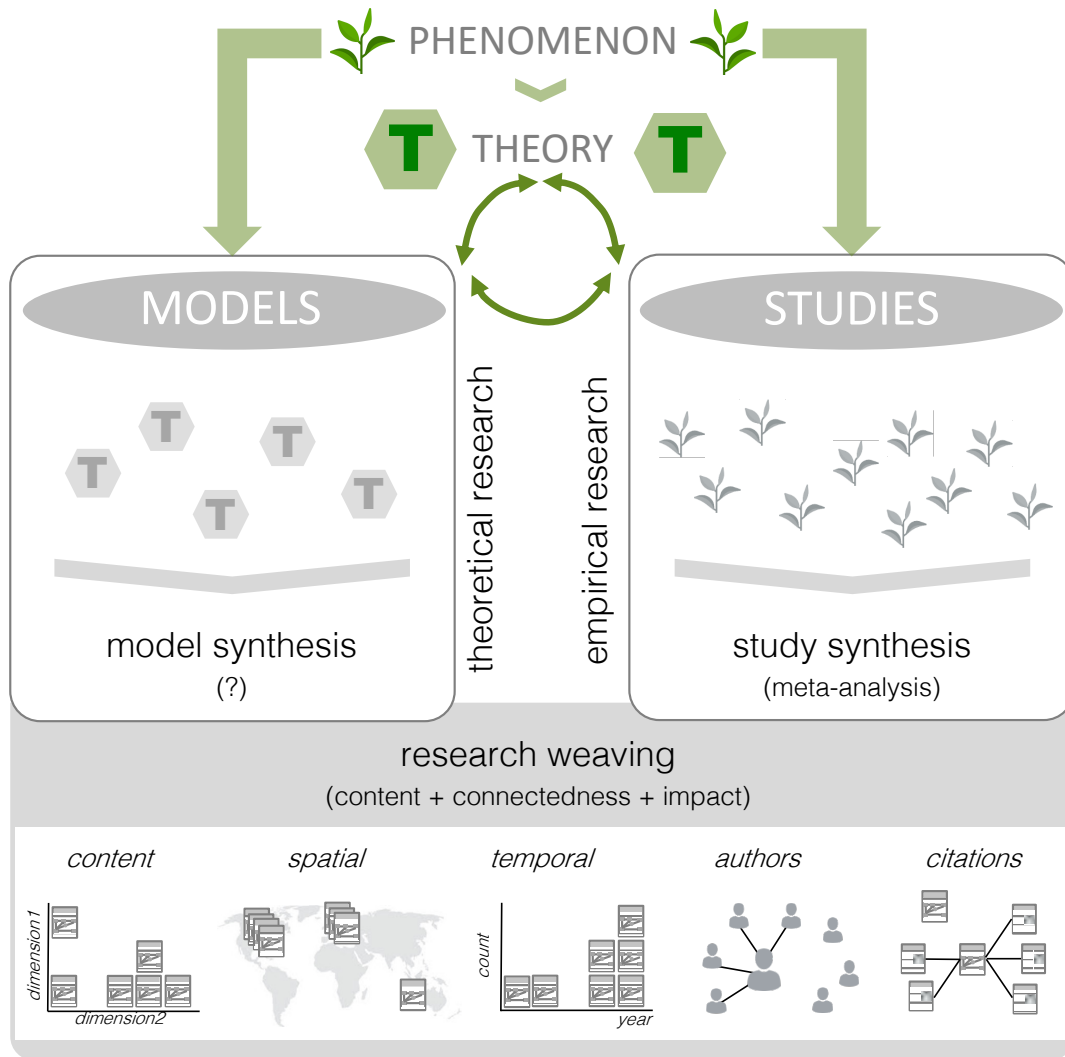
Fig. 2. A depiction of a scientific cycle. Researchers seek to understand a

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

FUTURE

Divide between empiricists and modelers

More modelers and closer collaboration with empiricists

Abundant research waste

Reduced research waste

theory
models

empirical research
reports

data

research waste

PROPOSED SOLUTIONS

development

education

collaboration

Inclusion Diversity Equity and Access (IDEA)
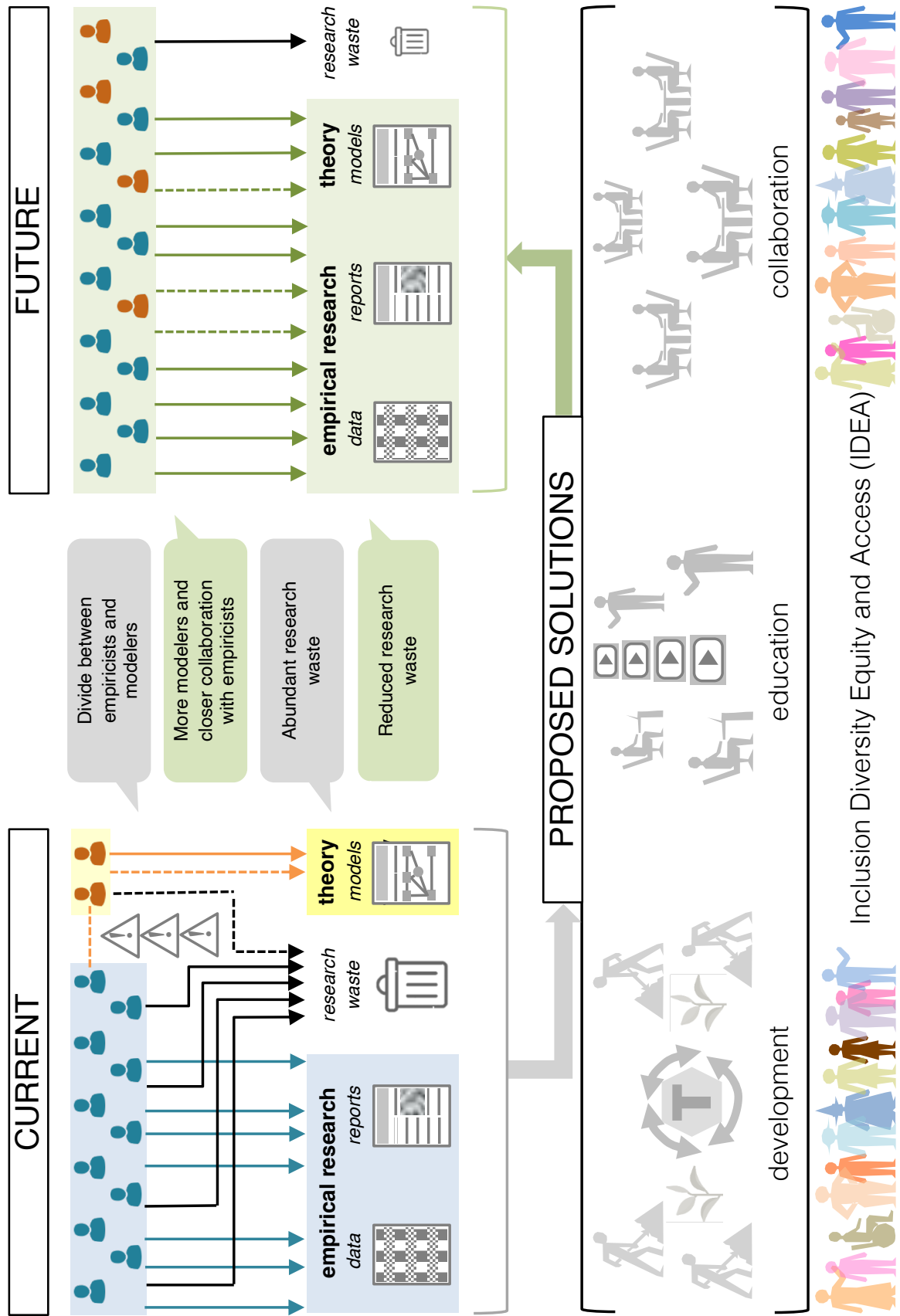
539   **Fig. 3.** The current and future of empirical and theoretical research. Currently, due to

540   miscommunications between theoreticians (minority) and empiricists (majority),

541   resulting in research waste. Via the proposed solutions, development, education and

542   collaboration, the future research community will have more theoreticians working

543   with empiricists, especially if learned societies can embrace the theory crisis and

544   promote the integration of theoretical and empirical work through IDEA. Solid lines

545   represent no direct collaborations, while dotted lines indicate direct collaborations

546   (the upper panels). While research waste may be an unavoidable part of the scientific

547   process, more research efficacy can be attainable.

548

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