Open Science in Developmental Science

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Abstract

Open science policies have proliferated in the social and behavioral sciences in recent years, including sharing study designs, protocols, and data, and pre-registering hypotheses. Developmental research has moved more slowly than some other disciplines in adopting open science practices, in part because developmental science is often descriptive, and does not always strictly adhere to a confirmatory approach. We assess the state of open science practices in developmental science and offer a broader definition of open science that includes replication, reproducibility, data reuse, and global reach.

"Progress in science is marked by reducing uncertainty about nature." (Nosek et al., 2018)

Developmental science seeks to understand how children learn and change across the environments of everyday life. Towards this goal, the field aims to accumulate increasingly precise observations and integrate them into theories that expand the breadth, depth, and predictive accuracy of knowledge (Munafò et al., 2017). However, findings in developmental psychology – as many other fields – do not always conform to a model of cumulative science (Ioannidis, 2005; Moody et al., 2022).

Many findings may not be *replicable* in new samples, meaning that new data yield results inconsistent with the original (Nosek et al., 2022; Open Science Collaboration, 2015). Perhaps even more troublingly, some scientific findings may not be *computationally reproducible*, meaning that their numerical conclusions cannot be duplicated by a new researcher starting from the same dataset (Hardwicke, 2019; Hardwicke et al., 2021; Stodden et al., 2018). Data *reuse* – in which researchers share their data to foster new questions and analyses – is also rare, leading to reduced impact of scientific investments. Finally, the lens of developmental science tends to be narrow in global *reach*, with most studies conducted by scientists in North America and Europe on children from a handful of countries (Kidd & Garcia, 2021; Nielsen et al., 2017). These four Rs – broad goals for an open science movement – are summarized in Table 1.

Research practices that interfere with these four goals are exacerbated in child development research (Davis-Kean & Ellis, 2019; Frank et al., 2017). Developmental studies often have low statistical power due to small samples of convenience that arise from the costs and challenges of recruiting and studying minors. Children are not always compliant participants, and coupled with typical challenges related to time, scheduling, and life circumstances that interrupt

adults and caregivers, high attrition rates magnify the complexities of securing valid and unbiased data. Furthermore, because direct instruction is not possible with young participants (e.g., infants), measurements may be inconsistent, and researchers are left to infer the meaning of highly variable responses (e.g., looking time, object manipulation, heart rate, or head-turns). And, because much of developmental science relies on video-recorded observations, sharing of raw data requires careful ethical consideration because faces and names are identifiable. Finally, disproportionate resources and access to research by investigators from different regions of the world limits the reach of developmental science.

Open science practices are designed to address these challenges, but scientific disciplines differ in the extent to which they value and adopt such practices. Moreover, within-discipline differences may exist depending on research design (e.g., pre-registration is more widely used and accepted in randomized control trials). Thus, given the wide range of what falls under the umbrella of developmental science, variation among researchers in open science practices is no surprise. The adoption of open science is not all or none, however. Instead, each additional practice moves the field incrementally towards the broader goals of reproducibility, replicability, reuse, and global reach (Klein et al., 2018).

Open science practices are, if anything, even more critically central to developmental science than to other subfields. Children as research participants are a vulnerable population of great societal importance and investment. And although public and private stakeholders uniformly agree on the need to protect children's well-being, there is no consensus on how best to do so, even within the scientific community. Thus, cultivating public trust in the scientific enterprise is paramount. Furthermore, the substantial financial and time investments required to study children's learning and development (including costs of equipment and time burden to parents

and children) mean that researchers have an ethical obligation to maximize the value of public investment and to accelerate scientific discoveries through open science practices.

In this review we present key goals for the broad application of open science practices in developmental science; address the challenges in doing so; and survey the current state of the field. Our review complements existing publications (Asarnow et al., 2018; Branney et al., 2019; Gehlbach & Robinson, 2021; Klein et al., 2018; Nosek et al., 2022; Tackett et al., 2019) and adds to the wealth of available resources on open science practices by addressing issues specific to developmental science. Notably, we move beyond narrow and rigid interpretations of open science that have likely impeded its wider acceptance and adoption: Open science is not, and should not be, narrowly defined by any specific policy, whether it be data sharing, preregistration, or badges rewarding such practices (Kidwell et al., 2016). A broad and flexible view of open science must include practices that increase transparency at all stages of the scientific enterprise (Soska et al., 2021).

The Goals of Open Science: The 4 R's

The open science movement pursues scientific transparency policies to enhance replicability, improve reproducibility, accelerate discovery through reuse, and broaden global reach. In this section, we briefly review policies and practices in the service of each of these goals. Box 1 provides select examples of precedent-setting initiatives in developmental science that work towards these goals.

Enhancing the Replicability of Results in New Samples

One major catalyst for the open science movement has been the failure of independent researchers to replicate the findings of many published studies (Moody et al., 2022; Nosek et al., 2022; Open Science Collaboration, 2015). Much ink has been spilled around what precisely

constitutes replication and when such a study should be considered successful (Nosek & Errington, 2020; Zwaan et al., 2018). In developmental science, not every finding *should* be replicable across samples and contexts. Yet failure of replication due to statistical issues in the original study is preventable: If a reported result is due to random sampling variation rather than true signal in the data, it is by definition un-replicable – leading to wasted efforts by teams that follow up on it. The practice of "p-hacking" – taking advantage of undisclosed analytic flexibility to report statistically significant findings – may be a major source of replication failures (Nosek et al., 2022; Open Science Collaboration, 2015).

Preregistration – traditionally defined as specifying outcomes and analyses in an open and independent repository before collecting data – is one response to the challenge of p-hacking. By reporting all conditions and measures in a study and planning hypothesis tests, experimenters can remove extra "degrees of freedom" that may lead to spurious discoveries (Nosek et al., 2018; Simmons et al., 2011). Preregistration is mandated in clinical trials (e.g., via clinicaltrials.gov) to avoid incorrect conclusions that could incur harm to patients; empirically, this policy has reduced publication and reporting bias (Kaplan & Irvin, 2015). Registered reports, in which manuscripts undergo peer review prior to data collection, are one especially promising form of preregistration for some study types (Nosek & Lakens, 2014).

Not all research in developmental science adheres to a hypothesis testing approach, however. Much research is descriptive or exploratory, with researchers annotating events based on video or audio recordings or language transcriptions, and sometimes live observations, in the absence of any expectations about what they will find. Such work provides critical insights into developmental processes and can spur new hypotheses that are grounded in careful documentation of behavior. Although descriptive and exploratory research (rather than

confirmatory experiments) may not fit with current norms of pre-registration, many aspects of research plans can be registered before embarking on an exploratory or descriptive study. For example, researchers can pre-register (1) the source of data, study design, methods, and stimuli/materials; (2) behaviors they plan to code from video-recorded observations or language transcripts; (3) plans for calculating reliability, (4) approaches to data quality assurance; and (5) tentative plans for analysis, perhaps accompanied by a note that additional analyses will be conducted based on what researchers find (Kosie & Lew-Williams, 2022). Researchers who are unsure about certain components of their research plans can engage in sequential pre-registration (Nosek et al., 2018). Such steps increase transparency about pre-planned aspects of a study while maintaining the flexibility necessary for description and discovery in rich datasets.

Increasing Analytic Reproducibility

Developmental research is rich in methodological and analytic breadth that continues to expand. For example, developmental research uses neuroscience, physiology, and computational models; the great reliance on analytic code in such work amplifies concerns about computational reproducibility. Because developmental psychology as a field has a newer culture around computational methods, cultural transfer of good coding practices such as the use of version control and code review may be less common than in other subfields (Poldrack et al., 2017). Thus, open science practices that seek to decrease errors and increase reproducibility are critical for developmental research.

Unfortunately, errors in data analysis and reporting are common. An analysis of research texts found that approximately half of published psychology articles contain at least one statistical reporting error (defined as a set of reported statistical values that are internally inconsistent with one another), an estimate that is likely conservative (Nuijten et al., 2016). Furthermore, when

teams of analysts download data from papers (which presupposes that the data are available), only around a third of findings can be fully reproduced without assistance from the authors (Chang & Li, 2017; Hardwicke et al., 2021). These findings suggest that when errors exist, they typically cannot be detected and corrected.

Transparency – sharing both analytic code and the data on which it operates – is both a motivator for better organization and documentation by the original authors and a step that allows others to identify errors or verify results (Klein et al., 2018). The creation and availability of computational technical tools that assist with reproducing analyses have facilitated the sharing of code and data together (Aust & Barth, 2018; Kluyver et al., 2016). In some cases, requiring authors to make data available as a condition of publication acceptance or the receipt of study funding has also helped researchers incorporate time and resources costs as part of the production of research output.

The availability of code and data not only facilitates the exact reproduction of a finding, it also allows analysts to check the robustness of the finding. Robustness in this case is a term used to describe how sensitive a finding is to specific analytic decisions (including, for example, coding of the dependent variable, inclusion or exclusion of certain independent variables or covariates, and related modeling decisions). A finding can be analytically reproducible but nevertheless of limited utility if it only emerges when certain control variables are entered into a regression model (Duncan, 2014). Increasingly, when their findings depend on a complex analytic model, researchers are encouraged to include robustness checks and perhaps even report a ”multiverse” analysis in which they conduct a large set of different analyses to examine sensitivity to certain modeling or analytic decisions more formally (Steegen et al., 2016).

Accelerating Discovery Through Reuse

A third goal of open science is to maximize the value of research and enable new discoveries by leveraging prior research investments. A lack of transparency and sharing of research methods and raw data creates considerable inefficiencies in the scientific enterprise by benefitting individual investigators while decreasing value for the broader scientific community. The rich data and methods employed by developmental scientists may make reuse opportunities even more important in developmental science than in other fields (Gilmore & Qian, 2022). As one example, video recordings of children and/or their interactions with caregivers are a cornerstone of many developmental studies that capture behaviors in the whole child and surrounding context. Their wide availability can foster video-based behavioral coding and scientific insights beyond the original motivations or primary research questions (Adolph, 2020). Similarly, readily available and publicly accessible data from resources such as the National Longitudinal Survey of Youth, the child supplement of the Panel Study of Income Dynamics, the NICHD Study of Child Care and Youth Development and the National Longitudinal Study of Adolescent Health have also been fundamental to accelerating discovery about the roles of children's broader family and social environments in development.

Open science practices also allow researchers to aggregate data across children and developmental contexts by combining available datasets to better understand mechanisms of developmental change (Frank et al., 2021). Among its many possible contributions, aggregation allows researchers to build a sufficient sample to investigate developmental processes that affect narrow populations (e.g., children with impaired vision or hearing). Policies that require researchers to share materials, data, and code in findable, accessible, interoperable, and reusable (FAIR) repositories have been much more successful and effective thansharing "on demand" or

"on request" (Wicherts et al., 2006). Such sharing maximizes the scientific value of a dataset, a goal that is relevant for both research participants and funders (Brakewood & Poldrack, 2013).

Finally, repeating and building on a study may require recreating materials developed by another investigator. Because developmental research can be sensitive to the nuances of particular stimuli, dissemination of materials can play an outsized role in guiding new experiments. Although proprietary attitudes about stimuli are common – perhaps because of a desire for exclusive access to stimuli that were costly to create or to avoid questions about original results (e.g., Phillips et al., 2015) – sharing of stimulus materials can be done in ways that credit creators and substantially increase the impact of published work. For example, all materials shared on sites like Databrary and OSF contain a Digital Object Identifier (DOI) that should be cited to credit the researcher who has shared resources (Simon et al., 2015).

Expanding Reach and Building Global Capacity

A final objective of open science practices is to expand the reach and inclusivity of developmental studies to represent researchers and children from regions across the globe. Variety in contexts, perspectives, and backgrounds is critical to building a global representative developmental science. However, most developmental samples are typically drawn from a narrow range of cultures, populations, and languages, which stymies efforts to draw generalizable conclusions about the nature of developmental variation and change (Kidd & Garcia, 2021; Nielsen et al., 2017). Nurturing scientific studies from a broad range of scholars and contexts can ensure the inclusion of different populations of children through their knowledge of and sensitivity toward their cultural community. Perhaps even more importantly, researchers from different cultural communities contribute new perspectives and questions that may be important in their context but overlooked in others. Practices that expand the reach of developmental science

include open access to scholarly products, open sharing of research materials (from protocols to raw data of all kinds), and democratization of research evaluation.

Open access to scholarly products means that researchers around the globe can access scientific research in a timely fashion. Much literature is published behind "paywalls", requiring an expensive institutional subscription for individuals to browse the literature freely. Individuals without institutional affiliations or those from less-resourced institutions often cannot access the most recent literature, a clear obstacle to their scientific contributions.

Open sharing of research products (e.g., protocols, stimuli, behavioral coding manuals, analytic code, video recordings, and raw and processed flat-tile data) reduces the cost of research for individuals in lower-resource contexts. Open sharing allows researchers to leverage existing materials and data in repositories for study replication, analytic reproducibility, and data reuse (e.g., coding new behaviors from video recordings of infants or by applying new analyses to longitudinal datasets). Furthermore, large collaborative projects and repositories can bring prominence to the contributions of researchers from across the globe.

Finally, open science practices that focus on transparency can shift emphasis away from the evaluation of research products based on institutional and individual reputation towards evaluation of the contribution of research products. For example, by providing third-party endorsement of quality standards met by the study, clearinghouses and "what works" registries (Hill & Buckley, 2021; *Home Visiting Evidence of Effectiveness Review*, n.d.) ease demands on users of research and incentivize transparency.

The State of Open Science in Developmental Science

Given the benefits of open science practices and many recent papers on the topic, where does the field of developmental science currently stand? In 2016, the Society for Research in

Child Development (SRCD, home to flagship journals of *Child Development* and *Child Development Perspectives*) convened a committee on Open Science Practices, charged with assessing the state of the field and issuing a consensus statement on behalf of the society. Three years later, the society ratified a policy suggesting that authors "note if and where" their materials are shared, and that society publications consider the future and role of pre-registered and replication studies in their flagship journals. The society's reluctance to mandate open-science practices reflected their sensitivity to variation in attitudes among society members and concerns that open science practices can impede rather than generate and accelerate scientific progress (Gennetian et al., 2020; Gilmore et al., 2020). How has adoption of these practices progressed since? In this section, we review uptake of open science policies in developmental science.

Progress toward replicability

Funders, journals, and professional societies have increasingly encouraged researchers to embrace practices around transparency and open sharing of all forms – including study methods and materials, the use of video for demonstrating study procedures, and the pre-registration of study questions and hypotheses. Such practices promise to increase the replicability of research. Changing expectations, attitudes, and behaviors around pre-registration offers one example. Researchers engaged in NIH funded clinical and behavioral interventions must now pre-register their research questions, hypotheses, analysis plans, etc. in clinicaltrials.org. Other research funders (e.g., the Arnold Foundation) have followed this lead. Still, much basic developmental research – which largely does not entail randomized trials – is not subject to such mandates. Nevertheless, researchers interested in preregistration can use independent registry sites such as AsPredicted.org or the Open Science Framework (OSF).

OSF represents one of the largest pre-registration portals available for developmental

researchers: It is host to over 10,000 projects identified under search terms “child development,” “cognitive development,” “brain development,” and “socio-emotional health.” Figure 1 shows for example that the number of registered studies through OSF when searching terms based on child development epochs “infant” or “adolescent” has increased seven-fold from 2012 to 2021. Although most preregistration templates focus on hypothesis testing for randomized experiments, guidelines on pre-registration of secondary data analyses (Akker et al., 2021), longitudinal research (Petersen et al., 2022), and descriptive, discovery science (Kosie & Lew-Williams, 2022) are emerging. Norms are slowly shifting with increases to preregistration of articles published in many flagship journals of developmental science. We offer a glance at this progress within a set of 20 peer-reviewed journals in Table 1.

Reproducibility and reuse: Data sharing policies

Data sharing is increasing in psychology. More than half of psychology researchers reported sharing their data, although the quality and reusability of shared datasets is often low (Borghi & Gulick, 2021; Hardwicke, 2019; Towse et al., 2021). Moreover, what constitutes sharing and what is shared (e.g., raw data vs. processed data; tabular data vs. video recordings) differs enormously across researchers.

As the primary mechanism for production of scientific scholarship, peer reviewed journals play a substantive role in shaping policies around data sharing and transparency. Yet journals have been reluctant to mandate data sharing or to enforce data-sharing policies (Wicherts et al., 2006). The Transparency and Openness Promotion (TOP) guidelines attempted to create uniform standards around data sharing practices (Nosek et al., 2015), but their adoption has been piecemeal (see Table 1). In contrast, funder mandates for data sharing have moved more quickly. Since 2011, the US National Science Foundation has required its grantees to submit a data

management plan, and the US National Institutes of Health mandated open data sharing for its grantees starting in 2023. Other major funders of developmental science have similarly adopted data sharing mandates, including the Wellcome Trust (2016) and the Robert Wood Johnson Foundation (2019). The next frontier for such policies will be to ensure that data are shared in a way that maximizes their value so that they are discoverable and can be combined with other data to accelerate scientific discovery.

Expanding global reach

Growing awareness of the need for diversity, equity, and inclusion in psychological studies has spurred efforts to broaden the representation of underrepresented groups around the world among both the scientists conducting research and the children participating in research. Such efforts include open access to publications; global access and contributions to the scientific database on children's development; transparency and thoroughness in reporting sample demographics in published works; and mechanisms for scientists to broadly collaborate on study design, implementation, and sharing of research products.

Open access to research products. Despite widespread endorsement of open access to published studies – with many researchers viewing open access as an ethical imperative – the adoption of such practices has been inconsistent and rife with challenges. Progress towards open access in psychology has been considerable, though far from perfect. By one estimate, more than 50% of published psychology articles are available through some form of open access. Within developmental science, "gold" (paid) open access is an option for many journals (Table 1). For open access advocates, the key challenge has been engaging funders and stakeholders to avoid exacerbating disparities by burdening authors with extra publication fees (Brainard, 2021) in what risks becoming a "pay to publish" system.

Yet the biggest change in the open access landscape has been the rise of "green" open access. Fueled in part by the need to disseminate research rapidly during the covid-19 pandemic (Watson, 2022), preprint servers like arXiv, bioArXiv, and psyArXiv have grown tremendously. At the time of writing, psyArXiv hosts more than 22,000 psychology papers and is growing by around 20 papers per day, with authors typically posting papers before submitting for publication at a peer-reviewed journal.

Preprints serve several purposes. First, they guarantee access to published work in un-typeset form even if the eventual published article is inaccessible. Second, and perhaps more important to their adoption, they allow authors to share their work when it is completed, addressing the career hurdles that may arise when papers are under review for months or even years. By listing preprints on a CV or in a grant application, early career researchers can gain credit for what they have accomplished to date, rather than only at the end of a long and uncertain publication process. Finally, by making research results available regardless of publication outcomes, preprints can help counter biases in the literature caused by the reluctance of some journals to publish null findings, failed replications, or applications of unconventional theories or methods (Wingen et al., 2022).

Transparency about samples. In 2020, the Society for Research on Child Development enacted policies on the reporting of sample characteristics, a direction spearheaded by former Editor in Chief Cynthia Garcia Coll. Specifically, SRCD's policy requires authors to clearly specify recruitment procedures and sampling decisions; participant characteristics including race/ethnicity, socioeconomic status, native language; and contextual information to frame the study, including the country, region, city, and so on where data were collected. Full transparency on the characteristics and contexts of developmental studies serves the dual goals of increasing

diversity in the participants of research and advancing efforts towards the replicability of findings.

Access to and contributing data to the knowledge base. The broad and open sharing of research methods, behavioral coding manuals, analytic code, and raw and processed data of all forms – in repositories such as OSF and Databrary – supports diversity, equity, and inclusion by allowing researchers from around the world to both access and contribute to the knowledge base on child development. Researchers only require an internet connection to download developmental data of all forms to ask new questions on existing data or to leverage research stimuli, methods, etc. to replicate and extend existing studies to new samples. Moreover, the ability of researchers to contribute data openly provides a valuable mechanism for expanding the knowledge base on child development – from the overly narrow samples of children represented in research today to samples drawn from around the world in future studies.

Creating spaces for collaboration. Cross-lab collaboration among researchers from different countries or regions of a country (e.g., rural and urban) allows investigators from different backgrounds, languages, and cultures to share their expertise, samples, and resources to address topics of mutual interest (Frank et al., 2017). Such collaborations in turn help ensure that developmental theories and findings are grounded in the experiences of children from a variety of backgrounds. Collaborative science also allows researchers to pool resources across sites to recruit a larger sample than would be possible by a single lab, an approach that is particularly important when recruiting children from special populations where generating a sample of sufficient size is a challenge (e.g., children with disabilities). Exciting new initiatives around consortia and data repositories, described next, provide platforms to facilitate collaboration and extend the reach of developmental science.

Consortia and Repositories: New Drivers of Open Science

As reviewed, the adoption of open science practices in developmental science has been uneven. At the same time, the field is steadily expanding. One of the most exciting trends in the open science landscape is the rise of open, collaborative mega-projects. These are sometimes described under the umbrella of "big team science" (Coles et al., 2022), in which difficult research challenges – data collection, behavioral coding, transcriptions, materials creation, and analyses – are distributed across a community, creating a larger and more impactful product by virtue of the collaboration. In developmental science, collaborative projects and big team science have typically taken the form of either data collection consortia or collaborative data repositories. Here we highlight a few select examples to illustrate how such mechanisms can drive progress towards open science goals.

Consortium research

Several developmental science consortia have adopted collaborative research initiatives that are grounded in an open-science framework. For example, ManyBabies (MB) is a research consortium for pursuing multi-lab collaborative projects. The first ManyBabies project was a replication of the well-known phenomenon of an infant-directed speech preference. The goal was to measure variability in findings across infant populations and experimental methods (ManyBabies Consortium, 2020); with 67 labs contributing data, this project represents one of the largest experimental investigations of infancy to date. Initially devised as a way of pursuing best-practices replications of important phenomena (Frank et al., 2017), the consortium has increasingly taken on new projects that require coordinated effort to solve a difficult theoretical or empirical challenge. Critically, open science practices are woven throughout ManyBabies projects: All projects are preregistered (typically as Registered Reports); all materials, analytic

code, and data are released as part of the project; and participation is open to the entire research community. By actively pursuing global collaborations and by lowering the barriers to participation, ManyBabies aims to broaden the set of labs and investigators contributing to cutting edge experimental work in developmental science, with a special focus on training graduate students and providing mentorship on open science practices.

The NIH-funded Play and Learning throughout A Year (PLAY) project describes a complementary but distinct model for pursuing open science goals within consortium research (play-project.org). Through a model of synergistic, collaborative science among 72 developmental researchers, PLAY will gather 1000+ hours of video of 12–24 month-old children and their mothers engaged in everyday activities in the home environment across 30 geographically distributed sites in the United States; transcribe language interactions between infants and mothers; and collaboratively annotate videos for behaviors of locomotion, emotion, object play, and language pragmatics (across 48 behavioral coding labs) following consensus standards created by subgroups of participating domain experts. The goal of PLAY is to create an openly available video corpus with annotations and associated metadata for authorized investigators on Databrary who can address new questions about learning and development during the second postnatal year. As with ManyBabies, PLAY openly shares consensus best-practice methods and guides that can be applied beyond the original study, including behavioral coding manuals, transcription guidelines, and newly created survey instruments for Spanish-English dual-language learners. Most centrally, PLAY uses video to demonstrate all aspects of the study protocol (e.g., recruitment of families; interviews with mothers about children's vocabulary, temperament, locomotor skills; how to conduct video tours of participants' homes, and so on).

These two projects – and others in psychology broadly (e.g., the Psychological Science

Accelerator; Moshontz et al., 2018) – share a commitment to open science practices with goals to broadly disseminate science practices and build capacity for researchers who likewise seek to engage in open science. For example, participants in the first ManyBabies study noted in an informal survey that they were much more likely to adopt open science practices in their own labs having tried them in a supportive context (Byers-Heinlein et al., 2020). In addition, use of the open standards, tools, and materials created by these projects provide illustrative models on the value of transparency for the next generation of student trainees and non-participating labs.

Open data repositories

Data repositories and platforms both promote open science and allow for generative research beyond the boundaries of original data collection goals or investigators. Large data repositories such as the Inter-University Consortium for Political and Social Research (ICPSR) provide a database of longitudinal and national studies with information about children's developmental environments and outcomes (e.g., the National Survey of Children's Health). Indeed, some of these repositories have arrangements with professional organizations to also serve as co-hosts for data deposits of published research articles (e.g. OpenICPSR collaborates with, for example, the American Education Research and American Economic Associations). Below, we describe three successful examples specific to developmental research that have overcome the perceived barriers of broad data availability related to working with vulnerable populations and collecting sensitive data.

TalkBank is an open-access repository of naturally occurring spoken language (MacWhinney, 2019). The TalkBank corpora currently contains 122 million words across 44 languages, and it has generated over 8000 publications across thousands of users. Developmental researchers have leveraged the openly shared transcripts of TalkBank to tackle questions about

language learning and speech production in monolingual and bilingual populations from diverse cultural communities, individuals experiencing language disfluencies (e.g., stuttering), persons with autism spectrum disorder, and so on, and it even contains transcripts from classroom settings. TalkBank's reliance on an openly shared uniform transcription format (CHAT), facilitates combining language data across studies, and thus allows researchers to analyze various components of language – phonology, lexicon, syntax, and discourse – across larger samples than would be possible in a single lab.

Databrary (databrary.org) is a restricted access video data library specialized for sharing, storing, and streaming video-based data in the form of inherently identifiable video and audio recordings of children with and without caregivers or demonstrating research methods. The database allows researchers to ask new questions by accessing video recordings of children of different ages, in different settings, engaged in a rich variety of activities (e.g., bookreading with caregivers, natural play in the home environment). Currently, Databrary has over 1,500 investigators at 700+ institutions across 5 continents, and contains over 90,000+ hours of video recordings. Databrary consent forms offer participants options for different release levels for data stored in the database, including sharing with authorized researchers, learning audiences (e.g., talks and classes), or the broader public.

Wordbank is an open database of children's vocabulary development, archiving data from a specific parent report instrument for measuring children's early language, the MacArthur-Bates Communicative Development Inventory (Frank et al., 2016). The repository contains data from more than 78,000 children and 39 languages, allowing for a rich characterization of how language learning varies across cultures and contexts (Frank et al., 2021). Unlike broader repositories such as OSF and Databrary, Wordbank takes advantage of the uniform format of its data to allow for

access and browsing of the data through both interactive online visualizations and a programmatic interface.

Challenges for Open Science in Developmental Science

Although developmental science has made substantial progress in embracing open science during the past ten years, many obstacles remain. In this section, we discuss three perceived challenges for open science in developmental science: tensions between exploration and confirmation, the potential for career risks, and how open science practices intersect with the goal of fostering an inclusive science. Each of these critiques is important to understand in its own right, and also because critiques of specific, narrowly construed policies can unproductively undermine perceptions of the value of open science more broadly.

Does open science limit exploration and discovery?

Initial open science reforms focused on correcting perceived issues in experimental psychology, for example by reducing the risk of p-hacking. Thus, many policies initially assumed that preregistration simply entailed registering a hypothesis about condition differences and depositing a single tabular data file in a repository. Although this narrow conceptualization may be a useful starting point, it does not conform to many developmentalist scientists' vision of their work, which can involve observational designs, rich behavioral and/or physiological measures, longitudinal observations, and deep appreciation of the limitations of generalizing across samples with different characteristics.

Recent reforms have been increasingly sensitive to the broader set of research goals and activities that define developmental science. For example, preregistrations may productively take many forms that promote transparency about the research process without a strict focus on hypothesis testing, as reflected in the breadth of preregistration templates available on the Open

Science Framework. Furthermore, initiatives like ManyBabies recognize that the combination of rich data and privacy concerns may lead to the need for more careful data sharing policies (e.g., sharing tabular data via an open channel like OSF and sharing raw video data through a more restricted access channel such as Databrary).

Does open science pose risks to career enhancement and development?

In a casual interaction between one of the authors of this paper and an early career scholar in psychology, a query about pre-registering new exploratory work was met with dismay by the early career scholar who declared, "if I pre-register this pilot work, I'll get yelled at by everyone for what I did not get right." Transparency in research is not always comfortable! Sharing data and analysis code can lead researchers to worry that mistakes in their work will be identified. Yet this worry may be misplaced: Researchers tend to be judged by whether they are open to correcting issues or errors in their work, not whether they are correct to begin with (Ebersole et al., 2016).

Sharing resources prior to publication can also lead researchers to worry that their work will be "scooped" or their ideas will be co-opted. Both might have more severe consequences for early career researchers. Collision of ideas is a part of science, especially in fast-moving fields (Kim & Corn, 2018), but – when used appropriately – open science practices can be part of the solution, not part of the problem. For example, posting preprints is an important way to establish precedence independent of the vagaries of peer review (Kriegeskorte, 2016). And while scooping is a real issue, its risks can be mitigated by strategic decision-making about which data to release and when (Popkin, 2019). For example, a researcher might decide to make a public release of only enough data from a larger dataset to ensure reproducibility of the key results in a paper, embargoing the full raw dataset for a set period (e.g., two years) to allow for completion of a

publication(s). This step would signal to observers that the researcher values openness and sharing, while also protecting the researcher's future interest.

Although it can be challenging for researchers to navigate the changing landscape of open science practices, many of these practices can have positive career value – by allowing greater transparency in understanding a researcher's contributions and by signaling a commitment to shared scientific values. Senior researchers should encourage doctoral and postdoctoral researchers in their labs – the next generation of developmental scientists – to list open-science practices on their resumes (e.g., publications for which they share video, stimuli, methods, behavioral coding manuals, data, analytic code, etc.) so they can be properly credited for their commitment to scientific transparency and integrity.

Does open science raise barriers for inclusion and diversity in who conducts science?

Many open science policies are compatible with – and in some cases, designed to – decrease historical barriers to involvement in science. Open access policies, especially preprint posting, democratize access to the scientific literature, removing the barrier of access to institutional journal subscriptions. Data, code, and materials sharing policies allow researchers without personal access to a scientific network to access experimental materials and analytic techniques to the same extent as those who occupy positions of privilege in the social network of science. Such changes are necessary to decrease inequities in science – but they are not in themselves sufficient. To diversify the research community in developmental science beyond majority groups in a small number of nations, developmental scientists must engage in active outreach, seeking to build networks that broaden participation and construct training pipelines and collaborative ventures that lead scholars from a wide range of backgrounds into the field. Such collaborations must be reciprocal in nature to ensure they are grounded in community input (i.e.,

participatory research) at all stages of the research process – from questions, to design and methods, to implementation of the study, to analyses and dissemination of findings.

When scientists engage with complex social issues, the chance of skepticism and criticism is high. Motivated individuals may seek to undermine findings that do not align with their personal beliefs, subjecting evidence to increased scrutiny based on desired outcomes rather than the quality of research. In the face of such scrutiny, researchers may be tempted to withhold details and to shy away from transparency. But researchers should do precisely the opposite. When work is conducted with full transparency, critics and advocates can assess the strength of the evidence and researchers can easily refute charges of selective or biased reporting. Furthermore, because controversial areas of research are precisely where public trust in science is likely to be lowest, researchers should be as scrupulous as possible in following policies that are designed to maximize credibility.

Suggestions for the Future

The 4Rs – replication, reproducibility, reuse, and reach – offer an organizing action-oriented framework for ongoing adoption and adaptation of open science practices in developmental science. As described, funder, journal, and institutional policies are key instruments for encouraging the adoption of open science practices. Yet, implemented in isolation, many policies meet with resistance and avoidance. Policy alone is not enough to produce concrete changes to behavior without educating stakeholders about why policies exist and how to follow them, fostering changes in social norms, creating incentives for compliance, and building capacity. We discuss each of these directions in turn.

Educating stakeholders

Policy interventions are most effective when the people they affect understand them

(Weisman & Markman, 2017), especially when compliance with a policy requires learning new tools or thinking through new issues. Thus, for open science policies to be maximally effective, researchers need to be educated about how and why to carry them out. First, the whys and hows of open-science practices should be included in curricula of research methods classes so that students understand the potential pitfalls of closed science and learn reproducible, transparent workflows from the outset (Frank & Saxe, 2012; Hawkins* et al., 2018). Educating students about open science also helps to create a pipeline of researchers who are passionate about collaborative, open research, and helping to change norms (Tackett et al., 2019). Second, beyond the classroom, researchers need access to educational resources that help them to understand and easily deploy open sciences practices. Professional societies must play a role by offering pre-conferences, webinars, and workshops to facilitate adoption of open science practices. Funders should incorporate budget lines for open sharing practices (e.g., open access to publications that arise from a grant; funds to prepare data so they are easily findable and usable by others). Furthermore, organizations and consortia such as ManyBabies and the PLAY project can take responsibility for educating participants about the values and reasons for adopting open science practices.

Changing norms

As social scientists know, behavior change is difficult, especially when researchers may perceive costs or risks in adopting new practices – as is precisely the situation for open science reforms. In the face of adoption challenges, one of the most effective tools for behavior change is through a change in social norms (Sunstein, 2019). If researchers perceive that the norm in their field is to post preprints, share data and materials, and to preregister the details of their studies, they will be more likely to adopt such practices, even if they are costly. To change norms – and to

change researchers' perceptions of norms – the open science movement needs to make visible the rapid adoption of open science practices over the past ten years. Such visibility can be especially powerful when social referents, scientists, and organizations with high status within their community advocate the practices (Prentice & Paluck, 2020). Thus, individual scientists – especially more prominent or senior ones – have the responsibility to adopt open science practices and endorse and advocate for those practices. Even an act as simple as highlighting policy compliance during peer review ("I commended the authors for sharing their code and data to allow me to reproduce their results") can signal shifting norms. Indeed, communicating values and norms around open science through modeling, direct encouragement, and explanations about the value of full transparency may be more powerful than signaling style strategies such as awarding badges to researchers who engage in open science. While 4 of the 20 journals that we reviewed give badges, this practice has engendered some mixed feelings in the community and has received limited support as an intervention (Rowhani-Farid et al., 2020).

Creating incentives

Crediting open science practices through informal and formal mechanisms can go a long way in incentivizing researchers to engage in such practices. Informally, individual lab policies can endorse open science practices, and encourage and train students to pre-register and openly share their research questions, hypotheses, protocols, behavioral coding, videos, raw data, analytic code, and so on in existing repositories. Course assignments that encourage students to access and use openly available data can highlight the value of open science by making them beneficiaries of the research investments made by others, and to one day pay it forward themselves. Such grassroots efforts will go a long way in producing the next generation of advocates for open science practices in developmental research.

Formal incentives for open science practices can be instituted through a variety of mechanisms, including creation of DOIs associated with shared stimuli, procedures, and data to be cited by researchers who access shared resources; consideration of open science practices in personnel and tenure reviews of faculty hires and promotions; required sections of grant applications stating how and when research products will be shared; and funding streams for the preparation of data for open sharing and the reuse of existing datasets to maximize investments.

Building capacity

One of the most common responses to policy shifts around data sharing is grumbling around "unfunded mandates." To recognize the importance of open science, institutions and funders must be willing to direct resources towards building and sustaining these practices. For example, the new NIH data sharing policy explicitly lists data sharing costs as allowable budget items; other funders would do well to make this norm explicit. The creation and maintenance of data sharing resources like Talkbank, Databrary, and Wordbank is also extremely resource intensive; although all three were created with US federal funding, few programs exist for funding the continued maintenance of such resources.

Finally, global collaboration requires mechanisms for creating capacity across institutions, especially outside the United States. As an example, the first ManyBabies study received a $50,000 grant from the Association for Psychological Science, which was regranted to participating labs around the world in small amounts from $500 - $2,500. Under most funding models, such small grants are impossible – for example, creating US federal subcontracts for these amounts would require dozens of hours of paperwork and paying overhead to two institutions – yet they create a substantial incentive to participate in an open, global network.

Conclusion

A narrow conception of open science can lead to a perceived mismatch between overly specific policies and the breadth of research that falls under the umbrella of developmental science. This conception is mistaken. We argue for a broad view of open science that revolves around four goals: increasing replicability, ensuring reproducibility, facilitating reuse, and broadening global reach. Despite impressive progress towards each of these goals in the last ten years, challenges remain. Nonetheless, there is reason to be optimistic: new practices like preprinting are expanding access to the scientific literature; new policy guidelines by funders, journals, and so on are ensuring greater levels of data sharing; and new consortia and repositories are leading the way towards a representative and robust research. These exciting new developments illustrate the ways that open and transparent science practices can be adapted to the rich variety of perspectives, methods, samples, and goals of developmental science.

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Table 1. The 4Rs: Values for a Broader Open Science.

Value	Description
Replication	Measurement of the same effect in a new sample of participants
Reproducibility	Calculation of the same numerical measures from the original dataset
Reuse	Use of shared code, data, or materials for new research
Reach	Broadening global access to scientific products

Table 2. Open Science Practices of Selected Journals in Developmental Research.

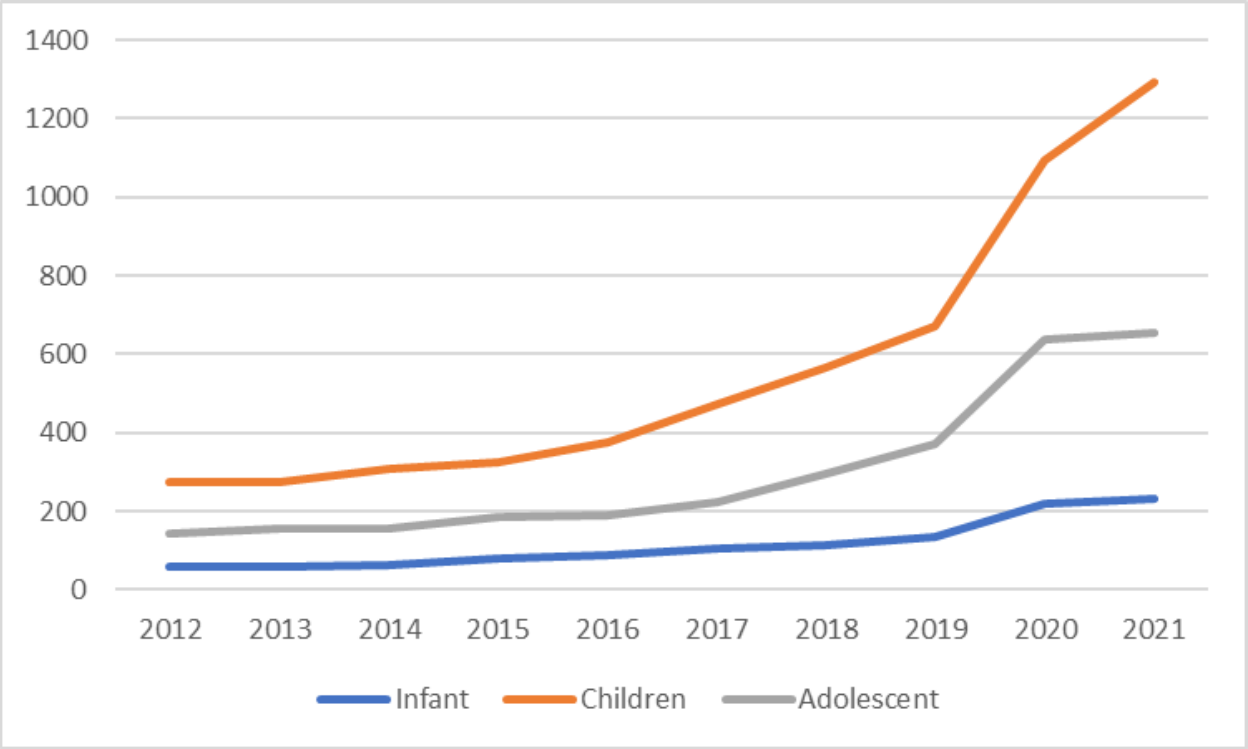
	Statement regarding open science	Socio-cultural sample description	Accepts registered reports[2]	Fee-based open access	Badges available	Pre-prints acceptable	Endorses publishing replications	Data availability policy
Annual Review of Developmental Psychology						X		None
Child Development*	X	X	X	X		X		Authors must state whether data, code, and materials are available, but information will not be used in review
Child Development Perspectives		X		X		X		None
Current Directions in Psychological Science*				X		X		None
Developmental Review*				X		X		Encouraged to state data availbility, if unaccessible or unsuitable to post, you can indicate why during the submission process
Developmental Psychology*	X	X	X			X	X	Must state whether data and study materials are available and if so where to access them - if not available, must state legal or ethical reasons
Developmental Science			X	X		X		Must include a data availbility statement to confirm if data is available and if so where it can be accessed
Educational Psychologist*				X		X		Must provide info about where the data can be found & must deposit in recognized repository
Educational Psychology Review*	X			X		X	X	Encourages authors where possible in applicable to deposit data that supports the findings in a public repository
Exceptional Children*	X		X		X	X	X	Make the data for the study available for independent review and provide access to procedures and code used in analysis
Human Development						X		Strongly encourage authors to make all datasets available without unnecessary restrictions, required to include statement
Infancy			X	X		X		Encourage data sharing through NYU Databrary, must include data availibility statement and link to repository used
Infant Behavior and Development	X		X	X		X		Encourages data sharing when appropriate and state availability of data in submission
J of Abnormal Psychology*	X		X		X	X		Must state whether data and study materials are available and where to access them - if not available, must state legal or ethical reasons
J of American Acad of Child and Adolescent Psychiatry*	X	X	X	X		X		Different requirements based on the type of study
J of Child Psychology and Psychiatry				X	X	X		Encourages authors to share the data and other artifacts supporting the results in an appropriate public repository
J of Cognition and Development	X		X	X	X	X		Required to provide a data availability statement detailing where associated data can be found and how it can be accessed, if not available must state why

J of the Learning Sciences*			X	X	Please provide information about where the data supporting the results or analyses presented in the paper can be found
Monographs of the SRCD	X	X	X	X	None
SRCD: Social Policy Report		X	X		None

Notes: X = Yes as of May 2022. Each of the journals included in this table mandates a conflict of disclosure form. Each of the journals also requires an indication from authors whether data used in the study are available and whether there are any restrictions. No journal listed here requires that data or analysis programs be made available as a condition of publication. * Journal identified as top 10 in 2020 in Development and Educational Psychology. Additional Js in the field of developmental science that accept registered reports include British J of Developmental Psychology; Developmental Cognitive Neuroscience; Infant and Child Development; J of Child Psychology; J of Child Language.

Figure 1

Number of studies registered on the Open Science Framework since 2012 for each of three keywords corresponding to epochs of child development.



BOX 1: Examples of Pioneering Open Science Precedents

Reproducibility and Replicability. An influential edited volume about the impact of poverty on children's development (Duncan & Brooks-Gunn, 1997) also modeled an early vision of reproducibility in developmental science. Authors were invited to contribute to a chapter of the volume with the condition that each chapter would begin with reporting on estimates that adhered to a regression model that followed an agreed-upon set of covariates as independent variables and an agreed-upon dependent variable. This practice resulted in a volume that could speak to the reproducibility and robustness of findings across data sets.

Reuse. Developmental science as a field has long recognized the importance of sharing datasets and technical tools that enable collaboration and reuse. For example, the Child Language Data Exchange System (CHILDES) has been a pioneer in making transcripts of speech to children freely available to the full research community (MacWhinney, 2000) since long before "big data" or "open science" were buzzwords.

Reach. One important goal of research in language acquisition is to characterize the shared learning mechanisms that – in combination with language specific environmental input – lead to the acquisition of a child's native language(s). Pursuing this goal requires research with global reach, as recognized by a set of pioneering studies of cross-linguistic language acquisition that sought to decrease the English-centric perspective of the psycholinguistics field (Slobin, 1985).