to faculty, postdoctoral fellows, and other researchers.

Researchers should also consider collaborations with specialists, such as artists, animators, and designers, to create more effective visualizations. A prominent historical example is the long-term collaboration between artist Irving Geis and crystallographer Richard Dickerson. Geis was an illustrator with *Scientific American* when he was asked to create a detailed painting of a 3D model of myoglobin, the first protein to have its structure solved by X-ray crystallography, in 1958 [12,13]. Geis went on to work with Dickerson to create iconic paintings and drawings of numerous molecules that have graced the pages of textbooks and journals.

Conferences that bring together experts in different fields can seed new collaborations and provide a venue for insightful discussions. Meetings of particular interest for biological visualization and communication include VizBi[ii], the Gordon Research Conference on Visualization in Science and Education[iii], the IEEE Scientific Visualization (SciViz) Conference[iv], and the annual meeting of the Association of Medical Illustrators (AMI)[v].

Visualization is a vital component of modern scientific research, allowing us to both better understand the processes we study and engage broad audiences. Our community has much to gain by encouraging scientists to create more and better visual models, whether by pencil, stylus, or mouse, and to share them openly with one another and with the public.

Resources

[i] https://blog.twitter.com/2014/what-fuels-a-tweets-engagement

[ii] http://vizbi.org/

[iii] www.grc.org/programs.aspx?id=14029

[iv] http://ieeevis.org/

[v] http://ami.org/annual-meeting

[1]Department of Biochemistry, University of Utah, Salt Lake City, UT 84112-5650, USA

*Correspondence: jiwasa@biochem.utah.edu (J.H. Iwasa).

http://dx.doi.org/10.1016/j.it.2016.02.002

References

1. Harris, J.C. (2010) Galileo Galilei: scientist and artist. *Arch. Gen. Psychiatry* 67, 770–771
2. Iwasa, J.H. (2010) Animating the model figure. *Trends Cell Biol.* 20, 699–704
3. Barber, M.E. and Elde, N.C. (2014) Nutritional immunity. Escape from bacterial piracy through rapid evolution of transferrin. *Science* 346, 1362–1366
4. Newe, A. *et al.* (2014) Application and evaluation of interactive 3D PDF for presenting and sharing planning results for liver surgery in clinical routine. *PLoS ONE* 9, e115697
5. Bress, N.E. *et al.* (2009) Snapshot: convenient, comprehensive, and now clickable. *Cell* 138, 1034
6. McGlll, G. (2008) Molecular movies. . . coming to a lecture near you. *Cell* 133, 1127–1132
7. Johnson, G.T. and Hertig, S. (2014) A guide to the visual analysis and communication of biomolecular structural data. *Nat. Rev. Mol. Cell Biol.* 15, 690–698
8. Iwasa, J.H. (2015) Bringing macromolecular machinery to life using 3D animation. *Curr. Opin. Struct. Biol.* 31, 84–88
9. Wong, B. (2010) Points of view: color coding. *Nat. Methods* 7, 573
10. Krzywinski, M. and Savig, E. (2013) Points of view: multidimensional data. *Nat. Methods* 19, 595
11. O'Donoguhue, S.I. *et al.* (2010) Visualizing biological data: supplement issue. *Nat. Methods* 7, S1–S68
12. Kendrew, J.C. *et al.* (1958) A three-dimensional model of the myoglobin structure obtained by X-ray analysis. *Nature* 181, 662–666
13. Kendrew, J.C. (1961) The three-dimensional structure of a protein molecule. *Sci. Am.* 205, 96–110

Special Issue: Communicating Science

Scientific Life

The Whiteboard Revolution: Illuminating Science Communication in the Digital Age

Florie Anne Mar,[1,*,@] Jose Ordovas-Montanes,[2] Nir Oksenberg,[3] and Alexander M. Olson[1]

Journal-based science communication is not accessible or comprehensible to a general public curious about science and eager for the next wave of scientific innovation. We propose an alternative medium for scientists to communicate their work to the general public in an engaging and digestible way through the use of whiteboard videos. We describe the process of producing science whiteboard videos and the benefits and challenges therein.

A Gap in Science Communication

What is the best way for scientists to communicate their knowledge and expertise? For dissemination among scientists, the paper-in-journal model has existed in some form since 1665 [1]. More recently, the internet era has given publishers the opportunity to evolve this process, including animated graphics or videos to enhance articles [2]. Despite this generally more accessible style, it still reaches only a very specific audience: a scientist's peers (and perhaps overly enthusiastic family members). Because of the difficulties of digesting journal articles, the large majority of citizens often rely on journalist-generated and media-curated content to enrich their understanding of our biological, chemical, and physical world. There is a significant gap in science communication between the research paper and the newspaper article, and we believe that scientists are the best equipped to bridge this gap.

Given that most research worldwide is supported by public funds, scientists should view the communication of results to the public, in a digestible manner, as an essential component of their research program. The American Association for the Advancement of Science (AAAS) has been very vocal about this issue and has conducted surveys to assess public support for science in the USA [3]. The results revealed a stark contrast between how scientists and the public viewed certain major scientific advances such as genetically modified (GM) food, animal research, evolution, vaccines, and climate

change. These gaps in scientific understanding and acceptance can lead to important policy outcomes, including the labeling of GM foods, funding for stem cell research, and CO_2 emission regulations. Reliable communication of the achievements and failures inherent to the scientific process is one way to ensure evidence-based decision making by improving transparency, enhancing public trust in science, and closing these gaps. Due to their experience and broad knowledge of science, scientists are the ideal candidates for taking on this challenge. Sir Mark Walport said it best: 'Science is not finished until it's communicated' [4].

Let's rephrase our initial question. What is the best way for scientists to communicate findings with individuals outside their immediate area of expertise? Our experience at Youreka Science (Box 1) is that whiteboard videos are an effective way to engage in scientist-driven science communication. Moreover, the process of producing scientific whiteboard videos encourages conceptual thinking and clear, audience-appropriate communication – skills that every scientist can use not only to communicate with the public but to enrich teaching and training experiences and interactions with colleagues.

The Making of a Science Whiteboard Video

The key to producing a compelling video that will capture and retain loyal viewers revolves around three questions. What is the goal of the video? Who is my audience? How will I reach my viewers? You can refer to the accompanying video (see Video S1 in the supplemental information online) for instructions on how to produce a whiteboard video.

The first step in producing a whiteboard video is identifying a topic to provide the basis for writing a script. Remember the first question: what is the goal of the video? When writing a script, think about three points you want to get across. For instance, in a video describing the discovery of CRISPR, the goal is to explain the process and outcome of this new technology. Important points may include the following.

(i) How was CRISPR discovered and how does it work?
(ii) Why is it getting so much attention in the news?
(iii) What are the benefits and ethical issues associated with it?

We generally like to start with a provocative question, fact, or humorous anecdote. When writing the script, use a conversational tone, keep explanations simple, employ analogies, focus on telling the story of how this question came about and how it was answered, and avoid unnecessary details that may distract the viewer. It is important to provide context around the topic. In a video on CRISPR, you may consider explaining the limitations of previous genome editing techniques and how this new discovery pushes the field forward. One concluding style is to circle back to the initial problem and provide insight into the implications of solving this question for medicine and public health. We suggest writing a script of 500–600 words, which generally produces a video of 3–5 minutes. We have found that a whiteboard video of this length is very effective in capturing viewers and provides enough time to cover a complex scientific topic.

The main challenge to overcome when writing a video script is to foster the process of science in a digestible way. This can be particularly difficult when writing about a topic you are intimately involved with, such as a PhD project. Effectively, whiteboard videos challenge the creators to distill content in a way that captures the essence while maintaining the accuracy of the initial work. Asking friends or family members to read your script and developing your 'elevator pitch' will help you identify the key points that will guide the logical flow of your script and make it more accessible [5]. It is also important to always remember who the audience is. The general rule of thumb is this: when communicating science to the general public, write in simple terms and avoid acronyms and jargon. If you communicate in such a way that your audience will be able to convey the message to others, you will have truly succeeded in your mission.

Once the script is of the proper length and scope, grab a blank piece of paper and use colored pens to draw out each scene you are envisioning for the video. Use the power of the visuals to clarify and supplement the script, providing analogies and using color coding. Consulting with an artist who has some background in the sciences can be an effective springboard for looking at your content from a fresh perspective and can help generate new ways to visualize the science.

Once the script and storyboards are finalized, it is on to filming, voice-over recording, and editing. Frequently, the video is accelerated to match the audio piece and cover more content in less time, so do not fret about the speed at which you populate the whiteboard. The last important piece that must not be understated is distribution. How will I get my video in front of the right audience? Do not get discouraged by the millions of views a cat video will receive and the several hundred or, if you are lucky, thousands your first science video will capture. The availability of great science content does not necessarily mean people will use it. Collaborating with an advocacy group is a great way to distribute content to those committed to the topic. At Youreka Science, we will gladly share and promote any high-quality science video.

Learning from the Viewers

Videos provide live metrics to track audience retention, giving the creator the ability to modify their process to fit the viewer's needs. Youreka Science has produced over 40 videos describing new scientific discoveries, complex public health topics, and the process of drug discovery.

Using these metrics, we have learned a great deal about our audience: understanding what the viewer likes and how the viewer learns. From the very first video, we have considered our audience, listened, and modified our process accordingly. For example, our first videos featured the article title in the first scene. When assessing audience retention, we noticed viewership fell sharply in the first 30 seconds relative the other YouTube videos. To better retain the viewers' attention, we modified our introductory scene to focus on the implications of the question to be answered. We learned that viewers were more captivated when videos started by describing the big picture (the 'why') instead of the results (the 'what'). Now we retain more viewers than the average YouTube video of a similar length and our audience watches an average of 70% of the video – about 4 minutes. In essence, we have reverse engineered our videos to capture and retain viewers as much as possible. Youreka Science videos have reached over 150 000 people: students, teachers, bartenders, homemakers, nurses, yoga instructors, and artists. Our videos are being viewed at home, in the classroom, and at conferences. We continue to strive to reach more people in more places.

The Benefits of Whiteboard Videos in Science Communication

Through the years, we have learned to appreciate the use of videos in science communication and the substantial value they provide for both the viewer and the creator. For the spectator, videos are an engaging and digestible visualization platform for science communication. Whiteboard videos take advantage of the intrinsically visual nature of science to provide a new dimension for the viewer. Illustrating a scientific concept can also provide a sense of scale for viewers who do not routinely think about how basic building blocks are organized within living systems. Furthermore, the storytelling aspect of this form of communication gives viewers the ability to integrate complex concepts more readily by building associations with the oldest means of passing knowledge through human communities [6].

Whiteboard videos are also a valuable educational tool for the creator (Box 1). The skills we have developed writing scripts, drawing storyboards, and filming scenes have been even more valuable outside our makeshift studio and transferable to many facets of our careers in academia, industry, and beyond. Some of the most critical skills we have developed include the ability to distill complex information into a few key points, to tell a story, to communicate clearly, and to lead a project. Becoming proficient in extracting the fundamental points necessary to address a specific question can help a scientist develop a research project, identify gaps or new avenues, and write a research paper or grant. Beyond the lab, this nontrivial skill will make him or her a competent problem solver. No whiteboard video captivates an audience without telling a compelling story. A whiteboard video will quickly turn its creator into a skilled storyteller and a valuable asset to any negotiation, concept review, or pitch. Whiteboard videos also teach valuable communication skills directly transferable to the classroom, the boardroom, and everywhere in between. Being an effective communicator is arguably the most important skill to ensure success in one's professional and personal life. Lastly, whiteboard videos provide concrete metrics of success and demonstrate one's ability to lead a complex and multifaceted project to completion.

There are many benefits to producing whiteboard videos for the creator and for the viewer, but only by aligning the

Box 1. A Personal Science Communication Anecdote

Like many graduate students embarking on advanced degrees in biology, I started graduate school with an interest in teaching and sharing my passion for science. This pushed me to spend a few days a month teaching science in local San Francisco public schools. In this new role, I felt both welcome and a bit surprised by the teachers' eagerness to learn about the specifics of my research, despite the topic being embedded in basic science and relatively complex experimental work.

As a basic science researcher, it is often difficult to build public support for one's work given that many regard 'fruit fly' or 'worm' research as irrelevant to human health. Yet, these teachers showed particular enthusiasm for my thesis research. A few weeks later, I was browsing the news for the latest science breakthroughs and was struck by the lack of high-quality content created by scientists to disseminate their latest findings. Reflecting on my time teaching in the classroom, I saw the value this type of content would offer. Teachers could use these materials to provide tangible examples describing how discoveries are made in the laboratory. More generally, content created by scientists for a general audience would grant citizens an increased understanding of what is being achieved with their tax dollars and could enhance their trust in the scientific process.

In 2012, I decided to make it my mission to improve public access to the latest scientific discoveries, from basic research to translational drug discoveries. I repurposed a whiteboard originally used for practicing presentations to create engaging videos that I posted on a YouTube channel and website aptly called Youreka Science. Youreka Science was born to empower scientists to communicate directly to citizens, improve public awareness of scientific progress, and motivate citizens to be their own science advocates. Four years, three whiteboards, and a few dozen markers later, we have produced over 40 videos, built many collaborations and forged lasting relationships. We are now a team of three: a script writer/content creator, an illustrator, and an editor. We have been rewarded with encouraging and inspirational feedback from our more than 150 000 viewers, who come from all walks of life. They have informed us that our videos have spiked their scientific curiosity and we are confident many have become more informed citizens. We have been outspoken about the benefits of scientist-driven science communication through the use of whiteboard videos and we are excited to share our story.

We encourage more scientists to accept our whiteboard video challenge and more citizens to be curious about science and offer 3–5 minutes of their day for scientists to inform, inspire, and motivate them. Read more about our work and see our videos by visiting http://www.YourekaScience.org, http://www.facebook.com/YourekaScience, or http://www.YouTube.com/YourekaScience.

interests of the two parties from the start will a video truly have an impact.

Encouraging Science Communication

Because of the benefits we have observed for both video creators and viewers, and because of the importance of communicating science clearly and more broadly, we call here for a 'whiteboard revolution'. We encourage institutions to introduce students and postdocs to whiteboard videos as part of their curriculum – in the context of a journal club or on publication of their research – and to reward principal investigators who encourage their trainees to take part in these programs. Whiteboard videos produced by scientists will benefit their career, enhance public access to science, and constitute a valuable resource for institutions to promote the high-caliber science they conduct.

We also encourage journals to sponsor video competitions explaining recently published findings. Having a hard deadline, the prospect of a monetary prize, and receiving assistance with dissemination will motivate students to produce their first science communication video, while increasing viewership of the journal. Furthermore, journals can provide resources to help scientists create more approachable pieces, including interactions with scientific editors.

Lastly, we challenge all scientists to collect a piece of paper, some colored pens, a camera, and a microphone and design your toughest experiment yet: tell the story of your research that your avid and curious grandmother could understand in 500 words or less. We acknowledge that this will delay some western blots or qPCR reactions, but the time investment is well worth the return. Remember, science communication is not only our responsibility, it is also a fun and rewarding activity. What better way to improve public understanding of science and help create more informed citizens than by bridging our creative and analytical cerebral hemispheres and giving science communication a whole new dimension? So grab your pen, and let's start the whiteboard revolution!

Supplemental Information

Supplemental information associated with this article can be found, in the online version, at doi:10.1016/j.it.2016.02.004.

[1]Youreka Science, San Francisco, CA, USA
[2]Institute for Medical Engineering & Science, Massachusetts Institute of Technology, Cambridge, MA USA
[3]Department of Plant Pathology, University of California, Davis, Davis, CA, USA

*Correspondence: florie@yourekascience.com (F.A. Mar).
@Twitter: @YourekaScience

http://dx.doi.org/10.1016/j.it.2016.02.004

References

1. Wells, E. (1976) A history of scientific & technical periodicals: the origins and development of the scientific and technical press, 1665–1790. *Bull. Med. Libr. Assoc.* 64, 1
2. Bubela, T. *et al.* (2009) Science communication reconsidered. *Nat. Biotechnol.* 27, 514–518
3. Funk, C. and Rainie, L. (2015) *Public and Scientists' Views on Science and Society*, Pew Research Center (www.pewinternet.org/2015/01/29/public-and-scientists-views-on-science-and-society/)
4. Ewles, H. (2013) *Sir Mark Walport Delivers CSaP Lecture on Climate Change*, Center for Science and Policy (www.csap.cam.ac.uk/news/article-mark-walport-csap-lecture-on-climate-change/)
5. Kwok, R. (2013) Communication: two minutes to impress. *Nat. Jobs* 494, 2
6. Green, M. (2004) Storytelling in teaching. *APS Observer* 17, 37–39

Special Issue: Communicating Science

Scientific Life

What Can Vampires Teach Us about Immunology?

David S. Schneider[1,*]

Speculative fiction examines the leading edge of science and can be used to introduce ideas into the classroom. For example, most students are already familiar with the fictional infectious diseases responsible for vampire and zombie outbreaks. The disease dynamics of these imaginary ailments follow the same rules we see for real diseases and can be used to remind students that they already understand the basic rules of disease ecology and immunology. By engaging writers of this sort of fiction in an effort to solve problems in immunology we may be able to perform a directed evolution experiment where we follow the evolution of plots rather than genetic traits.

When I first started teaching, my Department had no courses that needed leadership, so I invented my own class; I led a freshman seminar where we studied the pathogenesis of infectious disease using horror movies (Table 1). I had this great pool of brilliant students with diverse interests and my hope was to introduce some of them to this exciting science and for them to help me think about pathogenesis in different ways. I remember one project that developed the sort of cross-disciplinary thinking I was trying to foster where the student aimed to develop a vaccine for gossip. She planned to test her vaccine by intentionally spreading rumors about another member of the class and gave an entertaining presentation of her plan in which she horrified us by suggesting she had actually begun the experiment.

Although I have not taught this course for years, I kept up with the literature. Now, having consumed a great stack of horror movies, novels, and comics, I think I see a practical application. As a field, we often argue that pathogens are the keenest students of immunology because their lives and fitness depend upon their ability to overcome the immune response of a host. Over evolutionary time, pathogens have explored immune space and have evolved methods of avoiding, tolerating, and resisting host responses. As scientists, we can mine this resource to learn