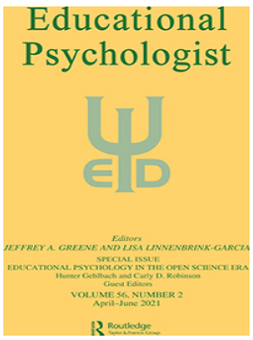

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Open accessibility in education research: Enhancing the credibility, equity, impact, and efficiency of research

Jesse I. Fleming[a], Sarah Emily Wilson[a], Sara A. Hart[b,c], William J. Therrien[a], and Bryan G. Cook[a]

[a]Curriculum, Instruction, and Special Education, University of Virginia; [b]Department of Psychology, Florida State University; [c]Florida Center for Reading Research, Florida State University

ABSTRACT

Openness is a foundational principle in science. Making the tools and products of scientific research openly accessible advances core aims and values of education researchers, such as the credibility, equity, impact, and efficiency of research. The digital revolution has expanded opportunities for providing greater access to research. In this article, we examine three open-science practices—open data and code, open materials, and open access—that education researchers can use to increase accessibility to the tools and products of research in the field. For each open-science practice, we discuss what the practice is and how it works, its primary benefits, some important limitations and challenges, and two thorny issues.

In the fields of education and educational psychology (which we refer to collectively in this article as education for the sake of brevity) a primary purpose of research is to generate credible evidence to inform practice, policy, and theory, with the end goal of improving learner outcomes. Many challenges exist to fulfilling this purpose. For example, collecting robust data sets and generating sound research materials require significant resources that many scholars do not have. Data and analytic code are seldom made publicly available to reproduce, examine the robustness of, and extend reported findings. A considerable portion of the published research base is behind a paywall, inaccessible to many of the policymakers and practitioners it is intended to benefit. Such issues can compromise the credibility (i.e., validity and legitimacy), equity (i.e., fair and impartial access to the process and products of research), impact (i.e., effect of research on policy, practice, theory, and other research), and efficiency (i.e., maximizing utility and minimizing unnecessary effort and expense) of education research. In this article, we discuss how making key research tools and products openly accessible (i.e., open data, open materials, and open access to publications) can help increase the credibility, impact, equity, and efficiency of education research. We define openness as the accessibility of research tools and products, including research reports (i.e., manuscripts) but also data and materials, to both researchers and research consumers.

One component of the scientific revolution in the 17th century is the openness of science afforded by the invention of the printing press and the advent of scientific journals (Bartling & Friesike, 2014; Fecher & Friesike, 2014; Stracke, 2020). Publications appearing in scientific journals, such as the Royal Society's *Philosophical Transactions*—published since 1665, enabled scientists to provide greater access to research findings than had been previously possible. Indeed, "publication" comes from the Latin *publicatio*, meaning "making public" (Bartling & Friesike, 2014). Such openness extended the influence of scientists' work and provided research consumers some opportunity to examine the methods used in reported research. Making public study methods is consistent with the empirical and skeptical stance of enlightenment scientists, as reflected in the motto of the Royal Society, adopted in 1663, *nullius in verba* or "take nobody's word for it." That is, credibility is based on verifiable, empirical research rather than authority or tradition.

Openness became a fundamental principle in science, as reflected in Merton's (1973 [1942]) norm of communism in which scientific knowledge is considered "common property" (p. 274). Open collaboration between contemporaries, as well as between past and present generations, enables scientists to stand on one another's metaphorical shoulders when developing knowledge bases. Openness is also consistent with Merton's norm of universalism, which holds that "free access to scientific pursuits is a functional imperative" (p. 272). Access to scientific knowledge and tools, as well as the merit of scientific findings, should not depend on individuals' attributes (e.g., status, nationality). Indeed, Merton suggested the norm of universalism represents the ethos of democratization, which he defined as the "elimination of restraints upon the exercise and development of socially valued capacities" (p. 273), in science.

Although journal publishing represented a significant leap in the openness and accessibility of science in the 1600s, the basic structure of publishing research has changed

CONTACT Bryan G. Cook bc3qu@virginia.edu Curriculum, Instruction, and Special Education, University of Virginia, Charlottesville, VA 22903-1738.

relatively little since, resulting in limited accessibility of the tools and products of science. For example, most published research lies behind a paywall and is not freely accessible unless one, or one's institution, subscribes to the publisher (Piwowar et al., 2018). Moreover, full data, analytic code, and materials used in research publications are not commonly made accessible. The advent of the internet has ushered in the possibility of a new era of openness in science, often referred to as open science, by providing the means to provide open access to research data, materials, and reports. Whereas open science encompasses a range of practices (see Gehlbach & Robinson, 2021/this issue; Reich, 2021/this issue), our focus in this article is on reforms to make the tools and products of science broadly and equitably available, consistent with the democratic school of open science (Fecher & Friesike, 2014).

We posit that increased access to the tools and products of science can benefit both education researchers and research consumers by enhancing the credibility, equity, impact, and efficiency of education research. For example, when an education researcher provides open access to the data and code used in a study, they enable other researchers to (a) independently analyze their data to verify the accuracy of reported analyses (i.e., enhance credibility), (b) conduct data-based research (i.e., enhance equity), (c) examine research questions beyond those of interest to the original researcher (i.e., enhance impact of the data), and (d) use their analytic code to examine similar research questions rather than having to develop their own (i.e., enhance efficiency). Although credibility, equity, impact, and efficiency are important goals in education research and the digital infrastructure exists to enable open practices, open science is not yet established as common practice among education researchers.

In this article, we describe and explore applications of open data (and analytic code), open materials, and open access (to scholarly manuscripts) in education research. Specifically, for each practice, we provide a brief overview of the practice, describe its primary benefits and limitations, and raise and discuss thorny issues that we expect will arise frequently but will not be easily resolved when education researchers apply the practice. Although we provide basic information regarding each of the open-science practices and how they work, this is not a how-to guide [see Open Science Framework (n.d.) and Soderberg (2018) for examples of how-to guides). Rather, our main intent is to (a) elucidate primary benefits and limitations, and (b) wrestle with and provide potential solutions to thorny issues for education researchers who are familiar with these open-science practices and are considering applying them. To introduce issues related to open science in education research, we use an extended vignette featuring Dr. Thompson, a hypothetical early-career education researcher.

> Dr. Thompson received her Ph.D. in educational psychology from a research-intensive university. She is a mixed-methods researcher. She conducted an exploratory sequential design for her dissertation in which she interviewed a small purposeful sample of secondary students with disabilities using a protocol she adapted from another researcher, and then surveyed a larger and more representative sample regarding the role of self-advocacy in students' identities and schooling. Dr. Thompson is now in the beginning of her second year as a faculty member at a large state college. She and her other early-career colleagues are feeling pressure to publish in high-tier journals to be promoted and tenured in the near future.
>
> When she was a doctoral student, one of her committee members was an advocate of open science and had coached her to post the manuscript that came out of her dissertation as a preprint and share her survey as supplementary material when she published that article. Her professor had convinced her that open science benefited the field and it seemed to Dr. Thompson to be the right thing to do. However, she now felt considerable pressure to focus on accumulating publications in journals with high impact factors, and taking additional time to make her research open just didn't seem a luxury she could afford. Moreover, when she thought about engaging in open data, open materials, and open access with the research she was conducting now, she had some questions about whether and how she could make her work open.

Open data and code

> Dr. Thompson's departmental mentor has told her that it is important for her to not publish with her doctoral advisor, so that she can show her own independent line of research for promotion and tenure. Dr. Thompson is concerned, because she did not have startup funds to collect her own data and funding rates are low, especially for early-career scholars. After seeing a conference presentation on open data, Dr. Thompson realized there were publicly shared datasets posted to data repositories she might be able to use to answer her own research questions. However, most of the data she found were quantitative, and for some of her key research questions she needs qualitative data. Remembering her doctoral committee member who advocated for open science, Dr. Thompson would also like to deposit the data she collected for her dissertation research into a data repository for others to use. However, she is concerned about how to ensure that her participants will not be identifiable to other researchers, particularly for her qualitative data.

What are open data and code?

Data are considered open when an investigator makes their cleaned (including fully deidentified), raw dataset available on a public repository or website, such as the Open Science Framework (OSF; https://osf.io/), the Inter-University Consortium for Political and Social Research (ICPSR; https://www.icpsr.umich.edu/web/pages/), and LDBase (https://ldbase.org). Often, researchers share data limited to the analyses reported in a specific paper, allowing others to re-analyze and reproduce those analyses. However, open data can also include the full data of a project, which we suggest is the gold standard to open the full power of data reuse and allow for the investigation of new research topics and questions. It is essential that researchers include detailed metadata accompanying open data. In the context of education research, metadata typically includes data documentation, such as codebooks, as well as a description of the data collection and the participants. Metadata allows others to understand one's data and determine whether and how the data can be used for their needs (Day, 2005). Preferably,

open data are posted in a noncommercial format that allows for free and open access (e.g., .csv). We recommend Logan et al. (in press) for an in-depth description of what data sharing is and a step-by-step guide on how to do it, and Meyer (2018) for a general review of best practices.

Open code typically involves posting the code, or syntax, used to run all the analyses presented in a published paper on a public repository or website. However, open code can also include the code used to prepare final cleaned datasets, which would likely include code to check the variable properties (e.g., checking for out-of-range values that sometimes occur in data entry), recoding variables, and the creation of new variables (e.g., the mean score of a questionnaire). Preferably, the code is fully annotated in a noncommercial format (e.g., .txt) to allow easy and broad reuse.

Benefits

Open data and code provide benefits to (a) education research and subsequently to the students, educators, and other stakeholders impacted by education research; (b) the data user; and (c) to the data depositor. The loftiest benefit is to the broad research and stakeholder communities. Open data and code can enhance the credibility of research by facilitating re-analysis and replication of reported study results, which helps the education community know what findings are credible and should be considered for translation into policy and practice. That is, other researchers can confirm the accuracy of reported findings by independently conducting the same analyses with the same data. Indeed, a recent Pew Research Center survey reported that among a sample of 3,627 U.S. adults, 57% said that they trust scientific research findings more when data are openly available (Funk, 2020).

Additionally, open data allow independent researchers to conduct robustness analyses that examine the same research questions posited in the original study using the same data set but different analyses. Open data and code also allow for testing totally new research questions, which facilitates creative solutions to difficult problems (Schofield et al., 2009; Vision, 2010). Take for example the Child Language Data Exchange System (CHILDES), which was a pioneer when it started in 1984 as an open-data repository of language acquisition corpora data. By 2000, the 230 corpora datasets within CHILDES had been used to publish over 5000 papers (MacWhinney, 2000). The contribution of CHILDES to the science of the language-acquisition community, and consequent benefits for educators and children, is substantial and beyond what could have been achieved by just the original research team. In this way, open data also enhance the impact and efficiency of research.

The second benefit of open data and code is to the data user. Given tight funding lines and diminishing research resources in an era of increasing research expectations, more education researchers find themselves unable to collect high-quality data to test their research questions. Open data provide education researchers data to support their research and careers, contributing to a more equitable research environment (Mangul et al., 2019). Indeed, open data democratize who can participate in science and, as such, diversifies the perspectives and approaches to posing and examining research questions in our field (Hall et al., 2008). Open data also benefits researchers conducting meta-analyses by allowing them to access raw data instead having to rely on summary statistics typically reported in published articles (see Patall, 2021/this issue for an extended discussion of open science and research syntheses).

The third benefit is to the original data creator themselves. Considerable effort goes into collecting high-quality education data. By releasing their data, researchers efficiently expand the potential application and impact of that hard-collected data. Open data and code are also typically assigned their own digital object identifier (DOI) and are therefore citable and reportable as scholarly products. Research suggests that shared data are associated with increased citations for publications (Piwowar & Vision, 2013), a commonly used metric for evaluating researchers. Finally, given the movement toward funding agencies requiring data being made open (e.g., Institute for Education Sciences [IES], 2020; National Institutes of Health, 2020), open data and code are becoming required for many funded investigators.

Limitations and challenges

For most education researchers, achieving open data and code is not done by simply dragging and dropping a dataset from their computer onto a data repository. Depending on one's data-cleaning pipeline, there may be multiple steps to get a fully clean and deidentified dataset ready. In addition, detailed data documentation will need to be produced. To achieve FAIR (Findable, Accessible, Interoperable, and Reusable; Wilkinson et al., 2016) data standards, most data repositories require multiple steps to upload and release one's data and code (e.g., provide metadata, assign release restrictions, assign copyright). These steps take time, resources, and expertise (see van Dijk et al., 2021, for suggestions on where to start; see Gilmore et al., 2018 for guidance on sharing audio and video data).

An additional challenge for education researchers is navigating the ethical regulations in place to protect research participants, including what can happen with their data. The New Common Rule has actually loosened many of these regulations (see Electronic Code of Federal Regulations, 2018), but not all institutional review boards (IRBs) are following the new guidelines. As such, depending on their IRB's practices, it can be difficult for some investigators to fully share their data and code. We recommend that, rather than assuming what their IRB requires, researchers talk with their IRB about open data. IRBs should be aware of the changing norms and funding body requirements concerning open data. For investigators with old datasets with restrictive informed consents, IRBs have the power to override old consent forms if the risk to participants would not change (and posting deidentified data should not change risk) by issuing a waiver of informed consent.

Researchers may be hesitant about sharing for other reasons, such as increased scrutiny and the possibility of inflating Type-1 error. Although it is possible that errors in one's data or code could be discovered through sharing, identification and subsequent correction of errors can be considered a valuable opportunity to improve the validity and credibility of education research. Interesting discussions have also emerged about whether analyzing the same dataset repeatedly, as occurs with open data, will inflate Type-1 error (see Logan et al., in press; Maxwell et al., 2017). If inflation of Type-1 error is a concern, researchers can share metadata only or provide only limited access to others upon request (e.g., storing the data privately on a data repository with access control options). These options provide greater benefit to the field, and are more secure, than simply storing data on one's computer.

Thorny issues

Guidelines and community support regarding data sharing have been slow to develop, leaving education researchers to grapple with some thorny issues regarding open data and code. The lack of established norms and incentives for data sharing creates real tradeoffs for early-career scholars like Dr. Thompson—should she invest time in still evolving practices or stay focused on more traditional publishing (without shared data and code)? Here we focus on two thorny issues, related to (a) issues in sharing qualitative data (Feldman & Shaw, 2019) and (b) data deidentification. Like quantitative researchers, qualitative researchers are experiencing increased expectations for data sharing from funders and journals (Mannheimer et al., 2019). However, there are unique concerns related to sharing qualitative data. Some concerns are epistemological; for instance, that shared data removed from the original context of the initial data collection (e.g., sharing data absent the context of the researcher who collected it, removing the personal details from the data) are incomplete or illegitimate (Walters, 2009). Other concerns exist related to ethics. For example, some qualitative researchers argue that data are generated by (not collected from) study participants and ownership is shared with the participants themselves, meaning the researcher alone cannot give permission for sharing (Broom et al., 2009; Moore, 2007). Additional concerns exist related to difficulties fully deidentifying qualitative data (Mannheimer et al., 2019).

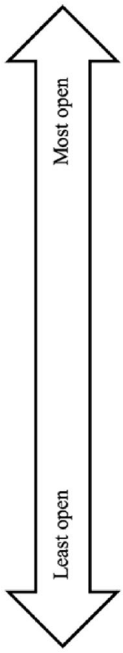
Despite these concerns, there is a growing belief that qualitative data can be shared and a growing number of resources available. Some have pointed out that even primary investigators cannot know the full context of the data they generate, and so holding secondary data users to this standard is not appropriate (Fielding, 2004). Indeed, there is a rich tradition of data sharing in some qualitative fields, such as history, where data archiving is well established (Fielding, 2004). Qualitative educational researchers could turn to these fields for examples of how their epistemologies might support data sharing (Broom et al., 2009). Decontextualization of anonymized secondary data sets will likely be a concern for some qualitative researchers, who will, ultimately, need to determine whether the benefits of data sharing outweigh their epistemological concerns (Mannheimer et al., 2019). Related to ethics concerns, scholars have begun to develop guidelines for how libraries and data repositories can help support qualitative researchers at the start of their research process (Mannheimer et al., 2019; see https://qdr.syr.edu/guidance/managing for additional resources).

Another thorny issue related to open data is whether and how researchers can adequately deidentify data, which can often be more difficult than it may appear at first for both quantitative and qualitative data. Most researchers realize that names, addresses, and the like are identifiable and should be removed from a dataset. However, extreme values, rare characteristics (e.g., certain disabilities), or certain combination of variables (e.g., being male and a kindergarten teacher) can also make a person identifiable in a dataset. It is difficult to provide a general rule of thumb to ensure data deidentification, as it is project dependent (e.g., in some geographical regions, a participant characteristic might be identifiable, but in other regions it would not). Also, techniques to deidentify data are still being developed and tested. However, there are resources that are available to help (see Edwards & Schatschneider, 2020a, 2020b, for less technical resources, and US Department of Health & Human Services, 2012, for a more technical resource).

Data deidentification is paramount when sharing sensitive data. We encourage researchers with highly sensitive data that cannot be fully deidentified to consider (a) sharing non-sensitive data from the data set and providing restricted access to more sensitive data (see Meyer, 2018), and (b) posting summary data (e.g., means, standard deviations, sample sizes and covariance matrices, broken into subgroups if possible) and project meta-data to a data repository. The latter enables other researchers to know about the data, use the summary data for meta-analyses and other statistical methods, and contact the original researchers about possible use of some or all of the data set.

Open materials

During the development of her dissertation proposal, Dr. Thompson's committee members had encouraged her to adapt an interview protocol that another researcher had shared as supplemental material to a published article. The protocol had been developed for use with special education teachers, but Dr. Thompson was able to modify the questions to apply to secondary students. After her dissertation research had been accepted for publication, Dr. Thompson wanted to share the survey she developed for the quantitative portion of her dissertation, which she hoped would also increase the impact of the measure and save time for others conducting similar research. As the survey was her original work, she was the copyright holder and was able to apply the copyright license of her choosing. Dr. Thompson wants to continue to use and share open materials as she develops her own line of research, but she is wary about potential copyright issues associated with open materials. Specifically, in her next study, she is planning to modify an intervention protocol developed by other researchers, but the copyright license of the protocol has been difficult to find. She is not sure whether or how she can share the adapted version of the intervention.



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CC BY-ND	Can copy and distribute material commercially, with attribution to original author, but cannot modify material
CC BY-NC-ND	Can copy and distribute material non-commercially, with attribution to original author, but cannot modify material

Figure 1. Creative Commons licenses from most to least open. *Note.* Figure is licensed by Sarah Emily Wilson, 2020, under a Creative Commons Attribution-Noncommercial 4.0 International License (CC BY-NC). Publicly available at https://osf.io/n35zy/.

What are open materials?

Open materials make researcher-created or -adapted study materials freely and publicly available to other researchers and research consumers. This is accomplished through sharing the materials on a data repository, such as OSF or ICPSR, or by including them in a journal's online supplemental repository published in conjunction with a journal article. Although policies regarding the openness of online supplemental materials may vary by publisher and journal, many publishers currently make supplemental materials openly available, even if the user does not have access to the article (see SAGE, 2021; Springer, 2020). Potentially shareable materials include, but are not limited to, intervention materials and implementation procedures, researcher-created dependent measures, fidelity and treatment integrity checklists, survey instruments, data collection forms, training procedures and manuals, interview or observational protocols, positionality or reflexivity statements, data integration methods, and deductive or inductive codebooks.

Open materials involve shifting some or all of the rights of the creator and copyright holder to others. Once created and shared in a fixed and tangible form, one's work becomes automatically copyrighted with the creator holding copyright ownership, even without registration with the copyright office (U.S. Copyright Office, n.d.). In holding copyright ownership, one has the right to reproduce, alter, and distribute their own work exclusively (U.S. Copyright Office, 2019). To engage in open materials, one must transfer some or all of their copyright permissions to others through the addition of a copyright license. A license grants the public some permissions, but—depending on the license—can retain some exclusive rights for the copyright owner. Creative Commons (CC) is a frequently used license provider that works in tandem with the provisions of copyright and allows for different levels of attribution, editing, and reuse by others (Creative Commons, n.d.-b). See Figure 1 for the different CC licenses available, and the rights afforded to others by each license. Once chosen, the license is clearly and prominently appended to the materials in a machine-readable format. When others use the licensed materials, they must attribute and cite the original authors, reuse, edit, and redistribute according to the license restrictions (Creative Commons, n.d.-a).

Benefits

In the same vein as open data, materials can be made open and accessible by researchers across paradigms and methodologies, benefitting many stakeholders, including researchers who use shared materials; researchers who share their materials; and educational policy makers and practitioners, as well as students. In sharing study materials, authors enable others to adapt and reuse materials in their own research (Miguel et al., 2014; Molloy, 2011) for a wide range of purposes, rather than have to create their own original materials. Sharing materials may particularly benefit early-career researchers, like Dr. Thompson, who have limited access to resources and funding, as well as limited experience developing rigorous materials. Additionally, making materials accessible allows researcher consumers to assess a study's methods more thoroughly and transparently, thus increasing the study's credibility—a critical aim for qualitative and quantitative researchers alike. Similarly, researchers using the same shared measure across studies can reduce a source of variance in research syntheses. Thus, using shared materials can enhance the equity, efficiency, and credibility of research. Openly sharing materials also benefits the researcher who shares. Once a researcher has published their materials openly through a data repository or as a

supplement to a journal article, the materials are assigned a DOI, and can be listed on the author's vitae. The open materials can then be cited by others.

Finally, increased accessibility of materials benefits the students and practitioners who are the end users of education research. By sharing research materials freely, practitioners can access high-quality and validated materials more easily, thereby facilitating improved student outcomes. Indeed, the inaccessibility of many research-validated programs may contribute to the research-to-practice gap in education. Making materials open and accessible to others facilitates practitioners' ability to apply education research with fidelity in schools. This benefit also increases the equity and impact of education research.

Limitations and challenges

Although open materials have clear benefits and can be straightforward, there are several limitations and challenges to consider. The first challenge is navigating copyright issues for sharing original materials and adapted materials (the latter is discussed in more detail in the subsequent section). Researchers should not share materials that they do not own, such as norm-referenced assessments, but they can share researcher-created materials as the copyright holder. Before sharing their original materials, we encourage authors to consult with their funding agencies, employers, and copyright lawyers that many universities employ through their library system to check for possible copyright or intellectual property restrictions that would prevent authors from legally sharing their own materials. Most original, noncommercially distributed work that a researcher created for the purpose of a study will not be restricted.

Once it is determined that the materials can be shared, the next challenge is formatting. Researchers should create, format, and share materials in ways that facilitate others accessing, editing, and using them. We recommend shared materials be formatted and shared in an editable file format that provides users with source-file access. In other words, materials should be saved and shared in a format (e.g., .txt, .html) that does not require specific software to access, thereby allowing users to open and interact with materials in the original, editable file. Similarly, if possible, materials should be shared in formats that allow for editing using common or freely accessible software that does not require a high level of expertise. Finally, we suggest that researchers include instructions, as needed, with shared material to allow others to meaningfully reuse the materials. For example, researchers might include an implementation guide alongside a shared intervention protocol, or administration and scoring guidelines alongside a shared assessment. Education researchers should carefully review shared materials before uploading, as they are not typically reviewed or vetted before being posted.

The next challenge is selecting the appropriate copyright license for one's work and digitally indicating the license on the shared materials. Although creators' work is automatically copyrighted when published online, clearly indicating the license of the work is helpful and supports open and transparent communication between the authors and those who might use their shared materials. Care should be taken to match the copyright license with the author's intended permission level of use by others because, once published, licensing options cannot be changed. CC provides material creators with an easy-to-use, step-by-step tool for matching intended use with the appropriate license (Creative Commons, n.d.-b). Once selected, the license should then be indicated clearly and prominently in a machine-readable format on the shared electronic materials (an example can be seen in the licensing of Figure 1). It is also important to note that copyright restrictions and permissions are not internationally held (U.S. Copyright Office, 2019). In most instances, copyright is determined by the publication's country of origin and is bound by that nation's copyright laws. Although international copyright treaties have simplified how users in other countries can maintain a creator's copyright license, this is not always the case. When sharing or using materials created outside of one's own country, we recommend consulting the *International Copyright Relations of the United States* (U.S. Copyright Office, 2021). To address these potential challenges proactively, van Dijk et al. (2021) recommended that plans for sharing be instigated at the start of a project, rather than after the fact.

Thorny issues

Open materials have received considerably less attention than open data and open access, with relatively little guidance available for researchers who encounter thorny issues. In this section, we discuss two such issues: (a) understanding restrictions for using and adapting materials that someone else has licensed for sharing, and (b) making aspects of researcher-adapted materials open when one does not own the copyright and the license for the original materials does not allow for sharing and redistribution.

To address both issues, the first step is to determine the copyright status and type of license for material one wishes to share. This is critical to determine what rights the creator holds exclusively, and what rights have been given to the public. Although creators typically hold the copyright for their own materials, it is not always straightforward to determine the copyright and licensure status of others' work. If not clearly displayed, we recommend contacting the original author and publisher regarding copyright licensing and permissions for reuse, as the copyright relationship between authors and publishers can vary.

Once copyright license status is determined, the first thorny issue arises when authors want to use materials previously shared by another author as allowed by the license of the material. In preparing to use shared material, it is important to understand the rights still held by the copyright holder and the specific permissions the license grants. If the original material is within the public domain or has a CC0 license, the materials can be reused and shared without attribution. If the material has a CC By Attribution (BY) license, it can be adapted and shared as long as the author

is properly attributed and cited. When assessing the restrictions that a CC license communicates, there are three additional terms to attend to that can be combined in various ways. First, licenses containing No Derivatives (ND) terms cannot be modified, but can be copied and distributed with attribution to the original author. Licenses with Noncommercial (NC) terms limit distribution to noncommercial products. Finally, licenses with a Share-Alike (SA) term must be licensed and shared under the same license restrictions as the original work. See Figure 1 for a description of possible CC licenses.

The second thorny issue arises when a researcher wants to share their adaptations to materials that do not have a license permitting sharing or redistribution and the copyright of the materials is fully retained by the original creator or a publisher. In these cases, we suggest that the researcher share a written, detailed description of the adaptation without sharing the original material, as this would infringe on the rights of the copyright holder. For example, a researcher might have investigated the efficacy of a packaged reading fluency intervention that they adapted, with permission, for a specialized population of learners. The packaged intervention is not licensed for sharing. When sharing their adaptation to the intervention, the researchers should properly cite and describe generally the original work, describe in specific detail the changes made to the intervention, and comply with the copyright restrictions by not sharing the original intervention protocol. Although this does not allow for the same level of openness as sharing researcher-created materials or researcher-adapted materials that allow for sharing, we posit that this degree of openness realizes many of the benefits of shared materials (e.g., improved equity, impact, and efficiency).

Open access

Dr. Thompson posted the study from her dissertation research as a preprint before she submitted it for publication. She was surprised at how easy it was to do—she just uploaded a .pdf version of her manuscript to a repository, provided some basic information about the manuscript, and it was assigned a DOI and became searchable and freely available the next day. She was pleased that the preprint had been downloaded many times, likely by many educators who would not otherwise have access to the manuscript. Additionally, she had received comments on the preprint from other researchers that helped her improve the paper before submitting it for publication. She recommended open-access prints to the administrators and teachers she worked with, because they could not typically access published journal articles without paying for them. One of the teachers asked her whether she could trust the research in the prints. Dr. Thompson hadn't fully considered the consequences of prints not being peer reviewed: some of the prints could, indeed, report flawed and misleading research. Additionally, Dr. Thompson had decided not to post a preprint for the study she had just finished writing up. She thought that colleagues who worked in her specific sub-field might see the preprint, and she hoped that they would be able to serve as blind peer reviewers when she submitted the paper for publication. She continued to see the advantages of open access but wondered if the problems of lack of peer review and the possibility of identifying authors before peer review for a journal might outweigh their benefits.

What is open access?

Although evidence-based reforms in education are premised on the notion of educators using research evidence to inform decisions related to policy and practice, most published research lies behind publisher paywalls (Piwowar et al., 2018), inaccessible to many education stakeholders. Access to scholarship behind publisher paywalls is often costly, and multiple institutions of higher education have taken steps to cut ties with major publishers to reduce cost and increase accessibility and equity (Taylor, 2020). The many forms of open access (OA; gold, hybrid, bronze, and green OA) help to democratize research evidence by removing paywalls and making scholarship openly accessible to anyone with internet access.

Gold OA journals are entirely open and accessible online. To cover publishing costs, most gold-OA journals charge an article-processing charge (APC) to authors, typically about $3,000 (Fleming & Cook, 2021). There are some gold-OA journals in education, such as *AERA Open*, *Education Policy Analysis Archives*, and *Journal of Educational Technology & Society*, but closed journals remain the norm in the field. Hybrid OA involves authors having the option to pay an APC to make their specific article OA in an otherwise closed journal. Most education journals published by large publishers provide hybrid-OA options. With bronze OA, the most common type of OA (Piwowar et al., 2018), publishers make specific articles of an otherwise closed journal open, at least temporarily, but without an OA license. For example, a journal may make the lead article of a special issue bronze OA to increase interest in the issue. Because bronze-OA articles are not licensed as OA, readers are restricted from sharing the content and articles can become closed at any time.

Green OA, which includes preprints and postprints, involves researchers posting author-formatted versions of manuscripts in open, online repositories. Preprints generally refer to manuscripts posted prior to undergoing peer review; whereas postprints are posted after peer review (Tennant et al., 2018). Green OA can also include working papers posted on an institutional or personal website. For example, EdPolicyWorks (n.d.) at the University of Virginia has a series of working papers on their website. Key differences between working papers and prints in the field of education include permanence and licensing. Generally, prints are permanent publications with assigned DOIs and are licensed to be OA, whereas working papers typically do not have a DOI, may be removed or moved, and are not licensed as OA.

Journal and publisher policies on green OA vary, and researchers should be familiar with the policies of targeted journals before posting their work publicly or on print repositories (Fleming & Cook, 2021). Print repositories where education research can be posted include the Social Science Research Network (www.ssrn.com), EdArXiv (www.edarxiv.org), and Advance (www.advance.sagepub.com). Journal and publisher green-OA policies can be found on the SHERPA/RoMEO website (http://sherpa.ac.uk/romeo/index.php), on journal websites, and by contacting journal editors.

Benefits

Most fundamentally, OA publishing democratizes access to scholarship to anyone with internet access, regardless of resources, career status, institution, or country of residence (Bahlai et al., 2019; Syed & Kathawalla, 2020). Accessibility is a critical component of democratization and equity, and OA publishing removes barriers of prestige and power associated with journal subscriptions. In addition to providing practitioners and families access to scholarship, OA also ensures that a study will not be excluded from meta-analyses and research syntheses because other researchers could not access it (see Patall, 2021/this issue). Additional benefits of OA publishing include increased efficiency, impact, and credibility of research and scholarship. Although important, peer review delays dissemination of research and scholarship. Depending on the number of rounds of review (potentially at multiple journals) before a manuscript is accepted, peer review can delay the availability of scholarship by many months or even years. Green OA allows education researchers to immediately disseminate their scholarship. This may be especially important for scholarship on time-sensitive matters (e.g., providing effective education during a pandemic).

Likely because of enhanced accessibility, there is a well-documented citation advantage for studies first posted as prints (Piwowar et al., 2018). Additionally, journal articles with corresponding prints have been shown to have more downloads and greater social media presence (Abdill & Blekhman, 2019; Fu & Hughey, 2019). Gold, hybrid, and bronze OA also provide for broad dissemination and can increase impact. For example, Gershenson et al. (2020) found that when a paywall was temporarily removed for six high-impact education journals (bronze OA), downloads increased 60 to 80% over a two-month period.

Lastly, prints have the potential to increase credibility of the education research base by helping to curb publication bias. There is a well-documented "file-drawer" problem (i.e., publication bias) in which studies with null or negative results are published less frequently than studies with positive findings (Franco et al., 2014; Polanin et al., 2016). For applied fields, such as education, publication bias can have important consequences for policy and practice that is informed by syntheses of the published research base that disproportionately excludes studies with null findings. Print repositories provide a dissemination outlet for all research, including studies that may be relatively unlikely to be published, such as those with null findings.

Limitations and challenges

Limitations and challenges associated with OA publishing include expense, limited awareness and use, and concerns about being scooped. The expense of APCs is a major limitation of gold and hybrid OA. We recommend posting prints to online repositories as a cost-free OA alternative. Another challenge is limited awareness and use among education researchers. Prints and OA publishing are relatively new to education research, whereas in fields such as physics, mathematics, and computer science posting prints to online repositories became common decades ago (Tennant et al., 2018). In fields where prints are better established, print repositories report over 2,000 uploads each month (Abdill & Blekhman, 2019). EdArXiv has 673 prints (as of 2/20/2021), which suggests that prints may be underutilized in education. Additional supports and incentives may increase the volume of print submissions in education. For example, guidance on how preprints fit into the publishing timeline and steps for posting prints (Fleming, 2020; Fleming & Cook, 2021; Kathawalla et al., 2020; Roehrig et al., 2018; Syed, 2020) can help increase awareness and promote greater use. Finally, researchers may also be concerned about their preprinted work being "scooped" (i.e., another researcher taking their idea and publishing it first). However, because preprints are timestamped, they actually serve to establish precedence and should be cited by others, just as a published article would.

Thorny issues

In this section, we discuss two thorny issues related to OA: (a) preprints are made publicly available without being peer reviewed, and (b) posting preprints may compromise subsequent blind peer review. Peer review is a well-established and strongly supported practice for vetting the rigor of published research (Tennant, 2018). Thus, absence of peer review in preprints raises important concerns about the dissemination of potentially flawed and misleading research. It is important to recognize that peer review is "prone to bias and abuse in numerous dimensions, frequently unreliable, and can fail to detect even fraudulent research" (Tennant et al., 2017, p. 2). Indeed, many hundreds of published, peer-reviewed papers are retracted each year (Brainard & You, 2018). Thus, we urge research consumers to take a skeptical, *caveat emptor* approach when consuming research, whether or not it is peer reviewed. Moreover, we note that Klein et al. (2019) found few differences between preprints and corresponding journal articles. As such, if one can locate the preprint version of a published article, it is likely to contain highly similar content and be of similar quality. Moreover, many journals and publishers allow researchers to post manuscripts as postprints after acceptance. In this way, researchers can update preprints by posting the author-formatted version of the peer-reviewed manuscript. However, when not updated with a peer-reviewed postprint, the absence of peer review in preprints is an important concern, perhaps especially so because preprints can be freely accessed by practitioners, parents, and others who typically do not have advanced training in research to critically evaluate research on their own. Many print repositories enable comments to be made on posted prints, so that peers can engage in ongoing peer review. That is, other researchers can point out strengths and weaknesses of study design and methods (i.e., review), to which the authors can respond (e.g., agree with, clarify, counter). Non-researchers can also leave questions they have about interpreting study findings, to which authors and other researchers can respond.

A second thorny issue is that preprints potentially jeopardize the pool of blind peer reviewers if and when authors submit a manuscript that has been posted as a preprint. In our experience most education journals use double-blind peer review, in which the identities of both the reviewers and authors are unknown to one another. If authors post a preprint before submitting a manuscript for publication, potential reviewers may see the preprint, discover the identity of the authors, and therefore not be able to serve as a blind reviewer. This may be especially problematic for researchers working in small subfields in which there are relatively few expert reviewers available. It is important to recognize that the issue of reviewers identifying authors is not unique to preprints. It is not uncommon for reviewers to discern the identities of the authors of supposedly blinded manuscripts (e.g., Baggs et al., 2008; Justice et al., 1998). For example, in our roles as journal editors, two of the authors have experienced multiple instances of invited reviewers declining to review blinded manuscripts because they identified the author (e.g., because of the topic or works cited). Indeed, we suspect that, given the information available on the internet, a motivated reviewer could likely identify the authors of many if not most manuscripts they are asked to review. As such, we encourage editors to ask reviewers to confirm they do not know the identity of the authors and will/did not actively attempt to identify the authors when accepting and submitting their reviews. If journals commit to using blind peer review, editors should verify whether the review was, indeed, blind, regardless of whether the manuscript had been posted as a preprint. We suspect that if reviewers respect an editor's request not to research authors' identities, the availability of a preprint should not significantly affect the availability of blind peer reviewers for most manuscripts.

Nonetheless, if authors wish to post a preprint without unmasking their identity, they can post preprints under a pseudonym, indicating in an author's note that the preprint will be updated with a postprint with the author's real name after peer review is complete. This would involve creating a pseudonymous account with the print repository. Alternatively, for this special issue, one of the guest editors posted preprints of manuscripts planned for the special issue under their name and requested in an author's note that the papers not be cited until after postprints with the authors' names are posted. These approaches allow for posting preprints while retaining anonymity of authors, though that work cannot be cited until after peer review is complete and a postprint is posted.

Conclusion: A final thorny issue

> Although there are challenges and thorny issues that complicate implementation of open science, Dr. Thompson is well positioned to implement the core practices described in this manuscript. Open-science practices were taught and valued at her doctoral granting institution and she is motivated to enact open-science reforms. Despite her motivation, it is unclear whether Dr. Thompson will be rewarded institutionally for her effort. Her university provides no funds for her to publish in gold-OA journals and senior faculty in her department do not engage in or value sharing data, sharing material, or OA publishing. Moreover, neither the annual merit review or the promotion and tenure guidelines used at her university mention open-science practices. As is the case in many institutions of higher education, the fate of Dr. Thompson's promotion and tenure case will primarily rest on her publishing first- and sole-authored articles that report studies in high-impact journals. Given faculty members' limited time and resources, the disregard of open practices in review, promotion, and tenure policies may encourage Dr. Thompson to devote her scarce time and resources to other, more traditional forms of scholarship that are rewarded explicitly. Thus, although Dr. Thompson remains motivated to implement open-science practices, she does so outside of the incentive structure of her university.

Unfortunately, Dr. Thompson's experience is similar to many other early-career education researchers. Indeed, in their review of faculty review, promotion, and tenure policies from 129 universities in the U.S. and Canada, Alperin et al. (2019) found that almost all policies mentioned traditional outputs such as journal articles and grants, whereas only 5% of institutions mentioned open access—and most of the mentions cautioned against publishing in OA venues! Thus, consideration of how to support education researchers, especially early-career researchers, to devote scarce time and resources to engage in open practices without harming their career advancement can be considered a final thorny issue. Although we are aware of many education researchers who, similar to Dr. Thompson, are innovators and early adopters of open science, we suspect that broad diffusion and long-term adoption of open-science reforms will require multiple levels of supports and incentives (see Mellor, 2021/this issue; Rogers, 2003).

Mellor (2021/this issue) proposed a 5-level pyramid for achieving research culture change that can serve as a framework for supporting broader adoption of open science in education research. The model posits that infrastructure, such as data repositories and print archives, is needed as a base to make open science possible. Then, at progressively higher levels of the pyramid, user experience is needed to make engaging in open science easy, communities to make it normative, incentives to make it rewarding, and—finally—policies to make it required. Education researchers can readily find infrastructure with suitable user-experience interfaces to post prints (e.g., EdArXiv), make their data and code publicly available (e.g., ICPSR, LDbase), and share their study materials (e.g., OSF). Some progress is occurring at the higher levels of the pyramid as well. For example, more education researchers are gaining experience in implementing different open-science practices (Makel et al., in press), communities of education researchers focused on open science are being formed (e.g., STEM Education Hub; Center for Open Science, n.d.), and funding agencies are encouraging and in some cases requiring open practices in funded research (IES, 2020). However, much work remains to support open practices being broadly adopted and sustained across the diverse research cultures in education. In particular, we see few institutional incentives for engaging in open science, which will be critical. Thus, we recommend that colleges of education and other research organizations

explore ways to recognize the value of open access in their review, promotion, and tenure guidelines (see Moher et al., 2018).

Strategies and support for open science will also need to be multifaceted to address the unique needs of different members of the education research community. For instance, as open practices have primarily been designed for quantitative research, additional attention to all levels of the pyramid is needed to encourage qualitative and mixed-method researchers to make their research open. Given the broad application of multiple research methodologies in the field, education researchers are well positioned to contribute to expanding open science. Incentives must also be in place for researchers across the career continuum, from doctoral students to full professors, to address the varied demands and contingencies at each career stage (see Allen & Mehler, 2019). For example, as full professors have been found to be less favorable toward preprints than their early career counterparts (Soderberg et al., 2020), researchers should identify the concerns of this influential group of scholars and develop strategies for addressing them. Finally, multiple stakeholders in education research (e.g., institutions of higher education, journals, professional organizations, funding agencies) should develop strategies supporting open practices to provide a multipronged, comprehensive approach (Adelson et al., 2019).

In this article, we explored three open-science practices targeting open access of the tools and products of research—open data and code, open materials, and OA—and how they can increase equity, credibility, impact, and efficiency in education research. Despite potential benefits, each practice has challenges and limitations associated with it, and education researchers are likely to face thorny issues that are not easily resolved as they apply the practices. To realize the benefits of and surmount the obstacles related to open-science practices, stakeholders will need to develop and implement strategies to shift the culture of education research from a field that not only makes open science possible to one that normalizes, rewards, and—eventually—requires open science.

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Authors' contributions

The authors contributed equally to the article and are listed in random order.

ORCID

Jesse I. Fleming http://orcid.org/0000-0001-7438-0374
Sarah Emily Wilson http://orcid.org/0000-0002-7389-7301
Sara A. Hart http://orcid.org/0000-0001-9793-0420
William J. Therrien http://orcid.org/0000-0003-0594-5129
Bryan G. Cook http://orcid.org/0000-0001-9294-0873

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