
Unchaining Collective Intelligence for Science, Research and Technology Development by Blockchain-Boosted Community Participation

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ABSTRACT

Since its launch just over a decade ago by the cryptocurrency Bitcoin, the distributed ledger technology (DLT) blockchain has followed a breathtaking trajectory into manifold application spaces. This paper analyses how key factors underpinning the success of this ground-breaking “internet of value” technology, such as staking of collateral (“skin in the game”), competitive crowdsourcing, crowdfunding, and prediction markets, can be applied to substantially innovate the legacy organization of science, research and technology development (RTD).

Here, we elaborate a highly integrative, community-based strategy where a token-based crypto-economy supports finding best possible consensus, trust and truth through adding unconventional elements known from reputation systems, betting, secondary markets and social networking. These tokens support the holder’s formalized reputation, and are used in liquid-democracy style governance and arbitration within projects or community-driven initiatives. This participatory research model serves as a solid basis for comprehensively leveraging collective intelligence by effectively incentivizing contributions from the crowd, such as intellectual property (IP), work, validation, assessment, infrastructure, education, assessment, governance, publication, and promotion of projects. On the analogy of its current blockbusters like peer-to-peer structured decentralized finance (“DeFi”), blockchain technology can seminally enhance the efficiency of science and RTD initiatives, even permitting to fully stage operations as a chiefless Decentralised Autonomous Organization (DAOs).

INDEX TERMS

blockchain, distributed ledger technology, science, research, token economy, cryptoeconomy, consensus, reputation systems, liquid democracy, participatory research, collective intelligence, wisdom of the crowd, decentralization

1 INTRODUCTION

From a bigger perspective, science, research and technology development (RTD) pursue the overarching goal of generating beneficial knowledge that aims to contribute to the good of mankind. Basic science is driven by the quest for learning and understanding as a core trait of human nature; often pursuing commercial

objectives, technology improves the quality of our lives, e.g., in terms of addressing fundamental needs in food, health and education, or providing convenience such as water, energy, transportation, automation, communication and entertainment.

While, at least in the public eye, major breakthroughs are often linked to a single person, practically all historical achievements in science and RTD are deeply rooted in the foundational work of a community which produced the fundamental research as well as enabling methods, equipment, and infrastructure within a supporting culture and, last but not least, a pool of highly qualified and motivated talent stimulating productivity within a competitive environment.

Generation of basic knowledge is presently, for the most part, sponsored by governmental organisations and foundations to address health, economic, scientific, societal, ethical, and environmental topics and issues, to boost prestige through high-impact publicity, or by businesses to gain a competitive edge for eventually enhancing their profits. Involvement of individuals in such initiatives may be motivated by a variety of objectives, ranging from career opportunity, reputation, social recognition, creativity, altruism and monetary rewards.

Recent decades have seen a strong trend towards globalization that has been enabled by sophisticated networks of logistics and highly intertwined global supply chains which are meticulously coordinated by transnationally operating information and communication technology (ICT). With the wide-scale penetration of internet, ensued by the availability of cloud computing and artificial intelligence (AI), possibly accessed by science as a service models [1], and 5G networks for real-time applications, even in remote and economically disadvantaged locations, access to and creation of knowledge has already reached historically unprecedented levels.

The recent past has also seen game-changing advances in ubiquitous / additive manufacturing (UM / AM), primarily by 3D printing [2], or open-source platforms, e.g., in software [3], electronics [4] and microsystems [5], virtualisation, for instance, through “digital twins” [6], open-access facilities for prototyping, characterization and application development [7-11] and data on demand [12]. The wide-scale availability of these novel resources will progressively empower individuals from the crowd, such as the “citizen scientist” [13, 14] or “garage entrepreneur”, to create, customize or sell many digital and physical goods from and to practically anywhere. In addition, the emergence of redistributed manufacture (RDM) echoes that production is becoming increasingly decentralised, e.g., even in the highly regulated pharmaceutical industry [15, 16] and aerospace [17].

Open science and community-based participatory research (CBPR) for socio-environmental issues is another area of focus [18]. Here, discovering and sharing goals that actors with different interests could tackle together (a ‘transcend’ method), in addition to ethical equity, fair access to data, and dialog, represent essential components. The constructive interplay of these strong trends set the path for a democratization of an inclusive science and RTD landscape where a wide range of actors, whether institutions or freelancers [19-21], can decisively contribute and receive their fair share in value creation.

CBPR has been regarded as the gold standard for equitable and partnered research in traditional communities [22]. In capturing the collaborative process between community-based organizations and academic investigators, CBPR models have demonstrated the potential to make research more responsive to existing needs, and to improve a community’s ability to address a range of common issues [23]. Such CBPR approaches can be enhanced by token systems (“tokenisation”) which, on the one hand, crypto-economically incentivize efficient crowdsourcing of collective intelligence [24, 25], while, on the other hand, requesting cryptoassets as collateral (“skin in the game”) to assure good quality of contributions.

This way such blockchain-based crypto-economical tools, possibly in tandem with the aforementioned CBPR, can also be key to address the notorious reproducibility crisis of science [26, 27]. The pervasive failure to replicate previous findings often roots in inappropriate practices of science, e.g., poor experimental design leading, almost unavoidably, to variability between the groups [28], hypothesizing after the results are known (“HARKing”) [29, 30], selective analysis and reporting [31-33], p-value hacking [34, 35], and missing raw data [36, 37]. Freedman *et al.* [38] demonstrated that in the United States, the high rate of irreproducibility,

estimated at 50% in preclinical research, induced high economical loss of approximately US\$28 billion per annum. In addition to waste of money and time, the poor reproducibility of data tends to markedly demotivate the idealistic scientific community.

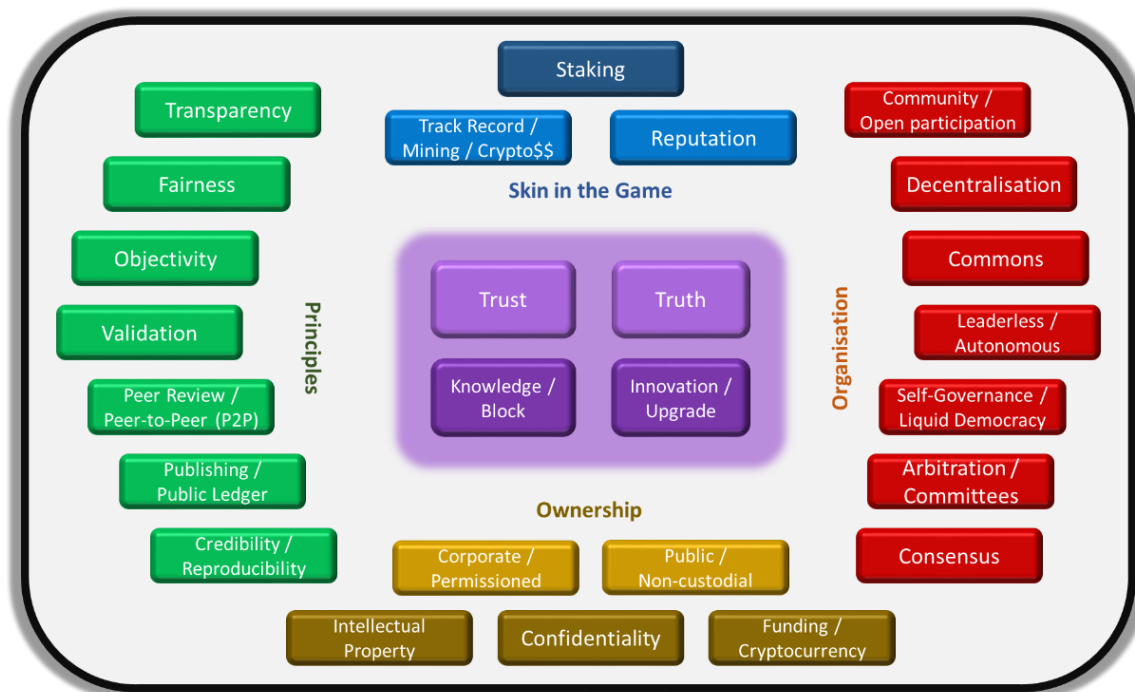


Figure 1 Buzz words in science and RTD which directly connect to equivalent elements in blockchain technology. The central objective is to create blocks of trust-and truthful knowledge / innovation and log them a public or permissioned ledger. Credibility of contributions is rewarded and staked by work efforts and reputation. Ownership and confidentiality of results depend on the source of funding, and may be kept as corporate secret or made public. The construct is framed by mechanisms to assure quality and credibility of results on the left, and involvement of the community on the right-hand side.

Furthermore, the recent shift towards open access in scientific publishing, even though widely regarded as worthwhile and necessary, has led to detrimental side effects; driven by profit, a slew of open access journals publish quasi any submission, since the costs have entirely shifted from the readers or subscribing libraries to the authors. This unintentional, very counterproductive development has led to a noticeable rise of such rather predatory journals with substandard editorial boards, peer reviewers and papers, and even to the loss of parts of the scientific record when their entirely profit focused publishing houses suddenly dissolve. This severe problem could well be addressed by increased transparency of the peer review system, as well as a robust identity and reputation systems of both authors, reviewers and journals, all of which can be successfully addressed by blockchain technologies, as described below.

This paper proposes a radically novel decentralized concept utilizing blockchain mechanisms based on reputation systems, betting, secondary markets and social networking to deliver well-qualified consensus for (best possible) “truth” (as validated according to commonly accepted scientific procedures) on delivery and assessment of plans, work and forecasts, to eventually amend “blocks” of scientifically or commercially valuable artefacts, knowledge or know-how to the public or corporate ledger of science & RTD, respectively. Figure 1 lists critical modules science & RTD that can be mapped to blockchain technology to seminally

update the way science and RTD have been organized over the last centuries, to ultimately confer optimum benefit to people, societies, and economies.

2 BLOCKCHAIN

Beyond its foundation in computer science, cryptography and finance, blockchain technology is not monolithic; its sophistication and application development now involve concepts from a wide range of disciplines encompassing economics, game theory, banking, risk management, data science, education, law, administration, political science, psychology, ethics, arts and social sciences. While gaining a thorough understanding of blockchain tends to be somewhat challenging, its diverse contributions bear strong potential to produce disruptive ideas, concepts and solutions that continuously drive the evolution of the overarching technology. In the following sections we provide an insight into the different facets of this Distributed Ledger Technology (DLT) [39] to then lay the ground for substantially improving legacy organization and processes in science and RTD.

2.1 A. DIGITAL CURRENCY

Blockchain originates from a white paper, authored by the pseudonymous person or group “Satoshi Nakamoto”, which launched the virtual currency “Bitcoin” in 2008/2009 [40-43]. By employing a computational “proof-of work” (PoW) in conjunction with incentivization for honest participation, this document described the world’s first realization of a peer-to-peer version of electronic cash that offers algorithm-enforced scarcity, solves the double-spending problem of digital assets, and allows online payments to be sent directly from one party to another without going through a financial institution.

Integrity and consensus on amending new “blocks” is achieved through a clever combination of cryptography and a decentralised peer-to-peer network of miners to validate and nodes to store a common, tamper-free, immutable, and time-stamped distributed ledger (file). The protocol runs without intermediaries, e.g., a central bank, whose monetary policies may be directed by short-term political objectives of the ruling administration, rather than protecting the interest of people, especially depositors, against inflation¹ and devaluation; uniquely, no physical goods such as bills, coins or precious metals are issued, stored, split, or transported, thus drastically reducing cost of ownership, security, and usage.

Bitcoin and many other cryptocurrencies may be traded on conventional or decentralised exchanges (“DEX”), “hodled” [44], i.e., held on the long term (“hodled”) in the prospect of large future profit or increased utility, saved to protect wealth against inflation or for longer-term gains in on- or off-chain wallets or vaults, or used to buy real-world goods and to access services with an expanding number of merchants [45]. By the time of writing, Bitcoin has reached a market far above 200 billion USD, thus being ranked the world’s 6th largest currency (depending on the referenced category of money supply). It is followed by Ethereum (ETH) [46, 47], the global payment network Ripple (XRP) [48] with about 45 and 13.2 billion US\$, respectively, and a host of further, often special purpose, “altcoins”.

2.2 COMPUTING POWER

Trust in Bitcoin is established through demanding PoW, i.e., staking huge computational power in a race to unravel a cryptographic “puzzle” (or, more accurately, by finding a partial hash collision through brute force), which nowadays requires designated, application-specific integrated circuits (ASICs) that frequently concentrate at larger-scale mining “farms”. Blockchains are commonly designed to be “Byzantine Fault tolerant” (BFT) [49], i.e., only an entity able to control a significant fraction (arguably specified between 1/3 to 51% under real-world circumstances) of the so-called “hash rate” (or alternative resource) would have a realistic chance to manipulate and thus devastatingly compromise trust in the blockchain; such attacks are efficiently counteracted by attractive rewards for mining or staking. It is widely accepted that only seminal

¹ This philosophy is also carved into Bitcoin’s genesis block stating “The Times 03/Jan/2009 Chancellor on brink of second bailout for banks.” issued in the middle of the 2008-2009 financial crisis.

enhancements of hash rates, e.g., by next-generation quantum computing, might pose a serious challenge to securing blockchains (more precisely: public PoW based chains that work on hash-collision based cost-functions) in the longer-term future.

2.3 PROGRAMMABLE MONEY

Another milestone flanking the emergence of blockchain technology was the introduction of “smart contracts” which allowed the development of decentralised apps (“DApps”) that are equipped with a locally running user interface (UI), with the business logic executed in a decentralised fashion, e.g., on the Ethereum Virtual Machine (EVM) as part of a network [50]. In this “Web 3.0”² technology launched in 2014, the execution of transactions on assets can be coupled to conditions represented by code that is permanently engraved and verified on the blockchain. Such programmability of a trusted digital currency has given DLT another tremendous, at times somewhat overhyped boost in the second half of the 2010s, in particular in the field of decentralised finance (“DeFi”) [51], which is presently spurred by hot topics like “yield farming” / “liquidity mining” [52-58].

High volatility of exchange rates with fiat currencies has been addressed by stablecoins, often soft- or hard-pegged against the US dollar [59-61]. Some companies insure against adverse events [62, 63] and professionally audit smart-contract constructs [64]. However, enforcement of severe regulation, e.g., around know-your-customer (KYC) and anti-money-laundering (“AML”) compliance policies [65] required in conventional financial services, is still regarded as major roadblocks for further, land-slide proliferation; while there is significant support for introduction of “crypto” from the corporate sector and important interest groups, increasing support is signaled from government agencies who would need to legally sanction certain steps and support integration with their work flows [66-71]. Alternative public blockchain-enabled cryptoassets like Bitcoin, numerous countries are seriously contemplating the introduction of Central Bank Digital Currencies (CBDCs).

2.4 ORACLES

Smart contracts may be deemed blockchain-based algorithms that deterministically trigger transactions, for instance, of cryptocurrencies, upon meeting well-defined conditionals on external input data, referred to as “oracles”. Blockchains themselves provide trust on information that can be sourced from its very own digital ecosystem, e.g., that a certain date has passed, or a certain amount of funds is available on a given crypto account. However, any real-world data feeds, e.g., on stock values, exchange rates, opinion polls or data obtained from the Internet of Things (IoT), to on-chain decision-making algorithms constitute potential chinks caused by poor quality or even forgery, and would thus devastatingly undermine trust in blockchain controlled processes. Access to reliable off-chain facts by properly vetted and incentivized “reporters” is thus instrumental for the implementation and acceptance of oracle-based smart contracts controlling transactions of value.

There are different types of oracles [72]: Software and hardware oracles receive data from online sources, and real-world information from physical sensors, respectively. In inbound and outbound oracles, digital information is fed to or issued from the blockchain. Consensus-based oracles rely on verification and approval by a cohort of individuals or groups. A range of initiatives already provide various forms of such blockchain-connected oracles [73-80]. Especially consensus-based oracles play an important role in this paper as they best reflect the well-proven trust-finding process already underpinning science and RTD.

2.5 PREDICTION MARKETS

Uncertainty on future events and developments remains a fundamental issue in our lives, economies, and societies. Examples are weather, climate, natural or manmade disasters, conflicts, health, election results, consumer behaviour, financial markets and economic growth from a macroscopic and corporate angle as well as advancements in science and technology. Undoubtedly, there is a huge value in having prior knowledge about upcoming events, e.g., to advise allocation of resources or to pre-emptively mitigate their expected

² Note that there various conflicting definitions exist for the terms “Web3” or “Web 3.0”.

fallout. Organisations like insurers, investors, governments, and companies rely on thorough data collection and analysis to have the best possible appraisal.

While small panels of pundits may be consulted for their insights, the collective wisdom of the crowds [81-83] has often delivered an astonishingly reliable source for predicting the future events, e.g., the outbreak of pandemics [84, 85], possibly because a broad population provides a multitude of information, perspectives and experiences to average out individual bias. However, it is also reasonable to put higher weight on forecasts uttered by specialists displaying a thoroughly verified “reputation”, i.e., a proven track record, untarnished credibility and relevant expertise in the area under consideration for optimizing the accuracy. For example, artificial intelligence (AI) supported DeFi platforms have been launched, involving reputation-staked collective intelligence of investors from the crowd to direct an open hedge fund [86].

Its combination of smart contract and trust without intermediaries has been a fertile ground to install several prediction markets on blockchains [87-92]; these next-generation platforms allow “anyone”, including automated market makers (AMMs), to create trade pairs and settle their “bets” at different stages prior to the completion of the event. As any crypto exchange, attracting sufficient liquidity is paramount for the viability of these platforms.

Evidently, precise definition of possible outcomes constitutes a critical prerequisite for setting up and settling the market. There are outcomes that are of binary, i.e., yes-no nature, or that can be expressed in exact numbers. Yet, even those events may fall out of a set list of outcomes, e.g., by cancellation or changing of goal posts due to unforeseeable force majeure. This may be handled by declaring the bet invalid followed by returning deposits to all stakeholders.

However, even such a decision may be disputable, possibly favoring certain stakeholders while leaving some others feeling betrayed. In this case trust in the platform is enhanced by providing a pre-defined and fair arbitration process [93-95]. Such consensus finding by broadly accepted dispute resolution schemes will also be required for judging on more complex outcomes, e.g., if a “soft” scientific or business goal cannot be expressed in a simple quantitative measure.

The main vulnerability of these blockchain-based betting portals resides in the accountability of oracles reporting on real-world data, i.e., they may accidentally, erroneously or deliberately feed inaccurate or untimely information which prompt irreversible “pay outs” linked to unstoppable smart contracts. Blockchain based prediction markets consequently need to put particular emphasis on trustful input sources; for assuring credibility or “best possible trust”, staking “skin in the game” as collateral thus needs to be demanded from reporters, e.g., by appropriate (crypto-)assets or formalized reputation, while penalizing deviation from the final consensus. Mechanisms for establishing trustful oracles have been developed, e.g., in the context of IoT [96].

2.6 CURATION MARKETS

Also in response to adverse crosswinds by regulatory agencies challenging the legitimacy of initial coin offerings (ICOs), so-called “token bonding curves” (TBCs) [97] have been devised to implement legally less controversial idea markets [98]. Tokens may be purchased and traded for proposals and ongoing projects; staked crypto deposits are safely stored on the blockchain to guarantee continuous liquidity. Their value is defined by a publicly accessible formula, for instance, with a price proportional to the number of tokens issued at a given point in time; in this exemplary model, investors in these curation markets [99] thus profit when more tokens circulate at the point of selling than at buying. Similar to conventional betting, stockbrokers or currency exchanges, a fraction of the revenues may be commissioned in a well-defined fashion to fund the project activities, and to support the creation of trustful prediction markets that can wisely inform decision making.

To avoid Ponzi schemes, rules must be established for an end game when the project has reached its milestones, e.g., delivered commercially, for the conversion of virtual token investments into real-world value. As direct pecuniary remuneration may raise the ire of federal authorities who might categorize them as securities to which rather tight regulation would apply to, tokens might be converted into formalized reputation or voting rights in community-driven initiatives seeking related expertise.

2.7 INCENTIVIZATION OF CONTRIBUTORS

The success of community-based approaches involving collective intelligence is intimately hinged on engagement of a critical mass of participants. The same applies to blockchain technologies themselves which can only thrive if a substantial number of active users and providers of independent nodes perform mining, maintenance, and upgrades to sustain the network.

A variety of schemes have been applied to stimulate employee participation in traditional companies; interestingly, it turns out that accompanying recognition and acknowledgement of quality work has a stronger long-term effect on employee motivation and performance than (stand-alone) bonuses and pay rises [100]. Incentivization or collaboration by blockchain-secured token systems has already been implemented by several big corporations. For instance, the Enterprise Ethereum Alliance (EEA) [101], backed by multinationals like Microsoft and Intel, issues reward and reputation tokens to stimulate collaboration on activities like editing and contributing to specifications, and adding code in software development. Penalty tokens may reflect lack of engagement or infringement of project delivery within target budgets, timelines and specifications. Spotting bugs and other flaws might be incentivized by posting bounties [102, 103], which may also be open to the public and may be rewarded through centralized or decentralized decision making mechanisms.

2.8 TOKENIZATION OF ASSETS

The ownership of certain unique assets such as real estate, vehicles, memorabilia, antiques, artwork [104-106] and other intellectual property (IP) representing intangible creations of human creativity [107] is normally handled by publicly sanctioned administrative entities, e.g., land registries or patent and trademark offices. Traditionally, the final proof of ownership is still linked to the possession or filing of a paper document that needs to be managed, transferred, archived, and kept accessible in a manner that is highly resilient to forgery, theft, disasters and physical decay over long, even historic periods of time.

As opposed to money or commodities like precious metals or natural resources, this specific class of goods is not directly interchangeable, i.e., title of such assets may need to be swapped, e.g., through cumbersome escrow and distribution mechanisms. For instance, the deeds of a house might not be divided in as straightforwardly as 100 units of a fiat currency might be split into several bills or coins that can be passed out to individuals. Also, a trustful, uninterrupted record of previous ownership, ideally tracing back to the origin, minimizes chances of legal disputes and counterfeit, and thus constitutes a high value.

The enormous potential of the distributed, unstoppable, time-stamped, cryptographically secured and thus inviolable public ledger to document non-repudiable ownership of this type of non-interchangeable assets in an “internet of value” is very evident. So-called “Non-Fungible Tokens” (NFTs, known as ERC-721 tokens [108] on the Ethereum blockchain) have been implemented on blockchains [109, 110]. These NFTs have first been utilized for trading unique digital artwork as part of online gaming [111]; by now, several blockchain initiatives have extended the concept of NFTs to real-world assets [106, 112-115] through digital security tokens.

Other projects also target recording and providing selective access to well-verified professional and educational qualifications on designated blockchains [116], e.g., to facilitate admission to academic programs, for streamlining corporate recruitment and for optimizing human resources (HR) [117].

2.9 FUNDING

In addition to conventional sponsorship by investors, foundations, public agencies, and charities through injection of fiat currency, blockchain technologies offer bespoke funding mechanisms which are linked to the trust without middlemen conferred by the decentralised, crypto-secured ledger and its smart contracts. Funding can, for instance, be raised by minting project-specific digital “coins”, e.g., so-called ERC-20 tokens [118] on Ethereum [50], which may be (pre-)mined and traded according to a transparent protocol. The value of these tokens is then freely determined by market dynamics. On top of their financial value, these cryptocurrencies might provide a “proof of stake” (PoS), e.g., for voting on upgrades or seats on arbitration panels, or for settling utility (transaction) fees charged to sustain the ecosystem of the underlying blockchain.

Trust in such monetary seigniorage [119], i.e., the difference between the value of new money and the cost of their creation, is best supported best by open source release of code, proper documentation and credible validation of progress to avoid scams. Also “gaming” of coins and tokens by speculators poses a mission-

critical risk to trust in projects, which is particularly pronounced with tiny trade volumes and limited numbers of independent stakeholders in the market.

Financial authorities have frequently categorized cryptoassets issued through initial coin offerings (ICO) for funding blockchain projects as equivalent to securities, which would require compliance to stringent rules similar to initial public offerings (IPOs) of “shares” on traditional (centralised) stock exchanges. Such classification requires enormous efforts on compliance. Alternative models have been developed for tokens not representing classical assets and ownership. They may be offered in initial (security) token offerings, ITOs or STOs, respectively, and may then be traded in secondary markets. Also the issue of legally sound incorporation of businesses (“LAOs”) using crypto-economic mechanisms has been elaborated [120]. The attraction of such democratized decision-making organization to venture capital (VC) funding remains to be seen.

2.10 ORGANIZATION

As it has already surfaced in the previous sections, the availability of smart contracts on blockchains opens manifold avenues for rethinking classical approaches to the organization of projects. From a certain point of view, novel implementations seek to extend trust finding by decentralization, majority vote and PoW / PoS from the core of blockchain to the entire management structure. This applies to commercial projects, e.g., to direct management and investment decisions in DeFi by sourcing the wisdom of the crowd; such decentralised governance, e.g., as implemented by liquid (delegated) democracy [121] based establishment of consensus, also invigorates trust and community spirit in initiatives pursuing “Commons”, i.e., shared goals on advancement of blockchain technologies or for the good of mankind.

Voting rights of stakeholders might be weighted by the amount (crypto-)assets which, in addition to purchase, may be earned by quality contributions to the entire gamut of the project such as work, validation, assessment, management, promotion, community building, forecasts, arbitration, governance, and by running infrastructure and further development of the underlying blockchain [122-124].

As the pinnacle of such developments, so-called Decentralised Autonomous Organisations [59, 122, 125-130] have been launched in the second half of the 2010s; these “DAOs” encode the complete organisational structure of a cooperative project into (a set of) smart contracts. DAOs are rapidly evolving into social tools and organizations that pursue a collective agenda for the benefit of the community or societies in general [123, 131]. While some of these community-run, smart-contract constructs have exposed major weaknesses or failed [126, 132, 133], e.g., due to vicious cyber-attacks or exploitation enabled by flawed or ill-coded smart contracts, several DAOs, some of them attracting up to billion-dollar volumes of crowdfunding [20, 134, 135], have been successfully established in the meantime. The launch of DAOs and DApps is frequently accompanied by posting bounties for spotting bugs and vulnerabilities in the code.

2.11 RESOURCES SHARING AND CIRCULAR ECONOMY

Depending on the field the blockchain technology is applied to, organizations can define a specific set of smart-contract implemented governance rules which suit the objectives of the supporting communities. These guidelines may improve, for instance, fairness, create equal opportunity or minimize environmental footprint, e.g., by blockchain-enabled sharing or even circular economies.

Examples for governing shared resources by DAOs are computing storage and processing, vehicles, office space, laboratories and virtual resources. Blockchain-leveraged tokenization may incentivize actions that bring value to communities, thereby shifting the focus on reutilizing idle or available resources which otherwise are very difficult to account for and are usually ignored.

2.12 CURRENT ADVANCES

In addition to coordination with governments and public agencies, which is supported by a rising number of large-scale corporate stakeholders [136], the blockchain community advances several technical aspects of underlying technologies.

Transaction Speed and Fees

As a victim of its unexpected popularity, severe deficiencies in scalability of the original peer-to-peer concept of Bitcoin-derived blockchains based on PoW have surfaced. Transaction throughput still dwells many orders of magnitudes below established systems, e.g., for facilitating payments with common credit card systems, albeit still generally faster than conventional banking; the limited bandwidth also led to soaring, occasionally even business impeding utility fees, e.g., for “gas” on the Ethereum blockchain powering the majority of DeFi.

Strategies such as increased block sizes [137-139] as well as refinements like “sharding” [140], side chains [141], “ZK rollups” [142, 143], recursive internetwork architecture [124] and the “lightning network” [144], which resort to mechanisms like transient forking or off-chain processing, are currently elaborated and integrated into different blockchains. With their upgrade to version 2.0 expected for 2021 [47], the impactful Ethereum blockchain plans to transition from PoW to PoS to effectively tackle problems of transaction throughput and fees.

Data Management

As designed for the rather small information affiliated with financial transactions, the blockchain data structure is not well suited for storing large files. Indeed, it would be orders of magnitude more expensive to store a given amount of data on blockchain’s ledger file distributed on a peer-to-peer network than on a single computer. Decentralised architectures [145-148] and certain access protocols [149, 150] have been paired with blockchain to provide untampered data sets. A common method is to generate a cryptographic hash, i.e., a unique, short, fixed size fingerprint for a large data file which sensitively changes by even the slightest modification. Only this brief hash and a link to the file is stored on the blockchain. Perspectives for blockchain-based data governance have been conceived [151].

Also, the ingestion of external data into the system in a way that provides a high degree of data integrity poses a technical challenge. And even if it can be proven that data has not been manipulated before entry, identifying the relationship between the transacting author and the data might not be completely automatable, although processes and protocols emerge, that might provide a foundation for automated and decentral rights management [152].

Interoperability, Configurability and Sustainability

There is a vast “zoo” of blockchain technologies and cryptocurrencies. Even the most established ones hardly communicate with each other. Large initiatives have formed towards building an “internet of blockchains” (IBC) which aims to establish standards and interoperability [153] of private and permissionless (public) blockchain protocols [154] as well as decentralised mechanisms for inter-chain exchange of crypto assets, e.g., atomic swaps [155] or DEX [156]. Similar to tool boxes for setting up web pages on classical internet, there are also initiatives to support rapid configuration of modular, open-source blockchains [157, 158].

With the skyrocketing popularity of ICOs, e.g., during their short-lived hype in 2017, the issue of sustainability of blockchains arose, i.e., what happens to the blockchain after the initial amount of funding has been spent, or its leaders lose interest and walk away. Amongst several constructs, treasury models which lock funds into smart contracts that are curated by stakeholders have been introduced to provide for continuous support and improvement [124].

Power Consumption

The substantial environmental footprint required to entertain the trust-constituting computing power as well as the tendency towards dominating the hash rate by an oligopoly of miners through such PoW is deemed a major problem by many interest groups. More flexible cryptographic challenges that are unfavorable for ASIC mining and / or consume much less energy, such as (delegated) PoS [47, 159-161] protocols, have been implemented on various other blockchains in the meantime. Alternatively, widely trusted institutions like universities may partner to form a small network of nodes in a public-permissioned blockchain. In proof-of-authority (PoA) based consensus formation [162], the consortium members vouch their valuable real-world reputation, rather than expensive computing power (PoW) or crypto assets (PoS), to underpin the trust and integrity in the blockchain. With the release of its “Beacon Chain” [163] in its 2.0 upgrade in December 2020,

Ethereum, the second largest blockchain by market cap, is gradually replacing PoW with a sophisticated, PoS-based consensus mechanism (amongst other improvements, e.g., regarding scalability) [163]. PoA or PoA consensus finding might be preferable for blockchain-based projects in the scientific / academic community.

Participation Models in Blockchains

The organizational properties of a blockchain fall into essentially two broad categories: public or private and permissioned or permissionless [164]. The decentralised ledgers of Bitcoin [41] or Ethereum [50] are purposely permissionless, open and public, implying that there is no central authority restricting access and participation in the consensus mechanism, thus providing trust and neutrality while eliminating censorship and regulation across global communities. On the contrary, private or permissioned blockchains [165] restrict different levels of access to the ledger file and participation in the consensus mechanism; they have been devised to address concerns regarding, e.g., performance, ownership, confidentiality, privacy, security, control, governance, scalability, configurability, consensus finding and environmental footprint.

Such federated or consortium blockchains are well established in the corporate world [166-169], but are perceived controversial by larger parts of the crypto-community. They tend to consider these permissioned setups as a variant of a conventional corporate database where a central authority tasks verifiers and authorizers, thus lacking major features in terms of securing trust and protection against vulnerability, compared to their public counterparts.

Organization and Governance

The term “DAO” is not clearly defined (yet). Its incorporation might not bode well with the local legislative framework and entail huge risks for its (identifiable) stakeholders, e.g., regarding liability. Possible advancements are Distributed Autonomous Associations (DAAs), a checks and balances system where individual roles are replaced by expert panels to disperse power from single points of failure. Suitable decision-making processes need to be clearly defined, e.g., consensus-driven liquid democracy governance delegating day-to-day business to their appointed managers who periodically report and seek approval on business-critical or strategic issues.

3 APPLICATION TO SCIENCE & RTD

The spirit at the heart of blockchain may be articulated as finding trust and consensus within a non-custodial network of independent, potentially even malicious players; the integrity of the blockchain is fortified by a transparent, reward-based competition which demands risking some form of collateral from participants, e.g., by investing in costly installation and operation of cutting-edge mining infrastructure.

Smart contracts and DApps have significantly extended the scope of applications that can be addressed by blockchain technologies; staking of crypto-assets and formalized reputation incentivize credible reporting of best possible truth to blockchain oracles and prediction markets, to optimize decision making on allocation of resources towards achieving common project goals. Smart contracts have also enabled new asset types such as NFTs [170], and sophisticated manifestations of self-governance by liquid democracy [121] and DAOs [125]. First initiatives for providing a digital ecosystem to support collaboration on innovation processes through blockchain mechanisms have already surfaced [171-177].

Similarly, the research community rewards scientific discovery and technology development as well as finding consensus on their validation to eventually add new “blocks” of community-verified knowledge to a public, “ledger-equivalent” library that is captured in widely accessible, perpetual archives [178]. Strong trends towards self-organization, autonomy of decision making, e.g., through peer review of publications and funding proposals, and even decentralization and competitive parallelization have always been a principal element of academic research.

Yet, the ranking and reward systems applying to researchers and institutions as well as career promotions, appointments to committees and invitations for high-caliber talks is not so rarely based on hidden rule sets and backroom arrangements. The valuation of intellectual assets, such as publications, inventions, and awards, remains somewhat obscure and inconsistent. Importantly, the community-aspect of achievements is often poorly captured and artificially restricted to small groups, rather than acknowledging and thus incentivizing pro-active engagement and commitment of lower-ranked group members, peers, referees, and even non-

institutionalized individuals. Greater involvement of the community, e.g., through hackathons and bounties, would certainly facilitate the formation of a critical mass of users, developers, and promoters, and thus energize fly-wheel effects to increase footprint and sustainability of projects.

This section sketches the future scenario of a more inclusive, community-based approach towards science and RTD organized as a sophisticated betting game; blockchain orchestrates an arsenal of crypto-economic instruments for finding trust and best possible truth at maximum transparency and minimum administrative costs for planning, funding, execution, management, assessment, arbitration, and exploitation of science and RTD projects. With some adequate modifications respecting the rule set and workflows of the corporate sector, the opportunity to flexibly tap into the increasingly broad pool of talent, expertise, creativity, labour and facilities within a global village, rather than limiting contributions to centralised RTD headquarters, might largely outweigh reservations, e.g., regarding ownership and protection of IP.

3.1 SPECIFICS OF SCIENCE & RTD

Investing in science and RTD is tied to a certain expectation towards the future, e.g., to address a material need or find the answer to an important issue or question in society. In a legacy approach, a rather small cohort of experts is consulted to identify relevant topics, evaluate proposals, validate data and assess outcomes.

Blockchain is so far mainly driven by software development for improving its own ecosystem and for its reach into new application spaces like industrial or food supply chains [124, 179, 180], authenticity of precious commodities [181-183] and enterprise solutions [166, 168]. Blockchain technologies also empower DeFi by creating novel financial instruments and investment vehicles such as yield farming [52] for scooping arbitrage gains, synthetic assets [56], barrier-free, financially inclusive (micro-)payment systems [48], DEX [184, 185] with automated market makers (AMMs), and services for auditing or insuring against crypto-specific risks [63]. While making smaller economic impact, also significant work on Commons led by social objectives, to illuminate information processing [186] and to support charitable initiatives has been carried out [131, 187].

Somewhat on the contrary, most members of the science and RTD community, whether on the payroll of academia or industry, are primarily motivated by creation of knowledge; in addition to bonuses or share options in industry, their commitment and devotion is stimulated by recognition, respect, attention, prestige, individual fulfilment, funding, personal career opportunity, self-fulfillment, joy of creativity, identification with their organization, utility to users and society, altruism, and, last but not least, having a saying in terms of management, refereeing or governance, and opportunity for promoting a topic they find important in front of key stakeholders and large audiences.

As outlined in the preceding sections, the token economy that can be quite uniquely staged by blockchain-enabled reputation systems [188] is able to cater for objectively awarding and safely recording such personal achievements, stake them as collateral for quality and credibility of contributions, and to improve prediction markets. Hence, we propose here for the first time a token-economy as the basis to garner valuable community engagement for delivering top-quality, well-reproducible and high-impact science and RTD.

This cooperative approach reflects characteristic features of the scientific community like self-organization, autonomy, open competition, decentralization, and transparency to set a solid foundation for establishing trust, credibility, and objectivity in finding best possible “truth”. Especially the clear trend towards virtualization, e.g., digital twin approaches, opens novel avenues towards widening participation of a global crowd to value creation, even to a novel type of freelance researcher, e.g., through contributing intriguing hypotheses, novel concepts, improved modelling, simulation, and validation services.

3.2 SCIENCE & RTD - THROUGH THE EYES OF BLOCKCHAIN

Along Figure 3, we illustrate the manifold similarities between the fabric of blockchain and the mechanisms underpinning the classic community of science and RTD. In DLT, transaction data is periodically collated, mined in an open cryptographic race (in public PoW networks), collectively verified, and selected according to pre-defined metrics and algorithms for amending a block to the existing chain. Crypto-economical mechanisms incentivize crowd participation and create trust.

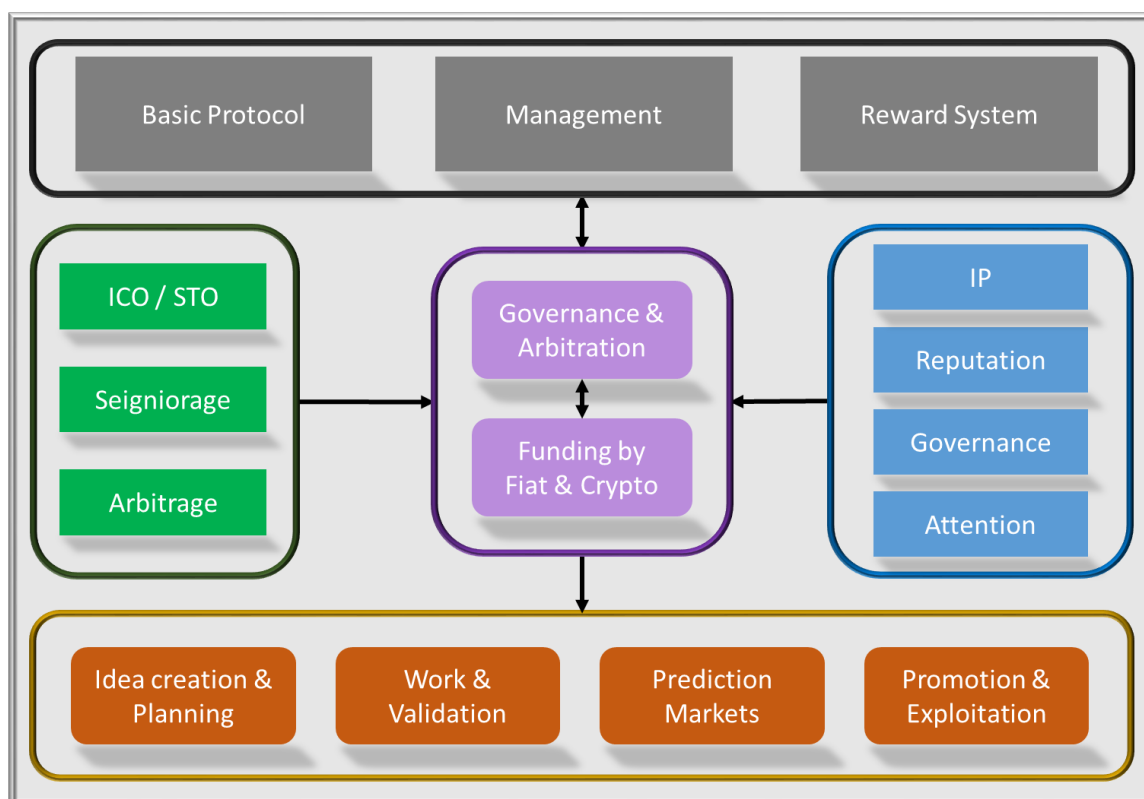


Figure 2 Organization of science & RTD by a token-based crypto-economy. A white paper documents a basic protocol, management structures and reward systems which are encoded and executed on a blockchain. Governance and arbitration following liquid democracy schemes are at the heart of decision flexible updating of rule sets, directing and conflict resolution. Blockchain mechanisms such as ICOs / ITOs / STOs, seigniorage and arbitrage generate conventional, fiat-convertible funding. A cohort of crypto tokens can be awarded to users in the crowd, e.g., for contributions such as ideas, planning, work, validation, forecasting, exploitation, and even to externals by learning about or referencing the project, and thus raise attention. The recipients might deploy these rewards to increase voting rights in the liquid democracy governance, to polish up their curriculum vitae (CV), to claim ownership in intellectual property (IP), and, in a potential secondary market, trade them into other crypto assets.

On a conceptual level, there are remarkable similarities of blockchain to the modus operandi of the scientific community. Scientific discoveries may, for instance, be expressed by a hypothesis that is embedded into a context, described by a model of understanding, verified by established experimental protocols and methods of data analysis. These “blocks” representing scientific discoveries, research data or technological inventions are then released to the scientific community for assessment and validation by peers according to widely accepted criteria and methods that tend to be specific to each research discipline, e.g., [189].

To optimize quality, and to avoid manipulation and scamming, authors stake their reputation (PoS). Upon approval, the blocks are appended to the “ledger of knowledge” that is archived in various forms, e.g., publicly in journal publications or patents, or in internal documents stored on institutional or corporate databases. In absence of immediate consensus, and analogously to “reorgs” and “forks” in blockchain, various

theories (“chains”) transiently compete until sufficient evidence (“blocks”) has been aggregated to convince a critical mass of the community.

Having identified these analogies to protocols in blockchain, we notice that involvement of the scientific community is highly relevant to reviewing, but contributions of the crowd at large to the creation of initial intellectual property (IP), validation and dissemination are rather poorly incentivized and acknowledged (Figure 3). The following sections describe how a blockchain-based token economy highly encourages a collaborative approach for the mutual benefit of contributors and the objectives of the project, as illustrated in Figure 4.

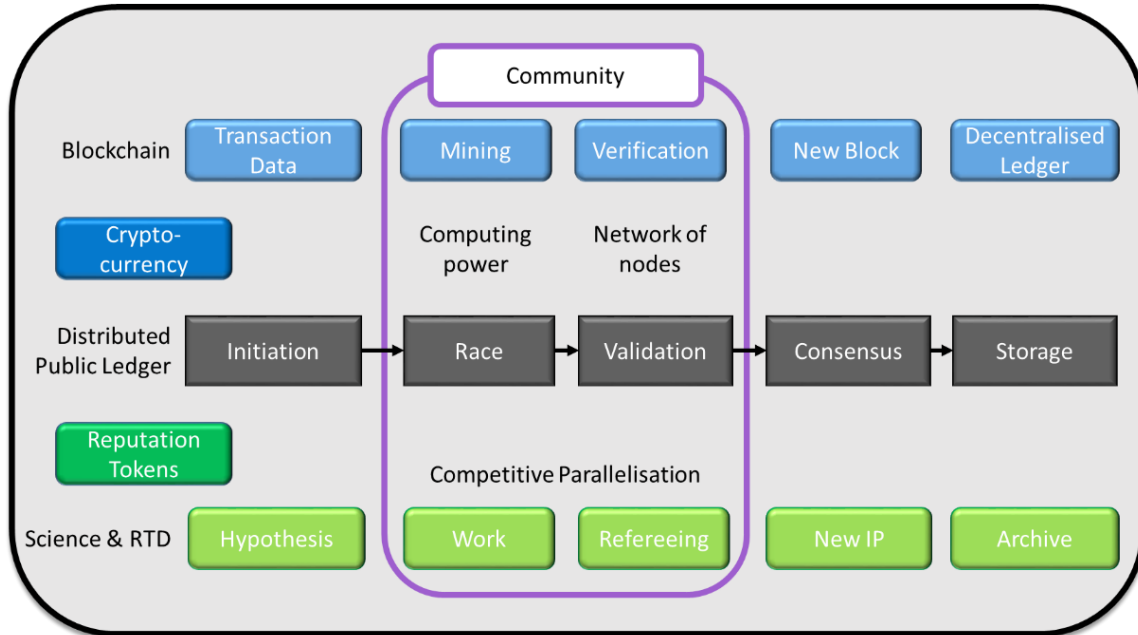


Figure 3 Analogies between science and RTD and the distributed ledger technologies (based on PoW). Permissionless blockchains, such as Bitcoin or Ethereum, can be interpreted as cooperative peer-to-peer networks of independent players for growing a record of transactions that are bundled in consecutive blocks. These packets of transaction data are competitively and redundantly created, time-stamped, verified and selected for inclusion according to a deterministic, code-based consensus protocol. Staking PoW through participation in an enormous group mining effort, reputation by PoS and utility costs mitigate spamming and reward contributions to securing the integrity of the decentralised, non-repudiable ledger. “Hashing”, e.g., by Merkle trees, intertwines new with existing blocks to firmly secure the blockchain. The “blocks” in science and RTD may be IP documented by articles, internal reports or patent fillings that describe new knowledge or know-how that has been reviewed by peers in the community. Trust and transparency are afforded by referencing and working according to established, collectively accepted methods. This IP is captured, e.g., as non-fungible tokens (NFTs), on public or private, quasi-eternal and unforgeable archives curated by trusted journals, publishing houses or patent offices. Authors, inventors, validators, and referees engage in a “race” to be first to add high-impact and well-reproducible results to this public “ledger of knowledge”. Their successful efforts may be rewarded by direct monetary benefits, but often even stronger incentivized by career options,

citations and overall recognition / prestige the community. Spamming of the ledger with “junk” is averted by peer review and risking reputation. Both systems prove to autonomously function without central authority to certify the integrity of data blocks and knowledge, respectively.

3.3 TOKENS

Blockchain technologies can uniquely implement transparent rule sets on its tamper-free and immutable ledger to incentivize, credit and reward a broad repertoire of community contributions. We first illustrate the benefits such a token economy can offer for science and RTD projects (Figure 4). Evidently, seigniorage [119], ICOs, ITOs, STOs, and dynamically evolving crowdfunding [20, 122, 190, 191] can channel financial resources at different stages of progression into a project. These assets may be used to directly recruit, crowdsource, and incentivize workforce, idea creation, contributions of expertise, management, and other services.

Historically, free-market economies, potentially padded with rule sets on anti-trust to avoid monopolies and social aspects, have proven to outperform centralised, state-directed economies, despite potential duplication and friction losses between competitors. In the same way, such “tokenization” can drive a healthy rivalry, also termed “competitive parallelization” [5], towards performance enhancement of the full gamut of project contributions, whether internally or externally crowdsourced [192], thus optimizing the overall outcome of science and RTD projects.

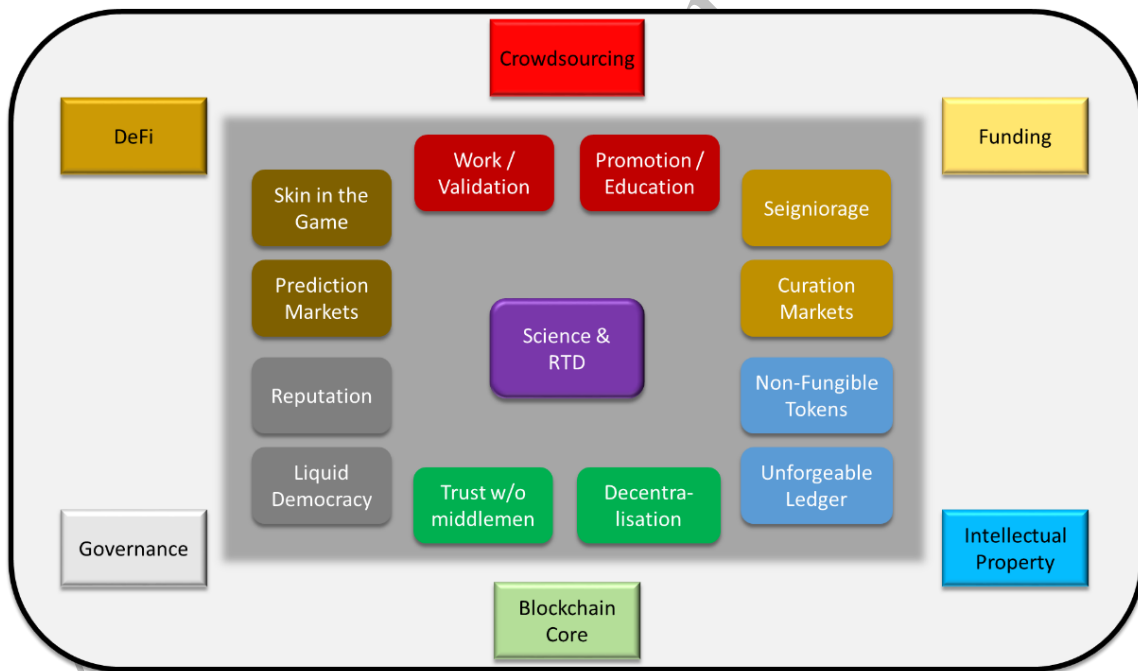


Figure 4 Innovation potential for science & RTD projects through crypto-economically incentivized involvement of collective intelligence. Core blockchain technologies provide trust and trust-finding mechanisms without requiring a central authority. Smart contracts enable skin-in-the-game staked prediction markets, novel, liquid-democracy style governance schemes involving formalized reputation, a tamper-proof and time-stamped ledger to register intellectual property (IP) which may be represented and traded as non-fungible token (NFT). In addition to conventional mechanisms, project funding can arise from seigniorage and curation markets. The blockchain-backed tokenization can thus effectively crowdsource

project contributions, e.g., work, validation, promotion and education, collective intelligence through remuneration and reputation tokens to thus optimize the project outcomes while acknowledging contributions from individual stakeholders.

In reputation systems [161, 188, 193, 194], tokens are earned or burned, depending on the best correlation between predictions and target outcomes [86]. Skin in the game schemes can effectively “dilute” compromised assessment, e.g., by malicious participants setting up a large number of pseudonymous identities and using them to gain a disproportionately large influence. Mechanisms for counteracting such “Sybil attacks” [195], e.g., through “proof-of-identity”, have been elaborated [196, 197]. Reputation tokens can mirror track record, e.g., obtained for quality and speed of project work, validation, advise, education, team building, promotion and leadership [101], to substantiate the overall credibility of contributors. In contrast with the current state where even the number of citations of a particular paper or author is usually only available under subscription models, blockchain implementation would offer rendering such records publicly available.

Similar to artwork or collectibles [104, 198], non-fungible tokens (NFTs) can issue a legally valid time-stamped proof of knowledge of intellectual assets, e.g., by provision of hypotheses, methodology, experimental design, theoretical framework, supporting data set and statistical interpretation, to indisputably claim inventorship to be recorded on patent applications or authorship on a scientific discovery. Portals already exist to capture and manage access to such IP [162, 199] and data [149, 150, 199-202].

In addition, many existing implementations rely on asset identification based on cryptographic hashes to act as generic signatures of data. Although they are well suited to uniquely identify a certain data instance, their lack of locality-preserving and perceptual hashing properties seriously limits application in the copyright and patent domain, especially considering automated processing. In order to unlock the full potential of this technology, alternative fingerprinting algorithms like International Standard Content Code (ISCC) [203] need to be explored. As patent and copyright law are intrinsically complex, the process involved might not be completely automatable; different instruments, such as the Open Content Certification Protocol (OCCP) [204], aim to provide a foundation for machine-to-machine communication and technology based trust, while still allowing for a soft factor of human assessment to be injected into the system.

Commercially relevant IP represented by NFTs might also be better tradable through tokens, especially for academic institutions whose technology transfer offices (TTOs) are usually netting significant losses. Issues around regulation and confidentiality might be addressed by permissioned blockchains [165]. To embed this novel mechanism into a legally sound framework, buy-in from patent offices is still to be pushed on the political level.

Even beyond such core innovative contributions, the entire team might be further incentivized by (potentially pan-institutional) reputation tokens, e.g., obtained for work, validation, advise, education, team building, leadership and promotion [101]. Smart contracts can also time-lock tokens, i.e., their “pay out” might be linked to sustainable outcomes that are evaluated as results have created measurable impact, rather than encouraging a transient flash in the pan.

Towards mustering a critical mass, tokens can also be issued to (external) users for popularizing the project [205], e.g., through referrals and postings, or by proof of “attention”, e.g., through completing specific tutorials and browsing activities [206, 207]. This, at first sight, altruistic give-away approach makes better sense if promotion is considered as instrumental for engaging a critical number of engaged users. In a certain way, researchers nowadays already accept similar marketing expenses, e.g., in the form of registration fees for presenting their results at conferences or for publishing open-access articles to optimize their reach and future citation counts. Furthermore, tokens might be passed out as “social signal” to teams in the community that follow similar research goals or ethical values [123], thus creating momentum in community building.

3.4 BENEFITS FOR TOKEN HOLDERS

Tokens may be deemed digital assets which may be swapped into alternative crypto-assets at secondary markets, converted into fiat currencies at various exchanges, be staked, simply “hodled” [44], or spent on settling utility fees for transactions on the blockchain. Tokens can also provide credibility for increasing the weight of a user’s saying in the project ecosystem, e.g., on blockchain-supported, liquid-democracy

equivalents to traditional governance, scientific advisory boards or arbitration panels, or a DAO where, in its purest implementation, most decisions need clearance by (token-weight) vote of their stakeholders.

Also the project itself might establish a rule set which tags an internal value to the tokens [208]. In addition to project ownership associated with participation in value creation (dividends) and project direction (management), blockchain-recorded personalized tokens can account for credible certification of soft skills, professional and academic qualifications [209], or hard facts like authorship, impact factors, research income and invention disclosures, e.g., to enhance CVs or for boosting job applications at different (participating) organisations. Here we can envision a conceptual and technological alignment with the domain of Self-Sovereign Identity (SSI), such as the Verifiable Credentials Data Model, developed by the W3C [210]. Other tokens may be accrued by team members to avail of popular incentives, e.g., career promotion, bonus payments, additional holidays, travel upgrades, a company car, or be pooled for sponsoring team events.

3.5 TOKEN-STAKED PREDICTION MARKETS

Further to the previously quoted benefits, tokens can be used as “skin in the game” to foster community approaches for optimized assessment, planning and forecasting project uncertainties. In fact, broad involvement of expertise, skill and labour in generating knowledge has always resided at the very core of science and RTD, and mostly administrative hurdles have confined outreach on a broader scale. At least in principle, these barriers, which are somewhat hampering progress and consensus on extending the “knowledge”, may be lifted by adopting previously described liquid democracy strategies, and staking mechanisms, such as PoW or PoS, that are already underpinning blockchain.

More specifically, prediction markets can be created where all interested parties, whether workers and investors as well as project-internal and external experts and evaluators, can stake their tokens to support their credibility for contributing, assessing, and future-proofing the project, thus creating synergistical win-win scenarios. Curation markets [99, 211] and TBCs [97] can be set up very swiftly on blockchain to receive valuable feedback, publicity and engagement on early-stage project ideas, their implementation plans and first results. In their endgame, and to differentiate them from ICOs that may be subject to rather strict financial legislation, contributors from the scientific community might be rewarded by formalized reputation tokens which acknowledge their capability to identify the potential while the project still dwells at its infant stage; the tokens earned this way can be used in other projects, e.g., to increase voting power on governance and arbitration boards. TBC protocols might also incorporate mechanisms for (partially) funding the projects, e.g., through arbitrage from trading tokens or providing liquidity to secondary markets.

While there is still some pioneering work to be carried out for conclusively demonstrating that non-fiscal instruments enhance a business proposal towards investors, e.g., in form of an ICO or DAO, tokens awarded for intellectual achievements would certainly epitomize a not (directly) monetizable value that most researchers would still be eager to accumulate and utilize for their interests.

3.6 PUBLICATION, PEER REVIEW & FUNDING SYSTEM

In the first half of the 20th century, scientific journals started filtering submissions through critical assessment by independent colleagues. This peer review system [212] has essentially survived into modern days, in some fields supplemented by electronic preprint servers [213, 214] which release manuscripts prior to full submission, usually to enquire constructive upfront feedback from colleagues in the community, and to establish precedence of the work. While the system of scientific publishing has proven to function for the most part, it is, at least at times, still prone to poor quality and even nepotism, e.g., due to paucity of highly qualified referees caused by poor incentivization, the once-off nature and anonymity of reviewer involvement, sub-standard publishing houses and the practical absence of rewards and penalties for poor judgement on project impact.

Blockchain technologies could also provide fair models for access to scientific data. In its current state, large portions of the scientific record are siloed in private enterprise or only available through pricy subscription models, including important metrics such as citation numbers.

It is evident that the collateral-backed reputation systems like token economies and prediction markets coordinated by blockchain’s decentralised and transparent peer-to-peer network would be well-suited to boost leverage of crowd intelligence, thus enhancing quality, credibility, reproducibility, and impact of findings,

and, importantly, their broad-scale adoption in the community. These shortcomings affect publications as well as typical funding mechanisms implemented by public agencies, where blockchain-based staking of reputation and crypto assets could help formulate calls and support scientific progress, monitor administration and exploitation.

However, note that the publishing based on blockchain technology and within its community, with exceptions [124, 172-174, 176, 199, 202, 215-224], is so far dominated by unaudited white papers, non-systematically archived web pages, unfiltered news releases and hardly traceable social media contributions which are commented on rather secluded internet forums. This rather Bohemian publishing culture, and a stark clash of jargon, contrasts the traditional path for publishing in the scientific community, which involves vigorous peer-review for affording credibility and quality, and reputed publishers for assuring documentation that is stable on the long term.

3.7 DECENTRALIZATION

Depending on the objective of the blockchain, different organizational setups may be chosen for the blockchain technology. Commercial RTD projects might want to deliberately restrict access in permissioned, corporate / consortium / federated blockchains, e.g., to guarantee confidentiality and retain full control of blockchain operations, and for lowering demands on computing infrastructure and their environmental footprint. On the other hand, academically minded scientific projects, e.g., for creating fundamental knowledge, might want to be more transparent, thus suggesting implementation on a permissionless or permissioned public blockchain.

As the visionary pinnacle of transformation, science and RTD could be managed by DAOs which assume the function of publishing and funding including review, monitoring and impact creation. This would actually well comply with the century-old aspiration of research towards autonomous self-administration in a decentralised and objective approach of the global community, which is driven by the productive interplay of healthy competition and self-interest to efficiently pursue Commons [131] for the good of people, societies and economies.

The management structure of DAOs would be transparently coded into blockchain-engraved algorithms which can be complemented by arbitration schemes, and upgraded by liquid democracy governance, as already executed in existing blockchain projects [93, 94]. By offering a broad range of involvement and commitment staked by reputation and crypto-assets, pivotal flywheel effects can be unleashed towards creating a critical mass of developers, early adopters and highly engaged users, which, in turn, would generate significant pressure on legislators to accommodate and embrace the great promise of blockchain technology for science and RTD.

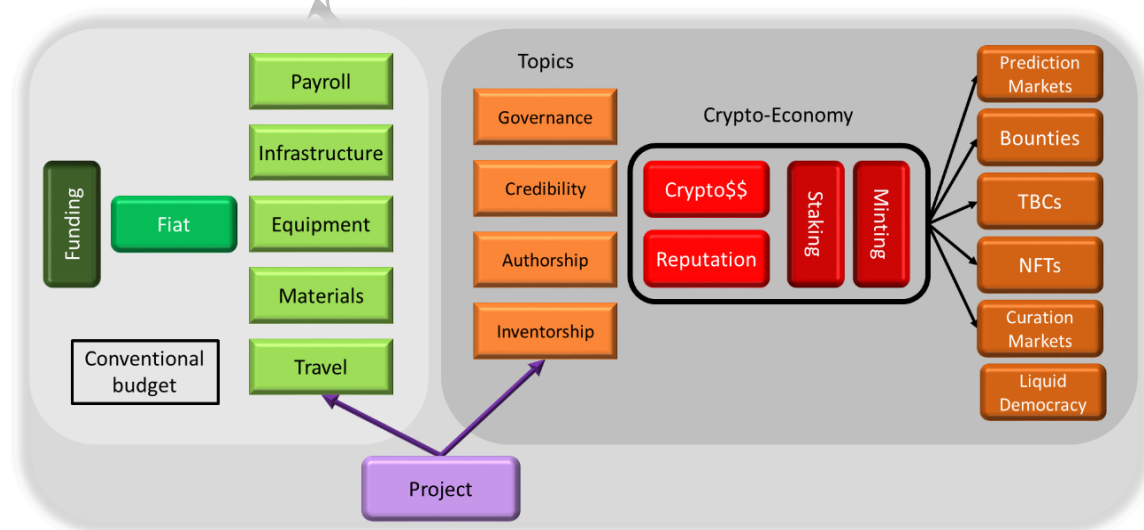


Figure 5 Concept for grafting a blockchain-enabled project onto existing funding and budget schemes. In a 2-pronged approach, real-world expenses and salaries are reimbursed by classical funding schemes in fiat money. Aspects of governance, credibility, author- and inventorship leverage a token economy revolving around minting and staking of tokens representing crypto-assets and reputation. This token economy offers novel instruments for project optimization such as prediction and curation markets, bounties rewarded for identifying or solving particular issues, token bonding curves (TBCs) to incentivize thorough assessment of early-stage ideas by skin in the game, non-fungible tokens (NFTs), e.g., for assigning contributions to IP, and a liquid democracy guided management structure. The portrayed strategy will seminally enhance project outcomes by comprehensive community involvement and increase motivation for contributors.

3.8 NUCLEATION OF PROJECTS

While the advantages of a blockchain-based implementation have been highlighted, the challenge will be to graft project funding onto present, agency-based architectures, as well as to create a critical mass of community involvement. To start out, a “Minimum Viable Product / Project” (MVP) needs to be defined which may be a scaled down version featuring only select aspects of the bigger picture sketched in this work. suggests a possible, dual-track strategy for projects to tap into conventional public or corporate funding streams, thus catering for real-world expenses to be reimbursed in fiat money, while entertaining a crypto-economically incentivized “betting” game for effectively involving the wisdom of the crowd way beyond legacy project structures.

In a subsequent stage, the project itself, including the left-hand part of Figure 5, could be managed through blockchain technologies, e.g., by operating with fiat-pegged stablecoins for conventional financial transfers. In this interim model, certain fiat could be converted into cryptocurrencies for increasing the incentives fueling the modules right-hand side. Transparent, multi-signature fund management and IP protection incentivizes individuals to contribute financially and intellectually.

In a decentralized future scenario, even the source of fiat, e.g., a public agency, foundation, or corporation, could be replaced by open crowdfunding, to ultimately integrate the entire organizational structure, encompassing publishing and exploitation, into a smart-contract encoded DAO that relies on PoS-linked skin in the game within a full-fledged crypto-economical ecosystem.

4 SUMMARY, CONCLUSIONS & OUTLOOK

We have surveyed key instruments of blockchain-enabled token economies that already underpin core elements of their ecosystem and a range of important application spaces such as store of value (mainly Bitcoin), decentralised finance (DeFi) and commercial supply chains as well as certification of provenance and ownership of unique goods like property and artwork (Non-Fungible Tokens).

We have argued that powerful reputation systems that are enabled by blockchain’s smart-contract supported crypto-economy can seminally augment the traditional processes in science and RTD to advance to a globally inclusive “internet of knowledge”. Incentivized by such crypto assets that are awarded for a wide range of project contributions like idea creation, planning, assessment, funding, work, interpretation, validation, tutoring, leadership, team building, management, marketing and exploitation, collective intelligence, skills and infrastructure can be efficiently crowdsourced for projects, whether in academic research, corporate consortia or grassroots initiatives.

Researchers can utilize these tokens to execute and possibly delegate their reputation-weighted voting rights in liquid-democracy style governance, stake them in secondary prediction markets, or to support their proposals for funding. In a competitive, firmly community-anchored participatory research approach, the token economy can thus markedly enhance the quality, credibility, reproducibility, speed, transparency, cost-efficiency and mission critical user engagement and adoption of project outcomes, and thus also decisively contribute to address the notorious reproducibility crisis of science.

By virtue of the outstanding importance of non-monetary reputation rewards for motivating most researchers, regulatory restrictions are unlikely to impede implementation of the token economy in science and RTD. It is foreseeable that, in combination with cloud computing, global logistics and world-wide open-access facilities providing co-working spaces, equipment, training and competent staff for making, characterizing and developing “things” [7, 8] that significantly lower entry barriers and risks for research activities, the token economy will breed new types of freelance researchers, citizen scientists, garage entrepreneurs and digital nomads whose special expertise and work force is flexibly recruited into projects based on objectivized performance criteria rather than affiliation.

A trusted, blockchain backed infrastructure that includes standards for token-backed funding, oracle services to prove the validity of the outcomes as well as mechanisms for protecting ideas and assuring a favorable compensation to workers and quality to funders, e.g., by as validated by independent auditors and proper dispute resolution processes, can lead to a paradigm shift towards an open, community-based organization of science and RTD. Blockchain-enabled decentralization thus nurtures the emergence of heterogeneity, of small, creative, and talented individuals or teams forming “solution centers” that can build up a reputation for efficiently solving a certain category of tasks while operating from anywhere on the planet. As elaborated in this work, the future of science and RTD will emerge on top of a new form of decentralised social networks.

Compelling advantages in trust, cost and speed will substantially push acceptance of token economies, administrative barriers may be overcome if continued to be driven by major academic and commercial players and the financial sector. Also, the present dialogue with governments, public entities like land registries, patent offices, funding agencies, regulatory bodies, and central banks [66-69, 225-231] needs to be intensified to fully embrace the blockchain.

Yet, strong adherence to tradition presents a tall barrier for gathering critical momentum for major revision of the legacy schemes in science and RTD. There is a blatant gap in culture, e.g., towards procedures for funding, publishing, documentation, reviewing and auditing. In fact, even for composing this very paper, many citations point to web sites hosting transient content, and evading independent peer review; they are thus likely to be biased and marketing driven, and less suitable for historical archiving than articles in traditional journal libraries. Furthermore, the still quite volatile environment of blockchain, with issues such as workflow compatibility, satisfactory user experience (UX) and understanding of the crypto-economy, need to be convincingly resolved to efficiently promote its wide-spread adoption in science and RTD scene.

Realistically, transition to a crypto-economical approach by science and RTD communities would have to be gradual, and possibly seeded by a sizeable crowd of benevolent early adopters; while the landslide proliferation of Bitcoin appears to prove the opposite, wide-scale adoption of the blockchain-founded concepts proposed here very likely needs to be fostered by well-funded campaigns to sensitize the community at large, for which the disruptive concepts of blockchain are still rather alien. Amara’s law [232] seems to well summarize the status quo and prospects for the opportunity for blockchain in science and RTD: “We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run.”

AUTHOR CONTRIBUTIONS

All authors reviewed the entire manuscript. JD developed the main concept and authored the full draft manuscript. RW, KW, AI, WP, DK and JL mainly advised on blockchain technology, TH on open science and community-based participatory research, SP on NFTs, decentralization and scarcity, ME and SB on blockchain for research, NW on the reproducibility crisis in science, IP on circular economy and TP on publishing.

CONFLICT OF INTEREST STATEMENTS

I, author Martin Etzrodt, was employed at Akasha Foundation. I declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

I, author Sönke Bartling, am the sole proprietor and owner of Blockchain for Science GmbH. I declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

I, author Sebastian Posth, am the sole proprietor and owner of Posth Werk BV. I declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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