Blockchain and the Scientific Method

James A. Evans,[1] Kweku Opoku-Agyemang,[2] Krishna Ratakonda,[3] Kush R. Varshney,[3] Lav R. Varshney[4,5]
[1]University of Chicago, [2]University of California, Berkeley, [3]IBM, [4]University of Illinois Urbana-Champaign,
[5]Brookhaven National Laboratory (lvarshney@bnl.gov)

I. Introduction

As more subtle, large-scale, or complex phenomena are being studied, scientific knowledge claims are becoming less trusted and alarms of a 'crisis in science' have been raised. The basic experimental hypothesis-testing process of scientific research that crystallized five centuries ago, however, has largely remained intertwined with trust embodied in institutions such as learned societies, universities, journals, and funding agencies. Such institutional trust enabled the scaling of the scientific enterprise beyond small social networks of participants with long-term relationships, but may be insufficient when the file drawer problem, p-hacking, hypothesizing after the results are known (HARKing), insufficient computational replicability, corrupted reagents, overstressed peer-review systems, misaligned incentives, biases in favor of particular interests, opaque misconduct investigations, and other such factors have eroded trust. In addition to eroded trust, science is also facing a challenge of reduced productivity. For example, the number of disruptive papers and novel concepts per unit cost have been slowing considerably. Known as Eroom's Law (the reverse of Moore's Law), the cost of drug discovery is doubling every nine years. Nearly all of these challenges are coming to the forefront during the scientific community's response to the COVID-19 pandemic; scientists and institutions are often bypassing their prevailing practices and culture in favor of expedience. These actions are being taken informally without attendant changes in the supporting infrastructure and tools.

Novel cognitive and communication tools have a general-purpose ability to accelerate scientific progress. Chalk and slate changed scientists' cognitive processes; modern statistical and computational tools enable discovery within large datasets; and artificial intelligence technologies are poised to suggest novel hypotheses. The printing press changed scientific communication by standardizing format in journals and facilitated citing previous publications; photocopying enabled a shift from editorial review to peer review; and preprint servers allowed timestamps to establish priority and credit, while also making knowledge public without delay. New blockchain technologies—originally developed to underpin cryptocurrencies but having recently found use in domains as diverse as global trade, political elections, food safety, and property rights management—offer an alternative mode of technology-mediated distributed trust. As such, blockchain has been touted as a panacea to numerous of science's ills. Several prototypes have been deployed for clinical trials, journals, etc. Yet, many argue that a simple database is all that is needed when blockchain is deployed. Here we argue that there are several problems in scientific discovery for which blockchain is appropriate.

At a high level, we propose the following paradigm for scientific research. A funding entity solicits research on a general topic of inquiry or specific goal and earmarks a purse that is to be awarded to contributors in advance to pursue certain goals or afterwards once those goals are met. Contributions in all parts of the scientific method are recognized, not only the final discovery. For example, background research, hypothesis generation, experimental design and preparation, data collection, data analysis, exposition of results, and simplification of conclusions for policymakers and the general public are all disaggregated individual steps of the scientific method that may receive awards for an eventual discovery. All contributions are treated as transactions and posted to a permissioned blockchain in appropriate formats without haste, perhaps in the form of non-fungible tokens (NFTs). They are immediately available for public inspection and expert review. Smart contracts trigger automatic solicitation of peer review as well as meta-analysis and assimilation of new contributions into the body of knowledge. Reproduction and replication are also incentivized in award schemes. In the case of post hoc prizes and bounties, the final rewards are also triggered by smart contracts once a goal has been met, reviewed, and sufficiently replicated. Findings can then be background research for a new cycle of the scientific method.

Technology is never a complete solution in the absence of cultural change, but here we argue that blockchain technologies have the potential to act as joint cognitive and communication (collective intelligence) tools to accelerate trusted science. Indeed, blockchain permits a reimagining of the scientific process in the digitally connected age, where anyone anywhere may contribute to a collectively evolving body of knowledge and be rewarded for it: an alternative scientific culture and practice of representation whose virtues could be accentuated in distributed discovery across numerous branches of science. We provide some further detail in the sequel.

II. Specific Challenges

It is clear that blockchain technologies may mitigate reproducibility and replicability challenges in science, but here we focus on other challenges.

A. Disaggregation of Contribution

Scientific papers are the key currency in the economics of science. Yet, there is a lot of scientific activity around building digital tools including data and code that is not credited by such a system. Given the growing importance of such tool building in science, however, it is important to ensure mechanisms of credit for workers engaged in these activities. It is clear that if an immutable ledger of smart contracts is used to keep track of analysis protocols, then all contributions will be recorded. This is not surprising since blockchain itself is an offshoot of cryptocurrency systems like bitcoin, which must keep records of all contributions as transactions. Engineering effort may be required to make things work in the context of human behavior, which itself will suggest new theoretical research questions, e.g. in the game theory of mechanism design. Moreover, although there are debates as to whether publications should be tours de force or least publishable units, scientific publications are certainly 'chunky' and only reveal the hypothesis and data *if* the findings 'work out.' This means that many hypotheses, datasets, and findings are omitted from the literature. A potential blockchain remedy is to 'publish' and link to hypotheses, data, methods, findings, and relevance, while yielding more equitable incentive structures.

B. Open, Fair, and Rapid Dissemination

Although many journals are named *Transactions*, current scientific publishing in scholarly conferences and journals is said to be slow and closed. One might wonder if blockchain-based mediums for dissemination may replace journals, building on current preprint mandate trends that have been motivated in part by mechanisms for establishing priority by researchers and in part as remedies for paywalls for readers. A promising innovation that is already influencing the scientific method is using blockchain to add a layer of rigor to peer-review by making the process more transparent than is currently possible. Such a solution improves on the status quo in terms of promoting reviewer recognition while lessening ethical compromises. Such innovations can help journals and outlets protect the integrity of their internal processes and potentially limit the concern of being biased in favor of better-resourced researchers, or researchers with whom they share professional relationships. Although there are protocols to prevent such outcomes, many fields are sufficiently small that overlap is difficult to entirely avoid in practice. We argue that such issues are inherently challenging for many disciplines and blockchain may help professions to be more open to novelty. Any datastore based on blockchain must be trusted by the entire academic community to scale, which is why we advocate for systems that are fully owned by the communities they hope to serve. Blockchain-based review and dissemination may also increase trust in fast-moving crisis situations such as the COVID-19 pandemic, and may facilitate dissemination to policymakers and the general public.

C. Post Hoc Filtering and Analysis

Information overload is a central concern in scientific knowledge, and this may cause an especially strong lock-in of paradigms in large and growing fields. Moreover, just because the data stored in a blockchain is immutable does not imply that scientific knowledge is immutable. In fact, scientific knowledge is mutable and continually evolves as new investigations are carried out. The same empirical results in the blockchain may be interpreted by different scientists differently, since they may have differing priors. Here we argue that crowdsourced and semi-automated annotation of meta-data with findings could allow the Bayesian update of facts from throughout the scientific literature. In fact, one might automate meta-analyses from raw data directly, or using AI techniques to read papers and perform meta-analyses. Such constant assessment and incorporation of new results can accelerate science.

D. Funding and What to Work On?

Scientific research, whether motivated by public-interest or curiosity-driven considerations, often requires funding. Many considerations enter into decisions about what types of scientific studies to fund, including striking a balance between exploratory and confirmatory research. Both safe and bold research help move science forward, but there is bias against novelty in science funding. Often these decisions informally reflect the mission, goals, and values of the funding agency. Inducement prizes allow strong expression of values, but they are inefficient as all-pay auctions. Grants have an information asymmetry / principal-agent problem. Contracting approaches are usually used for principal-agent problems, but better monitoring alleviates it also. Blockchains may provide an approach to monitoring that gives stronger ability for funding agencies to express these values.

Besides the mission, goals, and values of the funding agency, the current state of knowledge within a field of study is also important in funding decisions. Moreover, exploratory research is more susceptible to non-replication, whereas confirmatory research is less likely to uncover exciting new discoveries. Fields investigating potentially ground-breaking avenues will produce results that are less replicable, on average, than fields that investigate highly likely, almost-established results. Indeed, a field could achieve near-perfect replicability if it limited its investigations to prosaic phenomena that were already well known. As such, the *uncertainty* could be one blockchain-enabled value that could be operationalized using prior probability. Tension can arise between replicability and discovery, specifically between the replicability and the novelty of the results. Hypotheses with low a priori probabilities are less likely to be replicated.

Further, smart contracts issued by funding agencies could enable programmatic articulation of their goals. Smart contracts could also support funded markets for ideas, conjectures, and other contributions with programmatic expression of goals.