Making Scientific Content More Accessible

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1 Introduction

Effectively communicating ideas is critical to the scientific enterprise. Presenting research results clearly and unambiguously in publications or presentations helps captures the attention of audiences, convinces colleagues of the veracity of one's conclusions, allows for more effective teaching and mentoring, and makes often complex scientific conclusions more readily accessible to the general public and decision-makers. Indeed, effective communication is so critical to scientific practice that helping scientists improve their communication skills has been a significant focus of energy for organizations ranging from academic societies to graduate training programs [1,2]. The need for effective communication could also be viewed as central to the burgeoning "Open Science" movement, among whose goals include making research products (e.g., data, code, scientific literature) more broadly readily available [3–5]. Despite these efforts, however, surprisingly little attention has been paid to one of the most central aspects of effective and open scientific communication – ensuring that one's results and presentations are accessible to all those wishing to take advantage of them, including members of the scientific community with sensory disabilities [6,7].

Accessibility can be defined as "the implementation of assistive or adaptive design considerations that account for differences in sensory perception, that often improve document usability for all users". Here we present

guidelines to help scientists make accessible research products and presentations. By working towards full adoption of these guidelines, we move the scientific community towards compliance with the UN Convention on the Rights of Persons with Disabilities, which recognizes access to information and communications technologies as a basic human right [8]. It is important to emphasize, however, that all scientists – not just those with disabilities – will benefit from making and sharing accessible publications and other research products accessible. Some of these benefits are obvious, e.g., the potential impact of research will increase with the size of and diversity of the audience it reaches. But improving accessibility for the relatively small proportion of colleagues with disabilities can have major payoffs for scientists when those colleagues are our students, supervisors, the reviewers of manuscripts or grant proposals, members of search committees, or policymakers.

The World Health Organization estimates 15% of the world population is disabled [9], although the dearth of data from many countries means the true value could be much higher. Although data on how many members of the research community are disabled are limited, 6.8% of the doctoral recipients in the United States report having one or more disabilities [10], and the economic impacts of these disabilities can be substantial. Overall, unemployment for doctorate holders is very low, less than 5% in most members of the European Union, Australia, the United States, and Canada [11,12]. Across all countries, graduation and employment rates are lower for people with disabilities than others; in the United States, for instance, only 27% of disabled adults with an undergraduate degree or higher participate in the workforce, in any field [13]. This is not for lack of interest – students with disabilities entering college and graduate school are just as interested in STEM careers as their peers without disabilities [14]. Publishing more accessible science can therefore play in an important role in helping to remove structural barriers to success for the students with disabilities who could one day become our colleagues. This could translate into important benefits to both individual scientists and the scientific community, including higher citation rates, increased opportunities for collaboration, and the translation and implementation of results beyond the ivory tower. Ultimately, accessible science facilitates collaboration among a more diverse suite of peers and allows outreach to broader audiences.

The fear that making scientific publications and presentations accessible requires expensive or complicated tools and workflows may have kept even well-intentioned scientists from striving for accessibility. Fortunately, using known best practices and existing standards from the fields of universal design and accessibility doesn't need to be complicated, and many of the tools for doing so are free or already embedded in commonly used software packages. A few guidelines for creating and sharing content can extend the reach of your scientific audience and increase broader participation in the scientific enterprise.

The following list does not exhaustively address all aspects of accessibility or how to make scientific publishing (and science) more inclusive; accessibility guidance is extensive and well documented, for example, web guidelines are available through the W3C Consortium (https://www.w3.org/WAI/WCAG20/glance/). Instead we hope these guidelines can be the start of a fruitful conversation for the whole community involved in creating and publishing scientific papers and presentations - authors, reviewers, editors, publishers, and readers. Achieving accessible publications across platforms and disciplines will require cooperation and collaboration from all these groups to create opportunities for improving access and addressing existing barriers. We invite readers to share their experiences, challenges, and ideas for improving accessibility in scientific publications in the Comments Section at the end of the this article.

2 Guidelines for Accessibility

2.1 Make "accessible" your default mindset

"I have something to communicate and will accommodate accessibility with intent"

Improving accessibility requires some foresight, planning, and preparation on the part of the presenter: accessibility-centered thinking. You are being a good citizen when you plan ahead, so do not leave accessibility

until the last minute.

Many common software packages used to create presentations have slide tools or templates designed for accessibility (e.g., PowerPoint's Office Theme). Many also have tools that evaluate the accessibility of presentations or documents (e.g., the built-in Accessibility Checker in Microsoft Office, the accessibility tools and options of the open source LibreOffice). Making use of these tools should become routine. Accessibility can be further improved with few simple practices: enlarging fonts and visual elements, choosing contrasting colors and using them consistently, and avoiding white backgrounds, which can be visually straining.

2.1.1 Additional Resources:

- Institute for Accessible Science Hub
- Accessible Conference Guide by the Special Interest Group on Accessible Computing
- Introduction to Web Accessibility by the W3C Web Accessibility Initiative
- List of accessibility resources by the W3C Web Accessibility Initiative

2.2 Design for the mode of delivery

The design elements required for accessibility will vary based on the the mode of delivery. While many design elements are shared among presentation formats, oral presentations often require more care (Table 1). For instance an oral presentation may require recording while a paper may not; it may also require more attention to the use of proper headings.

Table 1. Key design elements for accessibility in presenting material for a broader audience. Note that attention to accessibility elements for text, figures and section headings are required for all presentation types.

Presentation Type	Text	Figures	Headings and sections	Visual cues within figures	Clear audio
Poster	Yes	Yes	Yes	No	No
Oral presentation	Yes	Yes	Yes	Yes	Yes
Paper	Yes	Yes	Yes	No	No

While pointers can often help those watching presentations, using them to draw attention to certain elements in figures without verbal explanations may actually reduce accessibility for individuals using a screen reader (software that analyzes content and reads it aloud to users). Individuals who have color-blindness may also struggle when speakers use laser pointers, since they may have difficulty resolving the pointer and its movement. During presentations extra consideration should go into preparing figures and highlighting dynamic elements, for instance accompanying visuals with oral descriptions. If you hear yourself saying hear "You can't really see what it is in this figure but..." then the content is not accessible and should be redesigned.

2.2.1 Additional Resources:

- Making your PowerPoint presentations accessible by Microsoft
- Web Accessibility Evaluation Tool by Web Accessibility in Mind
- How to Make Presentations Accessible to All by the W3C Web Accessibility Initiative

2.3 Use the right markup for your presentation's structure

Using the built-in headings and section breaks supplied by your presentation software supports accessibility by providing a road-map for assistive technologies, which make heavy use of document metadata [15]. If you choose to define sections using only bold text or some other non-structural formatting, a user might not be able to follow along (Fig 1).

Document maps vary between presentation types. The program Pages (Mac) calls their document maps 'headings', while Microsoft PowerPoint (Windows) calls theirs 'sections'. Poster design can use clearly defined regions, or a visual hierarchy such as boxes, numbers, or arrows. Use the appropriate indicators for your presentation medium, but ensure they provide a clear road-map, both visually and with regards to assistive technologies.

Figure 1: Just using bold and large size font to indicate sections and section headings is not sufficient for most modern software. (A) shows how headers generated with bolded text or italics may be rendered as sections within a screen reader or other assistive technology. (B) proper "Headers" and section formatting make the document more accessible by providing clear sections in the document.

2.3.1 Additional Resources:

- Creating accessible structure and markup by Drupal.
- Accessibility: What's Your Markup Saying to You? by Envato Tutorials.

2.4 Use clear and simple figures and graphics

Many scientists recognize the importance of figures in publications to simply and effectively communicate their results, and some journals are even now requiring authors to include visual abstracts. By tweaking a few aspects of figures and other graphics, one can easily make them much more accessible to many more people.

Simple images are better than complex ones – the latter can be difficult to process visually and may misdirect the audience's attention. They can also be difficult to describe with text (see the large enough to be clearly visible, without being cluttered. Keep image file sizes minimal. Large file sizes take longer to download and may render in unexpected ways depending on the software, this is a particular problem for readers with limited Internet bandwidth.

2.4.1 Additional Resources:

- Ten Simple Rules for Better Figures

2.5 Choose colors carefully

Considering color choices isn't just for the colorblind (Fig 2). Using shadows, or other text effects can be difficult to read or render, particularly if people are using screen-readers in the audience. Not all colors or effects can be rendered on lower resolution devices or with slow Internet speeds.

Avoid using color as the only indicator of priority of importance. In tables and in text, font style and size can be used to help emphasise key elements, like table headings and significance, rather than color.

Use high contrast color schemes in presentations and posters, e.g., where dark colours are very dark and light colours are very light (Fig 2). Increasing the contrast allows the text to be more easily distinguished from the background by people with low vision and in poorly lit rooms. Low contrast colour schemes typically have a grey wash, where black appears dark grey and white appears light grey. Many software programs have color scheme templates. For example, Microsoft Powerpoint, a common program for making scientific posters and presentations, allows users to check if their slides are readable in "High Contrast Mode".

2.5.1 Additional Resources:

- Color Universal Design, how to make figures and presentations that are friendly to Colorblind people
- Color Contrast Checker by Web Accessibility in Mind

2.6 Support images with text

Since scientific publications frequently rely on images to convey critical information without accompanying explanatory text, so improving image accessibility is critical [15]. Images and graphics should include accompanying text that describes the visual. Often referred to as image descriptions or "alt-text," this text can be thought of as a more detailed version of a caption.

While a caption complements a figure to briefly explain a concept or what is being shown, an image description allows the reader to understand the figure without seeing it. This visual description is especially important for people using screen readers. Many programs, such as Microsoft Office and WordPress, have easy templates for adding alt-text to help create accessible presentation materials.

Accompanying text isn't just to benefit screen readers and their users. Depending on screen size or image resolution, your graphics may not be visible to all viewers. Text scales much more easily than images in size and resolution. For people with slow Internet connections opening up publications, images may fail to load, but that is less often true with text.

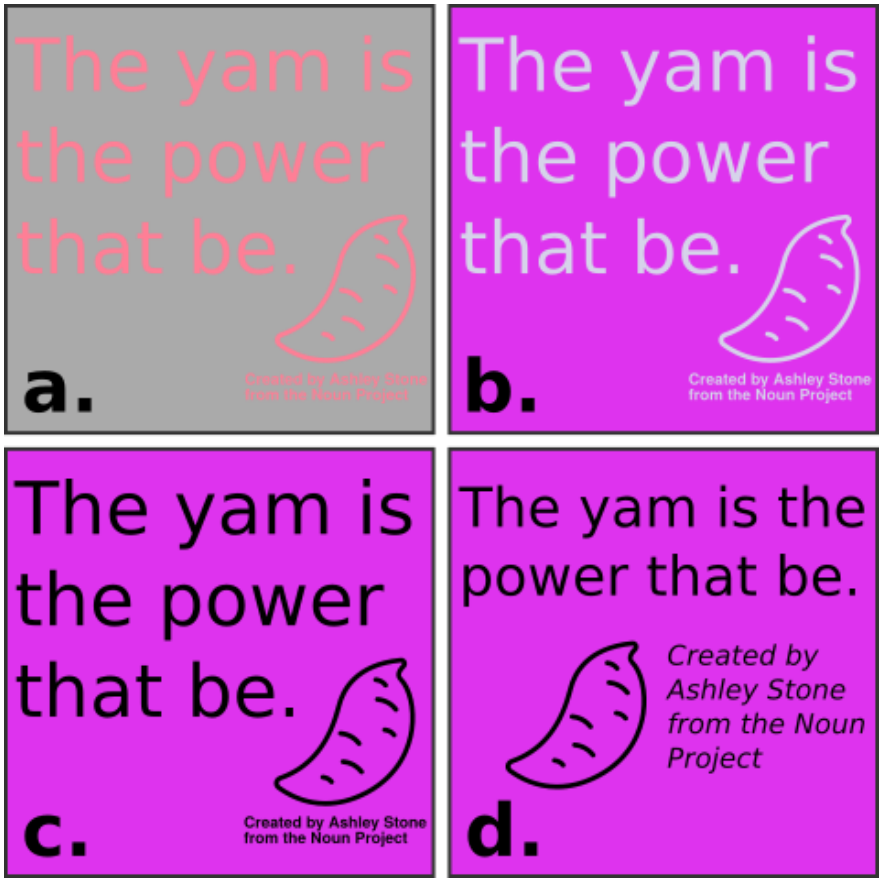

Figure 2: Figure design and coloring can play a large role in readability. (A) is nearly indistinguishable for readers with deuteronopia, which is the most common form of color blindness. (B) Even when color blindness is taken into account, low contrast images, even those with large type, are challenging for some readers. (C) is still difficult to distinguish despite the high contrast for the attribution credit for panel. (D) improved text sizing and color choice provides a high quality illustration of Kendrick Lamar's lyrics in the song "King Kunta".

2.6.1 Additional Resources:

- No More Excuses - The Definitive Guide to the Alt-Text Field by Phase2 Technology
- Fangs Screen Reader Emulator add-on for the Firefox web browser

2.7 Write clearly

Clear and concise technical writing is imperative to producing effective science publications, and is sometimes formally taught as part of scientific graduate education [1]. This includes introducing and defining abbreviations and field-specific terms (*aka* jargon). A recent trend at scientific conferences has been panels where speakers are challenged to restrict their presentations to commonly used words (e.g., Up Goer Five: https://xkcd.com/1133/), intended to engage people outside of traditional disciplinary silos and outside of academia entirely. While those exercises may be extreme, concern about the exclusionary nature of acronyms and jargon is longstanding [16,17].

2.7.1 Additional Resources:

- Writing Clearly and Simply by Web Accessibility in Mind
- Tips on Writing for Web Accessibility by the W3C Web Accessibility Initiative

2.8 Use audio with accompanying text.

While most scientific publications generally contain only written and visual components, audio is becoming more common. Some journals are encouraging video abstracts that incorporate audio or video. Regardless, most scientists present their research in both written publications and in-person presentations, with the latter often before submitting or finalizing the former. When presenting, scientists now generally use "modern" presentation styles (think TED talks) with minimalist and punchy slide design, heavy on images with little to no accompanying text, with all the verbal content being spoken by the presenter.

Speaking clearly about your research is just as important as writing clearly. When ambiguity in word choice was eliminated from orally describing STEM terms, there was increased understanding among students even when they did not have access to accompanying visual or written materials [18,19].

It is also just as important to provide text to accompany audio, to provide better access for deaf and hard of hearing audience members, as well as listeners who are non-native language users [20]. There are several options for text to accompany audio- including transcripts and captions. Providing the text or slides of a talk in advance to interested audience members can improve access for blind and low vision users, as well as deaf and hard of hearing participants. Captions have also been found to support increased understanding by audience members with intellectual disabilities [21]. Yet captions overwhelming used by and benefit non-disabled media consumers. A 2006 survey by the BBC Office of Communications found 80% of people using closed captions on videos are hearing and use them to improve their comprehension of the audio material [22]. Providing accompanying text with audio greatly benefits content creators - users watch longer and get more of the videos [23].

2.8.1 Additional Resources:

- Add your own subtitles & closed captions to YouTube videos by Google
- Tips for creating a transcript file for YouTube videos by Google
- Create captions and transcripts using Amara by Amara

2.9 Make sure hyperlinks are clear & unambiguous

As most scientific publications are now available online, embedded hyperlinks are becoming more common. It is important that these hyperlinks be cleared labeled to explain what happens when a reader clicks it. This is especially for people using screen-readers since screen-readers often create a list of all the links on a webpage, and ambiguously labeled links would create a vague list of terms, e.g., "link, click here, this" [15]. Descriptively labeling the link (e.g., "(link)" in Fig 3) would prevent this ambiguity and increase hyperlink access and usability. Additionally, using the title tag (in HTML) or a roll-over tool-tip makes the link more useful since users can scroll over the text to find out more about where the link leads.

2.9.1 Additional Resource:

- Accessible R Markdown Documents by A. Jonathan R. Godfrey

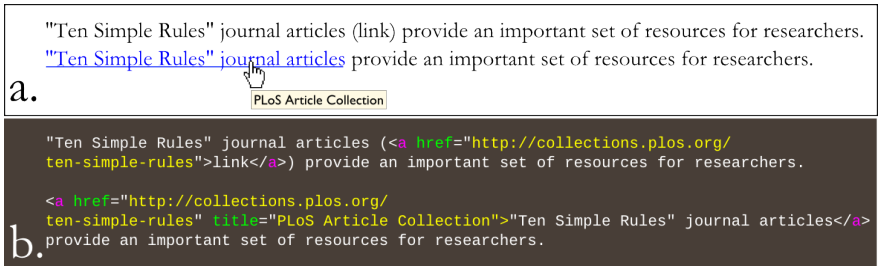

Figure 3: Hyperlinks with clear and unambiguous references provide support for web readers, but also make text machine-readable. (A) The web representation is anchored with a *title* parameter; (B) the HTML code associated with the rendered text.

2.10 Stick to widely used & open file formats

Share your work using open and widely used formats. While it might be a fun exercise to push the limits by generating your presentation as an STL file (used for 3D printing), you limit the audience for your science by using proprietary formats, or formats that can't be rendered by most common software packages. For example, text-to-speech readers can reliably convert PDF (when text is rendered), PowerPoint, HTML and other common file formats used by publishers. Ensuring your publication is available in multiple formats to allow the end-user a choice of formats to best suit their assistive technology, Internet speed, or other needs.

Many journals and conferences offer hosting services for sharing supplemental paper and presentation materials. Yet hosting options that allow you to manage your own content and ensure that access is continuous and robust are preferable. External hosting options may also provide other benefits, such as having a digital object identifier (DOI) so the content can be stably and reliably cited.

2.10.1 Additional Resources:

- Making Files Accessible by the US Government, Health and Human Services

3 Conclusion

Many universities, government agencies, and research institutions publish accessibility guidelines for a variety of document standards. Where they exist, most accessibility offices provide support to help people ensure that their publications and presentations meet accessibility standards. Although the principles of accessibility may be unfamiliar to many scientists, there is a whole body of knowledge associated with best practices and the impacts and effects of accessibility practices. By its nature, this article is a simplified overview that aims to empower people to make conscious design choices that improve both the reach of their publications and presentations, as well as access for individuals with perceptual limitations.

More broadly, we hope to engage scientists to think about the democratization of science. Practice is an important component of ensuring that we create an equitable environment. If as individuals we have the capacity of enjoying presentations without assistive technologies, we should put effort into our own presentations to ensure that all individuals can share that enjoyment, regardless of perceptual capacity. This goes beyond our role as content creators. We urge individuals in positions to oversee content presentation, such as meeting organizers and journal editors, to examine these guidelines and engage with the research community to ensure that scientific content presented in their fora addresses the issues raised here. As presenters, attendees, and consumers of content, all of us should also act as advocates for accessibility; whether we require these assistive technologies and approaches or not we nevertheless benefit from their use.

We have chosen to write these guidelines because we believe that diversity is critical within the scientific community, and that we have a part to play in increasing equity within the scientific enterprise. Changes in behavior will come as we work together, as organizers and participants, to help improve the accessibility of scientific products.

By putting these guidelines into practice, we hope that readers will join us in motivating this change and inviting a wider audience to share in our scientific discoveries, passions, and curiosity.

4 Acknowledgements

We acknowledge the advocates who continue to push us to act as better role models in recognizing and accommodating the wide variety of audiences who are interested, engaged, and active in the scientific enterprise. We also like to acknowledge the leadership and contributions of organizations, like the Institute for Accessible Science and Science Education for Students with Disabilities, and collaborative publications, like "From College to Careers: Fostering Inclusion of Persons with Disabilities in STEM" published by the American Academy for the Advancement of Science, on this important topic.

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