IN PRESS AT ORGANIZATIONAL BEHAVIOR AND HUMAN DECISION PROCESSES

Practice What You Preach:

Credibility-Enhancing Displays and the Growth of Open Science

Gordon T. Kraft-Todd[a*] and David G. Rand[b]

[a]Department of Psychology, Boston College, McGuinn Hall 300, Chestnut Hill MA 02467

[b]Sloan School and Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, 100 Main Street, Cambridge MA 02138

*corresponding author; email: gordon.kraft-todd@bc.edu; phone: 9786216120; fax: 6175520523

Abstract

How can individual scientists most effectively spread the adoption of open science practices? Engaging in open science practices presents a social dilemma because they are individually costly (given the current incentive schemes in academia) but collectively beneficial (due to production of higher quality and more accessible science). Mechanisms for promoting cooperation in social dilemmas typically rely on normativity—but open science practices are still comparatively rare. Further, individuals may be tempted to dishonestly "virtue signal" due to growing support for open science. We formulate a solution based on the theory of credibility-enhancing displays: advocates who are known to themselves practice the behavior they are advocating for (particularly if they are prestigious) are more effective at convincing others—specifically because their actions provide an honest signal of their belief in the behavior's value. Thus, advocates for open science practices should find ways to engage in those practices visibly and often.

Introduction

In recent years, concern over scientific integrity (e.g. Simmons, Nelson, & Simonsohn, 2011) has motivated a substantial movement within the behavioral sciences (and psychology in particular) to improve a wide range of research practices. “Open science” has become a rallying cry for methodological reform (OSC, 2012), encapsulating numerous specific solutions, including preregistration, open data, and open materials (Eich et al., 2019). We refer to these practices as open science practices (OSPs) and define the concept of *open science* in its ideal sense, i.e. free and globally accessible dissemination of scientific research. We focus on the role of individuals in promoting the spread of open science from the “bottom-up” (Tankard & Paluck, 2016), rather than “top-down” approaches involving institutional actors (as discussed elsewhere, e.g. Nosek & Bar-Anan, 2012). We examine the challenge of spreading OSPs through two frameworks from the behavioral sciences—social dilemmas and social normativity—and provide a novel argument for catalyzing the spread of OSPs using the cultural evolutionary theory of *credibility-enhancing displays* (CREDs; Henrich, 2009).

We begin by briefly reviewing the recent methodological concerns motivating the open science movement in psychology. We then provide the historical and economic context for this movement, framing open science as a public good. Consistent with our public good framing, we argue that the first challenge to spreading OSPs is that they demonstrate the characteristics of a social dilemma (Everett & Earp, 2015). We briefly review mechanisms promoting cooperation in social dilemmas (Rand & Nowak, 2013), explaining the crucial role of normativity (Bicchieri, 2006). We then argue that the second challenge to spreading OSPs is their non-normativity, summarizing studies which demonstrate that despite growing support for the movement (Tenopir et al., 2015), OSPs remain uncommon (Hardwicke et al., 2020). Taken together, these data suggest a third challenge to spreading OSPs: the temptation to engage in dishonest virtue signaling (Kraft-Todd, Kleiman-Weiner, & Young, 2020). We then summarize the challenges facing the spread of OSPs before discussing the logic of our solution leveraging the theory of credibility-enhancing displays (Henrich, 2009). We then review methods to catalyze the spread of open science, including the recruitment of prestigious advocates (Henrich & Gil-White, 2001), as well as increasing its observability (e.g. Yoeli, Hoffman, Rand, & Nowak, 2013) across reputational platforms (such as personal websites and Google Scholar). We conclude with a brief consideration of the role of institutional actors in further catalyzing the spread of open science.

The recent open science movement in psychology

Over the past decade, increasing concern about the reliability of published results—including the discovery of prominent cases of data fraud (e.g. Simonsohn, 2013) as well as a series of articles that criticized unacceptably high false positive rates (e.g. OSC, 2015; Simmons et al., 2011)—spurred the declaration of a "replication crisis" in psychology (Pashler & Wagenmakers, 2012)[1]. These disturbing observations were but the latest additions to a growing collection of troubling methodological trends, e.g. the practice of hypothesizing after results are known (HARKing; Kerr, 1998), concern about underpowered studies (Rossi, 1990), and the prevalence of errors in statistical reporting (Bakker & Wicherts, 2011). Accordingly, many wrote about the problems facing replicability, including the roles of various actors such as funding institutions (Gold et al., 2019), journals (Nosek et al., 2015), editors, reviewers, university administrations, departmental hiring committees, and teachers of methodology (for reviews, see: Asendorpf et al., 2013; Munafò et al., 2017). Regarding the role of individual scientists—the

[1] Psychology is not the only field that has experienced a replication crisis—such concerns are widespread across empirical scientific disciplines (Ioannidis, 2005).

focus of the present argument—related work identified *questionable research practices* (QRPs), such as "*p*-hacking" which describes the practice of "trying multiple analyses to obtain statistical significance" (Simonsohn, Nelson, & Simmons, 2014). Research employing self-report measures (John, Loewenstein, & Prelec, 2012) and systematic review (Banks, Rogelberg, Woznyj, Landis, & Rupp, 2016) showed that the prevalence of QRPs was shockingly high.

In response to concerns over QRPs and replicability, many authors and organizations have proposed measures for improving scientific practice. "Open science" (Miguel et al., 2014; OSC, 2012; Vicente-Saez & Martinez-Fuentes, 2018) has become an umbrella term used to encompass many of these proposed solutions. The Center for Open Science's badge system (Eich et al., 2019) exemplifies the prominence of three specific research practices in open science advocacy: preregistering study design and analysis, providing open data, and providing open materials. The aim of these practices is to improve the reproducibility and replicability of science, and to facilitate scientists building off of and extending prior work (Miguel et al., 2014; Munafò et al., 2017; Nosek & Bar-Anan, 2012). First, the goal of preregistration is to make reported results more reliable by preventing researchers from (intentionally or unintentionally) selectively reporting outcomes or statistical tests that yield desired results, using problematic optional stopping rules (e.g. terminating data collection when a scientist achieves significant results), and—if hypotheses are also preregistered—HARKing (Nosek, Ebersole, DeHaven, & Mellor, 2018). Next, open data promote the evaluation of reproducibility (by allowing other researchers to directly attempt to reproduce published results), the discovery of analysis errors, and the detection of fraud, as well as allowing for novel research using data already collected for other purposes. Finally, open materials make it easier to conduct replication studies, as well as facilitating cumulative science by allowing future studies to build off prior materials. Thus, many scholars feel that wider adoption of these and related practices would be greatly beneficial (or perhaps essential) for scientific progress[2].

The historic and economic context of open science

We will first place the recent movement for open science in psychology within its historical and economic context to frame the challenges facing efforts to spread open science practices (OSPs). In sum, though the modern scientific revolution sowed the seeds of open science, open science ideals have only recently come to fruition. Alongside the budding of these ideals, advances in economic theory provide greater conceptual precision helping to illuminate the perils and promise of promoting open science.

Open science ideals developed in connection with the economics of the production of knowledge and technological innovations. The seed of open science was planted in 1439 with Gutenberg's invention of movable type (Hesse, 2018). Predating Copernicus' heliocentric theory (1543) and the start of the modern scientific revolution by just over a century (Kuhn, 2012), the printing press held the first real promise of widely disseminating knowledge. Yet, another two centuries passed before the founding of the Royal Society in England in 1660 began to free scientists from their reliance on aristocratic patronage, allowing ideals about the open dissemination of knowledge to sprout (David, 2004). Two more centuries passed before the public could begin to reap a harvest, when Edward Youmans printed the first mass-produced science periodical Popular Science in New York in 1872 (Lewenstein, 1987). The first connection between nodes of ARPANET (the precursor of the internet) in 1969 precipitated the

[2] Of course, these are not the only open science approaches—other methods of engagement in open science, for both individual and institutional actors, have been helpfully compiled elsewhere (McKiernan et al., 2016; Meyer, 2018; Nosek & Bar-Anan, 2012).

blossoming of open science as we think about it today (Crane, 1972; McLuhan, Gordon, Lamberti, & Scheffel-Dunand, 2011). Open science ideals have grown rapidly over the past half-century, imagined in intimate connection with concurrent technological developments in computer science (Nielsen, 2012).

Just over a decade before the birth of the internet allowed open science ideals to blossom, a formalism in economic theory marked the early development of the conceptual rigor required to realize these ideals. The concept of *rivalry*—i.e. whether some people consuming a good precludes others from consuming it—helped distinguish common consumer goods (e.g. clothes, which are rivalrous) from *public goods* (Samuelson, 1954). The categorization of goods was later refined by the concept of *excludability*, i.e. the extent to which access to consuming a good can be restricted (e.g. Ostrom, 1990). The resulting 2x2 matrix became a staple in economics to distinguish types of goods (Mankiw, 2008): *private goods* (excludable and rivalrous, e.g. cars), *club goods* (excludable and non-rivalrous, e.g. movie theaters), *common-pool resources* (non-excludable and rivalrous, e.g. fishing stocks), and *public goods* (non-excludable and non-rivalrous, e.g. air). Despite the success of market theory in describing the provision of private goods, unregulated markets are commonly considered inefficient in provisioning the other three classes of goods and therefore attract the attention of those interested in policy (Wood, 2017). In particular, non-excludable goods (i.e. common-pool resources and public goods) are often treated synonymously because game theoretic analysis demonstrates that they share similar incentive structures for individuals (Camerer, 2003)[3]. Both types of goods generate externalities which often requires policy intervention in order for these goods to be adequately provisioned.

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[3] Although carefully designed experiments demonstrate that individuals in these settings behave differently (Apesteguia & Maier-Rigaud, 2006).

Considered according to this framework, open science—by our definition, free and globally accessible dissemination of scientific research—is a clear example of a public good. It is self-evidently non-rivalrous, in that someone consuming knowledge does not preclude anyone else consuming it. The bulk of the work in making science "open" is to make it non-excludable, in that the goal is to ensure that no one's access to knowledge is limited. Thus open science (in its ideal form) closely resembles other concepts frequently cited as examples of public goods, such as "knowledge" (Stiglitz, 1999) and "the information commons" (Benkler, 2017). Open science provides positive externalities, in that producers of open science benefit the scientific community (as well as the general public) without compensation for providing this benefit. Open science may prove challenging for "top-down" approaches unless sufficient political will is mustered to adjust these incentives (as seen recently, e.g. by the US National Science Foundation's Directorate of Social, Behavioral and Economic Sciences; Munafò et al., 2017). We conclude by considering possible actions for institutional actors, but focus our discussion on "bottom-up" approaches to promoting open science, e.g. through social norms. Before considering this possibility, we first discuss individuals' incentives to contribute to open science.

Challenge 1: Open science is a social dilemma

In its ideal form, open science is a public good: free access to knowledge could improve the lives of individuals and enable unprecedented collaboration and societal benefit (Nielsen, 2012). In addition to our discussion above on how OSPs specifically benefit the scientific community, they also provide benefits to the public, including improving public confidence in science and the impact of government-funded research (for more consideration of these points, see Paxton & Tullett, 2019). Given these social benefits—to both the scientific community and society at large—why don't individual scientists adopt OSPs? In sum, many scholars see such practices as individually costly.

These costs come in various forms. For example, by preventing p-hacking and optional stopping, preregistration (by design) reduces the number of positive results one can expect to observe. If one's goal is merely to publish papers, then this is undesirable, because journals are more likely to publish positive results. If one's goal is to uncover the truth, however, then this is desirable, because these measures are more likely to eliminate false positives (while true positive will still be observed). Indeed, Nelson, Simmons, and Simonsohn (2012) have explicitly advocated publishing fewer papers. But given the strong incentive to publish, and the tendency for journals to favor positive results over negative results, preregistration can be costly to one's career by reducing the number of papers published.

OSPs often also require the investment of time and effort (and sometimes money, particularly in the case of journals which require authors to pay for their articles to be published with open access). Completing preregistrations—particularly when one is not familiar with the practice—can seem daunting. Consistent with this reasoning, a recent survey of attitudes toward data sharing administered to 600 psychologists (Houtkoop et al., 2018) found that 55% of participants agreed with the statement, "Preparing data is too time consuming" whereas only 33% disagreed (on a 1: "strongly disagree" to 7: "strongly agree" Likert scale; these percentages represent the sum of responses 5-7 and 1-3 respectively). Further, some respondents indicated that they did know how to share data (implying a need to invest time in learning how to do so, if they were to share their data). Similar arguments can be made regarding the sharing of materials.

Another perceived cost of open data documented in this study was the fear that the researcher will be scooped if they share their data. And—even more self-interestedly—some scholars fear that posting their data may harm their reputations by making it more likely that others will find statistical errors in their papers (Wicherts, Bakker, & Molenaar, 2011).

Overall, then, the decision of an individual scientist to engage in open sciences practices is often a matter of paying (at least perceived) personal costs to provide others with benefits. Thus, in game theoretic terms, OSPs present researchers with a social dilemma (Everett & Earp, 2015). Decades of research on game theory (Nash, 1950) have modeled these interactions (e.g. in the prisoner's dilemma; Flood, 1958), formalizing the conflict between the social efficiency of mutual cooperation (i.e. individuals paying a cost to provide others with benefits) and the self-interested rationality of defection (i.e. individuals refraining from paying this cost). Two mechanisms that are commonly invoked to explain cooperation, and which we focus on here as potential ways to support the adoption of open science practices, are *direct reciprocity* and *indirect reciprocity*.

Normativity is a key for typical cooperation interventions

Direct and indirect reciprocity are powerful mechanisms supporting human cooperation (Rand & Nowak, 2013). It is therefore tempting to suggest that they might be leveraged to promote OSPs. To summarize the argument below, these mechanisms crucially rely on cooperation being *normative*, i.e. that cooperation is either common or expected. We conclude this section by discussing the concept of normativity, and in the next section apply it to OSPs.

The theory of *direct reciprocity* (Trivers, 1971) proposed that cooperation can be supported in cases where an individual who cooperates with another has the opportunity to receive cooperation from the other in return in the future. A study of computer programs playing a prisoner’s dilemma tournament popularized this concept (Axelrod, 1984); the winner, “tit-fortat" (TFT), simply copied its partner's last move, defeating programs with more sophisticated decision-rules. This was a clear demonstration of the crucial mechanism of direct reciprocity: repeated interactions. The idea is that when a turn-taking interaction like the prisoner's dilemma is sufficiently long in duration, it is worth it for each individual to pay the cost of cooperation in each round to ensure their partner's cooperation in next. While two TFT programs that played against each other would benefit greatly from mutual cooperation over repeated interactions, a TFT program that played against a "meaner" program (such as "always defect") would not be taken as a sucker because both would simply continuously defect on each other. Even a TFT program that played against a generally "nice" program that sometimes made mistakes (i.e. usually cooperated but sometimes defected) would still reap benefits from mutual cooperation in the long run. Examining the entirety of repeated interactions on the whole, we can see that they can therefore result in cooperation, but only when it is common.

The theory of *indirect reciprocity* (Nowak & Sigmund, 1998) expanded this logic beyond two-party interactions, demonstrating that if third-parties know whether actors cooperate or defect with others, they can use this information in future interactions with these actors. Here, information about actors' behavior (which need not be reciprocal with each other) constitutes their reputation. Third-parties might gain such reputational knowledge by observing these interactions, or merely hearing about it from others. The crucial mechanism for maintaining cooperation here is the decision rule stipulating how actors' reputations should be updated after a particular behavior (Ohtsuki & Iwasa, 2006). Cooperation can be supported when the reputational decision rule (i.e. expectation) requires players to defect against actors with bad reputations and cooperate with those who have good reputations. If a sufficiently large fraction of players adopt this strategy, then it becomes self-interested to cooperate (with those in good reputation) in order to maintain a good reputation oneself. Thus, indirect reciprocity also crucially relies on cooperation being normative; here, in the sense that cooperation is (commonly) expected.

Field experiments have exploited these principles to encourage cooperation across a wide range of settings (Rand, Yoeli, & Hoffman, 2014). For example, simply providing information about what others commonly do can cause us to conform—even when such information is seemingly irrelevant—such as whether other hotel guests who stayed in the same room previously reused their towels (Goldstein, Cialdini, & Griskevicius, 2008). Because we are so concerned with our reputations, making our behavior observable to others can also cause us to conform with expectations, for example by publicly displaying sign-up sheets for a blackout prevention program in apartment building mailrooms (Yoeli et al., 2013). Accordingly, a large body of field experimental evidence has demonstrated the effectiveness of normativity information and observability to promote cooperative behaviors (for a review, see Kraft-Todd, Yoeli, Bhanot, & Rand, 2015).

Unfortunately, however, these mechanisms are typically more effective for *maintaining* cooperative behaviors once they are already common, rather than spreading new cooperative behaviors. This can be seen, for example, in theoretical models of indirect reciprocity (Ohtsuki & Iwasa, 2006) where reputation can create cooperative equilibria—that is, reputation can make it such that if everyone else is cooperating, then it is advantageous for you to also cooperate. But non-cooperation always remains an equilibrium—such that, if others are not cooperating, there is little incentive for you to cooperate. Similar effects can also be seen empirically, for example, when providing people with information about others' behavior (Cialdini et al., 2006).

Before examining whether direct and indirect reciprocity can be harnessed to encourage OSPs, it is worth providing a framework which unifies the concepts of whether cooperation is common or expected: *social normativity*. In the psychological literature, perhaps the most used framework distinguishes a behavior's *descriptive* normativity, i.e. whether people (commonly) engage in the behavior, from its *injunctive* normativity, i.e. whether there is an expectation that people should engage in the behavior (Cialdini, Kallgren, & Reno, 1991). Other recent work (Bicchieri, 2006), however, usefully delineates another dimension which is useful for understanding a behavior's normativity based on whether people's preference to engage in the behavior is socially *independent*, i.e. that people would engage in the behavior regardless of others' expectations, or socially *interdependent*, i.e. that people's decision to engage in the behavior is contingent upon others' expectations. Categorizing behaviors within this 2x2 matrix (following examples in Bicchieri, 2006), we can identify: *customs*, which are characterized by descriptive normativity and independent preferences (e.g. using an umbrella when it rains); *descriptive norms*, which are characterized by descriptive normativity and interdependent preferences (e.g. driving on the right side of the road); *moral rules*, which are characterized by injunctive normativity and independent preferences (e.g. refraining from physically harming others); and *social norms*, which are characterized by injunctive normativity and interdependent preferences (e.g. recycling). We now examine data on the social normativity of open science to understand how it fits into this framework which will inform potential interventions.

Challenge 2: Open science is (descriptively) non-normative

In considering the normativity of OSPs, it is worth noting that there is not much data on the subject, and most of what exists concerns descriptive normativity (both actual and perceived) of open data in particular; we therefore focus on this literature below. Also, while the adoption rates of open data, open materials, and preregistration are correlated, their absolute levels vary; and both their correlation and levels vary across fields (e.g. Christensen et al., 2020). In sum, OSPs appear to have low descriptive normativity and there is also widespread approval of open science, suggesting injunctive normativity and/or independent preferences to engage in OSPs.

Early in the recent open science movement, a self-report survey of 1,329 international scientists across disciplines found that only 36% reported that others could access their data easily (and only 23% among social scientists; Tenopir et al., 2011). This finding is consistent with evidence from a more recent study in which researchers requested data for 394 papers in psychology, but only 38% of authors contacted complied (Vanpaemel, Vermorgen, Deriemaecker, & Storms, 2015). Even more recently, a survey of psychologists' perceptions of descriptive norms found that 68% of participants agreed with the statement, "Sharing data is not a common practice in my field" whereas only 18% disagreed (tabulated as described above; Houtkoop et al., 2018). Encouragingly, in perhaps the most sophisticated and among the most recent self-report studies of N=2,801 social scientists (21.3% in psychology) in 2018, an estimated upper bound of 73% reported ever having publicly posted their data (although only 51% among psychologists; Christensen et al., 2020). Still, these trends are far from representative across the field as a whole, particularly in cross-sectional analysis; for example, in a contemporary audit study of 250 psychology articles published between 2014 and 2017, only 2% had open data (Hardwicke et al., 2020). These trends are similar for other OSPs: while 60% of psychologists report ever having posted open materials and 44% of psychologists report ever having preregistered an experiment (Christensen et al., 2020), of papers audited, only 14% had open materials and only 3% of papers audited had preregistered experiments (Hardwicke et al., 2020).

Thus, OSPs appear to have low descriptive normativity. Other data suggests injunctive normativity and/or socially independent motivation to engage in OSPs. A series of studies conducted over the past decade document that scientists' support for open science is on the rise (Tenopir et al., 2011; Tenopir et al., 2015; Tenopir et al., 2020). Most recently, for example, 86.7% of 2,184 scientists surveyed across disciplines (and 80% of psychologists) reported that they would be willing to share their data (Tenopir et al., 2020). Similarly, a recent study found a nearly 85% favorability rating for OSPs among psychologists (Christensen et al., 2020).
It is unclear whether support for and favorability of open science, as well as willingness to share data are indicative of injunctive normativity (expectations) or independent motivations (not contingent on others' expectations) to engage in OSPs.

Crucially for the solution we propose, social scientists also grossly underestimate the self-reported prevalence of and support for OSPs. Specifically, they predict that half as many (or fewer) other social scientists engage in and express support for OSPs as self-report that they do (Christensen et al., 2020). In other words, despite scientists' (first-order) beliefs in the benefits of open science, many have inaccurate beliefs about others' beliefs (i.e. second-order beliefs) about these benefits. Thus—unless this discrepancy is entirely due to social desirability bias in self-report (Crowne & Marlowe, 1960)—social scientists underestimate the normativity of OSPs.

What does this logic imply for interventions to encourage the spread of OSPs? In light of our discussion on encouraging cooperation above, the low descriptive normativity of OSPs suggests that it is unlikely that typical cooperation interventions will be effective in this context. While high support for OSPs might suggest their high injunctive normativity (i.e. expectations to engage in them), more evidence is needed to yield confidence in this interpretation. Troublingly, the combination of low descriptive normativity of OSPs with high support for them may create another obstacle for increasing their prevalence.

Challenge 3: The virtue signaling trap

The discrepancy between the low descriptive normativity of OSPs and high support for them creates a temptation for individual scientists: publicly express support for open science while refraining from paying the costs of engaging in OSPs, i.e. engage in "mere" (or dishonest) *virtue signaling*. The concept of virtue signaling—coined to pejoratively describe the increasingly common practice of expressing support for a cause on social media (Bartholomew, 2015)—has not received much attention in the academic literature (though see closely related work on hypocrisy; Jordan, Sommers, Bloom, & Rand, 2017). Virtue signaling bears resemblance to the constructs of "moral grandstanding" (Grubbs, Warmke, Tosi, James, & Campbell, 2019), "moral outrage" (Crockett, 2017; Spring, Cameron, & Cikara, 2018), "humblebragging" (Sezer, Gino, & Norton, 2018), and "slacktivism" (Kristofferson, White, & Peloza, 2013). We understand the concept as "conspicuously public displays of prosocial behavior" (Kraft-Todd et al., 2020), devoid of the original definition's negatively-valenced connotation, which may be genuinely or strategically motivated (or both; Jordan & Rand, 2019). The heart of the controversy over the virtue of virtue signaling is likely to be whether the signal is "honest"; for example, our disapproval of false (i.e. dishonest) virtue signaling likely drives our condemnation of hypocrisy (Jordan et al., 2017). In line with this research, we can examine the truthfulness of a signal through *costly signaling* theory (Zahavi, 1975), which we now briefly review as its logic helps to explain both this pitfall as well as our proposed solution.

In evolutionary biology, explaining the difficult problem of mate choice in sexually-reproducing animals (in the classic example, peafowl) was the original impetus for formulating costly signaling theory. In that context, the fundamental problem is that individuals (e.g. peahens) want to optimize the quality of their mate's (e.g. peacocks) genotype, but they are only able to observe potential mates' phenotypes (i.e. traits, behaviors, etc.; for peacocks, their tail), which their genotype generates in a causally complex and therefore opaque manner. To solve this problem, particularly fit potential mates evolve honest (i.e. unfakeable) signals of their fitness through costly investment in phenotypes (e.g. large and beautiful tails) that less fit potential mates cannot afford to produce. The critical mechanism is the differential costliness of these signals (e.g. large tails impede flight, increasing predation risk): the cost has to be sufficiently high for bad types that it is only worth producing the signal if you are a good type (creating a separating equilibrium; Selten, 1988).

Applying this logic to virtue signaling, we can evaluate the honesty of the signal by considering its cost. Indeed, skepticism over the authenticity of relatively costless expressions of support for causes on social media was the impetus for coining the term "virtue signaling" (Bartholomew, 2015), although we maintain that such signals may be honest or dishonest (or a mix of both). Temptation to engage in dishonest virtue signaling may be particularly high when a cause has widespread support (and may therefore be rewarded), but action is costly. Because this describes current perceptions of OSPs, we might be reasonably concerned about whether expressions in support of open science are likely to herald subsequent adoption of OSPs.

Summary of the challenges of promoting open science

At this point we have articulated the three major challenges facing the spread of OSPs:

1) Open science is a social dilemma (i.e. costly to individuals but beneficial to society), and therefore requires some mechanism to offset the disincentive individuals face to contribution.
2) OSPs are (at least descriptively) non-normative, and therefore traditional cooperation interventions relying on normativity are unlikely to be effective in this case.
3) Low descriptive normativity of and high support for OSPs creates a temptation to engage in dishonest virtue signaling, whereby individuals publicly express support for open science but refrain from taking costly action.

As we mention above, it is unclear whether high support for OSPs implies injunctive normativity and/or socially independent motivations, but for argument's sake, we can assume some heterogeneity along these dimensions. It would therefore be reasonable to believe that individuals conceptualize OSPs in one of three ways (returning to the framework introduced by Bicchieri, 2006). For behavioral scientists who perceive OSPs as having *high* injunctive normativity, they might conceptualize OSPs as (1) *moral rules*, if they are motivated to engage in OSPs regardless of others' expectations (i.e. socially independently) or as (2) *social norms*, if they are only motivated to engage in OSPs contingent on others' expectations (i.e. socially interdependently). For behavioral scientists who perceive OSPs as having *low* injunctive normativity—which may be true of those with weak second-order beliefs, i.e. who particularly underestimate their prevalence and support (Hardwicke et al., 2020), as discussed above—they might conceptualize OSPs as (3) novel and non-normative. Reflecting on the incentives behavioral scientists have for engaging in OSPs based on this typology, we can infer that type (1) will be intrinsically motivated to engage in OSPs and types (2) and (3) will be motivated to engage in OSPs to the extent that they perceive stronger expectation from others that they should, while type (3) may also require additional information about others' expectations. Even without data on the prevalence of these "types", the normativity framework (Bicchieri, 2006) provides us with a tractable formulation of the problem of encouraging the spread of OSPs: *How can we leverage those who have intrinsic motivation to engage in OSPs* (i.e. type 1) *to more widely spread their belief in the benefits of open science* (encouraging type 3) *and strengthen expectations for engaging in OSPs* (encouraging types 2 and 3)*?* Despite the complexities of this challenge, our novel solution leverages the adaptive logic of the deceptively simple idiom "actions speak louder than words."

The logic of credibility-enhancing displays: why "actions speak louder than words"

The cultural evolutionary theory of *credibility-enhancing displays* (CREDs; Henrich, 2009) provides an adaptive logic for why "actions speak louder than words." The crux of CREDs theory is that because our behaviors can be costly, they are therefore a more honest signal of our beliefs than our words. To paraphrase a classic example (Henrich, 2009), imagine that I present you with an unfamiliar mushroom that I have foraged from the woods; would you be more likely to eat it if I told you that it was edible or if you saw me eat one just like it? The reason the latter strategy is likely to be more convincing is because of the potential costs I could incur in each case; while my act of telling you that a poisonous mushroom is edible is costless (i.e. with regard to only my speech act, and not to the likely retaliation I would suffer), my act of eating a poisonous mushroom could be quite costly. Because of this difference in the potential cost, you are therefore more likely to be confident (and accurate) in your assessment of my belief (i.e. your second-order belief) when I communicate my belief via actions rather than words. In other words (to unpack the acronym), my *display enhances* your judgment of the *credibility* of my beliefs.

The adaptive problem CREDs theory addresses employs evolutionary logic, building on insights from dual-inheritance theory (Richerson & Boyd, 1978), which considers humans as the product of two intertwined evolutionary processes (i.e. "gene-culture coevolution"; Cavalli-Sforza & Feldman, 1973): biological evolution, in which our genes are subject to natural selection (Darwin, 1859), as well as cultural evolution, in which our memes (Dawkins, 1976/2006) are subject to cultural selection (Henrich & Boyd, 2002). Specifically, CREDs integrates insights from the (biological) evolutionary theory of costly signaling (Zahavi, 1975) with the (cultural) evolutionary theory of cultural learning (Henrich & McElreath, 2003; Tomasello, Kruger, & Ratner, 1993) to provide an adaptive solution the problem of others' deceptive speech, particularly with regard to particular individuals whose espoused beliefs we are more likely to copy. Though originally formulated to explain the cultural transmission of religious beliefs in particular, CREDs theory sheds light on novel problems in the cultural transmission of beliefs in general, including our central concern here: how to spread non-normative cooperation.

CREDs is primarily a theory of *cultural learning* (Henrich & McElreath, 2003; Tomasello et al., 1993). In the literature on cultural evolution (e.g. Henrich & McElreath, 2003) "culture" is often operationalized as the sum of all socially learned information in a group. Human culture is cumulative, and so the challenge for cultural learners is that we are born into a (social) world which contains vastly more information than an individual learner could hope to master in a lifetime (Henrich, 2016). An often-used example is the pencil: though a common and mundane object, the know-how required for the acquisition of materials, techniques of processing, and methods of construction required to make one are beyond the grasp of any one individual. Because we are born into a world surrounded by such objects, as well as countless rituals, traditions, norms, and other intangible aspects of culture, our best chance of success is to simply copy those around us; a strategy described as “default copying bias” (Boyd & Richerson, 1985). This bias is best (and often humorously) exemplified in the developmental literature on “overimitation” (Lyons, Young, & Keil, 2007), where numerous studies have documented human children copying the unnecessary actions of adult teachers in situations (e.g. puzzle boxes containing food) where chimpanzees do not (e.g. Nagell, Olguin, & Tomasello, 1993).

We are not mere sponges, however, but “picky infocopiers” (Henrich & Gil-White, 2001) who select our models based on their social status. Specifically, we pay special attention to a type of status unique to cultural species such as ours: *prestige*, i.e. deference received for valued skill or expertise (Henrich & Gil-White, 2001). Henrich and Gil-White (2001) usefully distinguished prestige from *dominance*, i.e. control over material resources—conceptually similar to most operationalizations of “power” (Magee & Galinsky, 2008)—which we share with many of our animal cousins. Copying prestigious individuals is an adaptive heuristic for cultural learners because among potential models, we are better served by copying not just anyone, but the most successful models. If, for example, we live in a culture which employs fish nets to acquire food, we would become better fishers by learning fish net making from the most successful fisher. Interestingly, however, we are likely to not only copy their fish net making technique, but other of the model’s idiosyncrasies, such as the cadence of their speech (Henrich & Gil-White, 2001). Prestigious individuals, then, have an outsized influence on the beliefs and behaviors we acquire. This is where deceptive speech can be particularly dangerous: if an enterprisingly selfish high prestige individual becomes aware that others look to that individual for their cultural beliefs, the exploitative entrepreneur might espouse beliefs that strictly benefit them at the cost of others (e.g. “I talk to angels. For a small monthly payment, I can offer you the best seat in heaven!"). Thus a prestigious individual who is also selfish can exploit the pickiness of our default copying bias for their personal gain.

Leveraging the logic of *costly signaling theory* (Zahavi, 1975; reviewed above), CREDs theory explains the adaptive logic of our defense against such deceptive speech (particularly from prestigious individuals): because actions can be costly (but talk is cheap), we should pay more attention to others' actions than their words when forming second-order beliefs (i.e. our beliefs about their beliefs). In the context of the transmission of religious beliefs—a primary concern for the original articulation of CREDs theory (Henrich, 2009)—we can compare our first would-be prophet ("I talk to angels. For a small monthly payment, I can offer you the best seat in heaven!") with a second, who says the same words, but also takes a vow of celibacy (e.g. because the angels told them to). The extreme cost the second pays suggests that we would be more likely to believe that they truly believe in their divine connection than the first (and consequently, that their "church" receives more donations).

In sum, the cultural evolutionary theory of CREDs posits that we are cultural learners with a default copying bias, and therefore the beliefs of people around us influence our beliefs, particularly individuals with high prestige. A problem arises because some individuals employ deceptive speech for their own benefit, and an adaptive solution is that we make stronger inferences about others' beliefs when they engage in costly behaviors which demonstrate the commitment to those beliefs. We now apply this logic the challenges of spreading open science.

CREDs and the spread of open science

To reiterate, we have described three challenges facing the spread of open science: 1) it is a social dilemma; 2) OSPs are (descriptively) non-normative; and 3) individuals may be tempted to dishonestly virtue signal their support for open science. Further, we have delineated three types of scientists with regard to their attitudes towards open science: 1) those who conceive of it as a moral rule, perceiving it to be injunctively normative (i.e. expected) and who are intrinsically (i.e. socially independently) motivated to engage in OSPs; 2) those who conceive of it as a social norm, perceiving it to be injunctively normative (i.e. expected) and whose (socially interdependent) motivation to engage in OSPs depends on others' expectations; and 3) those who perceive it injunctively non-normative (i.e. not expected) but who might have (socially interdependent) motivation to engage in OSPs depending on others' expectations. We now consider how our CREDs-inspired solution—making (type 3) scientists' OSPs more observable (particularly if they are prestigious)—addresses each of these challenges and provide practical methods of implementing this solution.

How does our CREDs-based solution address the challenge of dishonest virtue signaling? Because OSPs are both descriptively non-normative and are highly approved of, there is a risk that individuals will be tempted to merely express their support for open science (i.e. dishonestly virtue signal) without engaging in the relevant costly behaviors. Virtue signaling, as we define it, may be dishonest (as in the original conceptualization of the term; Bartholomew, 2015) or honest (or both; Jordan & Rand, 2019). When determining the honesty of signal, it is crucial to consider its cost (Zahavi, 1975), and CREDs theory explains that because our actions can be costly, they are therefore more likely to be interpreted as an honest signal of our beliefs (Henrich, 2009). In focusing on the visibility of open science *behaviors*, rather than mere speech, our solution therefore both counteracts attributions of dishonest virtue signaling, while also making it more likely that others believe that we believe in the benefits of open science. Therefore, we encourage advocates of open science to rely not on rhetorically expounding upon the benefits of open science, but on finding ways to observably demonstrate their OSPs, and provide examples of how this might be accomplished below.

How does our CREDs-based solution address the challenge that open science is a social dilemma? Because many express support for open science, it is unlikely that they do not understand the social benefit of OSPs. Yet, the low descriptive normativity of OSPs suggests that they may instead overestimate the personal cost or underestimate the personal benefit of engaging in them. Scientists' widespread support of OSPs might suggest that they have expectations that others will engage in OSPs; if so, scientists could accrue personal benefits by fulfilling these expectations. Therefore, scientists may underestimate these benefits because they underestimate others' approval of and engagement in OSPs (Hardwicke et al., 2020). Thus, similar to typical cases CREDs theory considers (e.g. religious beliefs or the edibility of novel foods), the crucial inference regards the benefit to the individual undertaking the action (as opposed to the societal benefit of open science, which scientists presumably know). Regardless, CREDs theory explains how, by observing scientists who engage in OSPs, others are more likely to infer that those scientists believe it is worth paying those costs. Thus, if we encourage scientists who are intrinsically motivated to engage in OSPs to make their behavior more observable, others will be more likely to believe in the high personal benefit (or low personal cost) of engaging in OSPs.

CREDs theory further suggests that the effect of making intrinsically motivated scientists' OSPs more visible may be amplified if those individuals are prestigious. It may seem natural that the current generation of early career researchers who came of age during the replication crisis would be predisposed towards adopt OSPs. Accordingly, younger scholars support open sciences practices to a greater extent than older scientists (Tenopir et al., 2015). Yet

CREDs theory suggests that as picky infocopiers, people are biased towards adopting the beliefs of prestigious role models whose success is already well established. Thus, it is incumbent upon senior scientists to also visibly adopt OSPs in order to catalyze their spread. Furthermore, given the job security that tenure provides, OSPs are less costly for senior researchers than they may be for early career researchers. Prestigious senior researchers, therefore, have the opportunity to create bigger change at lower cost—and we call upon them to do so.

How, then, can we amplify the observability of OSPs? The Center for Open Science introduced open science badges (Eich et al., 2019), which are one very effective way to facilitate this. They make it easy for those who practice open science to visibly demonstrate their engagement in the context of the papers they publish. The badges may also be seen as a signal that the work itself is more likely to be replicable, which may make people more likely to cite it (McKiernan et al., 2016; Piwowar & Vision, 2013). These badges act as a CRED, and thus help convince others through belief contagion. The badges also signal that the authors of the paper personally value improving science, and so they may also help to create reputational rewards by communicating the authors' expectation that others should too. This is particularly true for prestigious scientists because observers may infer that if they also engage in OSPs, they might gain increased opportunities for collaboration, hiring, awards, etc.

Beyond submitting to journals which employ open science badges—and pursuing this certification when they do—there are also many other ways for advocates to make their OSPs visible. For example, during presentations, scholars can explicitly indicate when they preregistered experiments or when data and materials are available. Further, personal research websites, CVs, and social media accounts can be used to provide links to preregistrations, open data, and open materials. Reviewers can also ask authors to add explicit statements to papers about whether or not authors preregistered their experiments and whether data and materials are available (where it is not already required by journals). This helps eliminate plausible deniability and create common knowledge regarding the use of these practices (Yoeli et al., 2017). Even more stringent efforts have been organized, for example the Peer Reviewers' Openness Initiative, where peer reviewers pledge to only review manuscripts ascribing to OSPs (Dahrendorf et al., 2019). Finally, in their mentorship of undergraduate and graduate scholars, established scholars could normalize OSPs by making it lab policy to follow these guidelines and instructors of research methods and statistics classes could include modules on OSPs (Sarafoglou, Hoogeveen, Matzke, & Wagenmakers, 2020), in particular demonstrating their utility in addressing questionable research practices (QRPs; as discussed above).

How does our CREDs-based solution address the challenge that OSPs are non-normative? As we reviewed above, most interventions to increase cooperation in social dilemmas rely on normativity. Without that lever, the power of actions (beyond words) to communicate the benefits of novel forms of cooperation may yet be sufficient. We have demonstrated the power of the CREDs framework for promoting a non-normative public good (residential solar panel installation; Kraft-Todd, Bollinger, Gillingham, Lamp, & Rand, 2018). Residential solar is akin to open science practices insomuch as although adoption is growing in popularity, it remains quite rare—for example, only about 0.3% of homes in the US had residential solar at the time of our study (Rogers & Wisland, 2014). Consistent with CREDs theory, community organizers who had installed solar panels themselves (compared to those who had not) were 63% more effective in encouraging residents in their town to install too. This research suggests that CREDs-inspired interventions may be able to overcome the barrier of non-normativity in the motivationally challenging context of encouraging contributions to public goods. In the context of open science, we would therefore suggest recruiting advocates who themselves demonstrate observable OSPs.

Network effects may also play a role in the spread of open science. In particular, it is useful to think about the role of prestigious individuals for catalyzing contagion within their social networks. Social network analysis has been employed to investigate relevant outcomes in academia, e.g. by investigating how coauthor networks predict h-index (McCarty, Jawitz, Hopkins, & Goldman, 2013) and future success (Daud, Ahmad, Malik, & Che, 2015). Further, focal individuals within local networks who have the opportunity to lower the cost or increase the benefits of public goods contributions can facilitate cooperation (McAuliffe, Wrangham, Glowacki, & Russell Andrew, 2015). In our context, highly prestigious individuals, such as principal investigators in a lab, have the ability to alter the incentives of OSPs, e.g. by creating standardized workflows for graduate students which streamline the participation in OSPs (thus lowering the cost of engaging in them). Also, unlike the simple contagion (e.g. disease or ideas), complex contagion (e.g. adopting media technology or new fashions) in social networks relies on multiple close contacts adopting them (Centola & Macy, 2007). Thus, for individuals to adopt OSPs, it may require a critical mass of others within their social networks to adopt OSPs, and prestigious individuals (e.g. senior members in a departmental area) can have an outsized impact in changing local norms by adopting OSPs themselves, triggering local cascades (e.g. to other professors in their area, to their respective lab members, to other areas in the department, etc.).

Here, we have reviewed various ways to increase the visibility of scientists' OSPs to amplify the (honest) signal that open science is beneficial and expected. By leveraging the behaviors (rather than words) of scientists who are intrinsically motivated to engage in OSPs (particularly those who are prestigious), other scientists who may only engage in OSPs if they perceive a sufficiently high personal benefit or expectation to do may follow suit. Our CREDs-based approach may therefore be able to help spread open science, even though it requires individuals to resist the temptation to dishonestly virtue signal and contribute to a non-normative public good.

Promoting open science from the top-down

Although we have focused our discussion on "bottom-up" approaches to norm change (Tankard & Paluck, 2016) by considering the actions that individual scientists can take to facilitate the spread of open sciences practices, there is of course also great potential for institutional actors to affect this change as well. Indeed, in grappling with the problems facing replicability, the recent open science movement has sparked discussions of the roles of funding institutions (Gold et al., 2019; Paxton & Tullett, 2019), journals (Nosek et al., 2015), editors, reviewers, university administrations, departmental hiring committees, and teachers of methodology (covered more extensively in other reviews; e.g. Asendorpf et al., 2013; Houtkoop et al., 2018; Munafò et al., 2017). While a complete account of these arguments is beyond the scope of the present work, we now briefly consider how institutional actors might also confront the challenge of spreading open science according to our framework.

As in our discussion of individuals, institutional action consistent with their statements in support of open science can also avoid perceptions of dishonest virtue signaling. For example, in addition to including pledges in support of open science on relevant webpages and materials, universities and departments could demonstrate their commitment to these practices by including links to faculty members' OSPs on their research pages (e.g. Reimer et al., 2019). Publication databases—most notably Google Scholar, but also preprint websites such as SSRN or

PsyArXiv—could also provide links (via automation or user input) to preregistrations, open data, and open materials along with their article indexing.

Institutions have the ability to directly address the extent to which open science represents a social dilemma by changing individuals' incentives. For example, journals can implement OSF badges (Eich et al., 2019) in their publishing procedure to increase the benefit individuals receive for engaging in OSPs. While APS journals have been an early adopter of open science badges in the psychology literature, other journals could easily adopt this system as well (although see challenges to doing so; Christian, Gooch, Vision, & Hull, 2020). The journal Psychological Science demonstrated the effectiveness of this approach; in 2019—six years after adopting the badge system—60% of papers had open data badges, although only 30% had preregistration badges and 50% had open materials badges (Lindsay, 2019). Rather than increasing the benefit of engaging in OSPs, journals also have much room for growth in the use of the more stringent strategy of requiring OSPs for publication (thereby increasing the cost for not engaging in OSPs). A recent study of 447 journals (21.5% in the social sciences) found that only 2.7% required open data for publication while an additional 7.8% required open data without stating its impact on publication (Resnik et al., 2019). Journals are not the only institutional actors with such power over affecting individuals' incentives; for example, funding agencies could require open science plans as a condition for obtaining grants and further, audit these practices in their reporting requirements. Also, hiring and tenure committees could incorporate open science into their decision criteria, e.g. by requiring application materials to demonstrate OSPs.

Institutional actors can also confront the challenge of open science's non-normativity. Consistent with our CREDs-based solution, highly prestigious institutions could begin to incorporate consideration of open science into their decision-making procedures to signal to other institutions (as well as individuals) the value of open science. Evidence is emerging that prestigious institutions are early adopters of OSPs—for example, journals with higher impact factors are more likely to require OSPs (Resnik et al., 2019)—although how this affects the spread of OSPs remains an open question. Regardless of an institution's prestige, institutions can leverage their communications to frame open science in a more favorable normative light. Suppose, for example, that high support for OSPs indicates high injunctive normativity; evidence from the lab that injunctive normativity on its own can encourage cooperation (Raihani & McAuliffe, 2014) might encourage a communications officer to leverage this information to promote open science. Yet, evidence from field experiments demonstrates that conflicting descriptive and injunctive normativity (as would be the case with open science) can have deleterious effects. A study in the Petrified National Forest demonstrated this most famously (Cialdini et al., 2006); signs were posted that implored visitors not to remove specimens because of how common this behavior was, and this intervention paradoxically *increased* the removal of petrified wood. Descriptive norms do not always override injunctive norms, however (Cialdini, Reno, & Kallgren, 1990); these authors argue that which norm people comply with will depend on which is salient to them in the moment. Therefore focusing messaging efforts on injunctive (rather than descriptive) norms for open science may have potential; although it is a narrow tightrope to walk. Perhaps more promising, research on "dynamic" norms, i.e. emphasizing how norms are changing over time (rather than typical considerations of "static" norms), shows that providing this information can be effective in changing behavior (e.g. to reduce meat consumption; Sparkman & Walton, 2017) even without strong descriptive norms.

Outside the regular operating procedure of traditional institutions, there are also opportunities for entrepreneurs to create systems to support open science through "gamification." A survey of high-energy physicists that found favorable attitudes toward such efforts to tracking OSPs (Feger, Dallmeier-Tiessen, Wozniak, & Schmidt, 2019) provides suggestive evidence for such an approach. The gamification of open science might could include, for example, developing author pages that augment Google Scholar citation data with indications of which papers used various OSPs (in the simplest version, just the author's self-report through the page-maintenance interface). The pages could then provide aggregate statistics showing the fraction of the authors' papers (overall and in, say, the last 5 years) that involved each open science practice. Again, such data could also be used to augment author pages, and leaderboards (e.g. on the review tracking site Publons) could potentially be created that indicate which scholars are engaging in open science to the greatest extent (although care would need to be taken that inducing an explicitly competitive frame to such public good contributions did not prove counterproductive).

Conclusion

Despite the societal benefits of and widespread support for open science, advocates face a three-pronged challenge: open science practices are individually costly, they are uncommon (i.e. descriptively non-normative), and they present individuals with a temptation to (dishonestly) virtue signal. We frame our "bottom-up" approach (Tankard & Paluck, 2016) to the problem of spreading open science in light of research on social dilemmas (Rand & Nowak, 2013) and social normativity (Bicchieri, 2006). We present a solution based on the theory of credibility-enhancing displays (CREDs; Henrich, 2009), which provides an adaptive logic for why "actions speak louder than words." We suggest that advocates—particularly individuals who are intrinsically motivated and those with high prestige—who make their open science practices (OSPs) more observable may effectively overcome the challenges to spreading open science. We provide a number of practical methods for applying this strategy and briefly consider the role of institutional actors. We hope our discussion inspires individuals and institutions to innovate additional ways to advertise their behaviors that contribute to open science.

Acknowledgments:

We gratefully acknowledge insightful comments from Jillian Jordan and funding from the John Templeton Foundation.

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