

extends, or otherwise refines the work of others, and be encouraging and supportive of authors who pursue these goals. The work that gets encapsulated in such publications should not be regarded as being second-class, or be dismissed as being insufficiently novel.

## 6.7 Incentives and barriers to reproducibility: investments and returns

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There have been many studies on what motivates people to change their behavior in their personal or professional lives [1]. Simply put, motivation is driven by need: the greater the need the greater the motivation. Other studies have focused on incentives as a means to change behaviours [2] while emphasizing the necessity to engineer the incentive to align with the need and goal to achieve and avoid the incentive to backfire [3]. For instance, as part of reaching better reproducibility, one should not build an incentive towards just making (any) code available, but rather the incentive should be built to make good quality code.

### 6.7.1 Investments of value

Table 5 lists the different investments of value from the different actors to achieve good reproducibility. The definition of actors is inspired by Section 6.4, with minor differences:

- **Creators** are persons responsible for the creation of possibly reproducible scientific artifacts, i.e. students, authors, academic leaders/lab directors, research software engineers, thesis supervisors, industrial researchers
- **Enablers** are persons and institutions enabling research to be conducted and published, e.g. funders, publishers, editors, institutions, academic leaders/lab directors, data providers, thesis supervisors, digital archives, professional societies, industry, research software engineers
- **Consumers** are persons and institutions consuming and utilizing scientific artifacts, e.g. readers, authors, students, policy makers, educators, adopters, technical communities, IT services, industrial researchers, users, research software engineers, PhD students
- **Examiners** are persons examining the quality of scientific artifacts, e.g. reviewers, thesis examiners, research evaluation committees, funders, policy makers, institutions, professional societies

Table 5 indicates a set of examples for each type of investment and which actors have to invest them.

### 6.7.2 Returns of Value

Table 6 indicates the returns of value from good reproducibility broken down with respect to the different actors.

### 6.7.3 Incentives

Having documented the investments, returns of value and the needs for reproducibility per actor (see Section 6.4), in the following we look at incentives required to transition from

■ **Table 5** Investments of value for creators (creat.), enablers (enabl.), consumers (consum.) and examiners (exam.)

Investments	Creat.	Enabl.	Consum.	Exam.
Artifact preparation (clean code, negotiate rights of code and data, annotate, document code and data, support incentives to promote reproducibility)	x			
Research documentation (carefully and reproducibly document all research steps, enable access to documentation)	x			
Education (training good reproducibility structures and methods, examine reproducibility knowledge)	x			x
Infrastructure (establish systems for reproducing computations, to publish reproducible research, and to review reproducibility)	x	x		
Citation (careful creating/citing literature, software, and data)	x		x	
project resources (enable researchers to make investments into reproducibility with respect to time and work force)		x		x
publication guidelines (prepare guidelines for authors and reviewers of publications with focus on reproducibility)		x		x
time for reviewers (give reviewers time to assess the reproducibility documentation of publications)		x		x
principles (create software citation, data management, and reproducibility plan principles)		x		x
requirements validation (establish methods to validate proposal with respect to established principles, adapt panel behaviours to follow principles)		x		x
credit mechanisms (establish community and institutional mechanisms to credit reproducible research)	x	x		

current behaviours to the desired ones to reach reproducibility. We do so in the context of four categories (natural, moral, financial and coercive), and their relationship to the actors. We adapted the categories of incentives from McClelland [3] and Dalkir [4] to address reproducibility as follows:

- **Natural Incentives:** an actor applies her/his curiosity towards PRIMAD, searches for the pursuit of true science, or wants to participate to accelerating research and innovation for the benefit of the social good in the world.
- **Moral incentives:** the choice made by the actor of embracing PRIMAD (see Section 6.1) to make her/his work reproducibility is widely regarded as the right thing to do, or as admirable and the actor can expect a sense of self-esteem, while the failure to adopt PRIMAD is condemned as the wrong thing to do, or as condemnable, and the actor can expect a sense of guilt.
- **Financial incentives:** the actor can expect some form of material reward (e.g. prize, grant, and more generally money) – in exchange for making her/his work reproducible.
- **Coercive incentives:** the actor failing to embrace PRIMAD will see her/his reputation shaken, portfolio of opportunities (e.g. grants, government budget) diminished.

■ **Table 6** Possible returns of value for creators (creat.), enablers (enabl.), consumers (consum.) and examiners (exam.)

Returns of Value	Creat.	Enabl.	Consum.	Exam.
Publicity (more citations and promotion for papers, code, and data, awareness of own and other communities, visibility for possible industry partners)	x	x		
Insight (better estimation of costs for reproducibility, easy incorporation into future proposal and plans)	x			
Impact in industry (commercialisation of research, recognition of results in industry, impact of research in industry)	x	x		
entry into industry (knowledge entry into industry eased, acceleration of transfer, wider economic value and relevance of research, easier reuse for industry)		x	x	
personal satisfaction (providing good reproducibility can give good conscience and satisfaction due to the good cause)	x	x		
incorporation in teaching (reduced preparation time and costs for education by using reproducible research artifacts)			x	
research reuse (easier, quicker, and more reliable research, building on reproducible results, code, data, and methods)	x	x	x	
innovation (more innovation through saving time to reproduce)			x	
ease of reproducibility (well-established mechanisms of reproducibility and accountability through introduction of common culture)	x	x	x	
funding effectivity (funding agencies get reproducible and reusable research, ineffective duplicated investigation and implementation is avoided, greater funds are conserved for novel research)		x	x	
interdisciplinarity (research between agencies, institutions, and labs becomes easier through a common ground of reproducibility)	x	x	x	
comparability (easier comparison with state of the art methods)			x	x

The principles underlined in the 4 reproducibility incentives categories are proposed to help design incentives that meet the reproducibility needs of each community and we expect that they will vary across communities, cultures and actors.

We propose below some examples of incentives per actor:

- The researcher who embraces PRIMAD creates a financial incentive (e.g. app research store) to get more investment from the funders, from industry into her/his research
- The researcher/community who embraces PRIMAD creates a coercive incentive (e.g. “no PRIMAD” stamp) for funders who ignore PRIMAD cost in research
- The community creates a natural incentive (e.g. best reproducibility award) for the researcher to make her/his research reproducible.
- The community creates a moral incentive (e.g. hall of fame) for the researcher to make her/his research reproducible
- The funders create a natural incentive (e.g. interdisciplinary badge) for the researcher to make her/his research reproducible where research is reused across scientific areas
- The funders create a coercive incentive (e.g. grant application section on reproducibility) for the researcher to make her/his research reproducible
- The funders create a financial incentive (e.g. grant, in kind resources) for the researcher to make her/his research reproducible

In structuring these incentives we also note the potential for deferred returns of value to act as a barrier for adoption and implementation of reproducibility. Where an actor must make an investment of value (Table 5), frequently as an individual, a significant period of time before reaping an equivalent or greater return of value (Table 6), often through membership of a community, the interim “debt” may become a disincentive to make that investment; i.e. beyond principled or altruistic motivations it may be difficult to justify that investment above the many other demands for priority faced by researchers and their organisations. As such, despite the long-term sustainability of reproducibility as an economic system through a beneficial cycle of investment and returns, it may be desirable – perhaps necessary – for enabling organisations to provide an initial pump priming investment of value to provide a “bridging loan” to creators until the system is self-sustained.

## References

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