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Proving the value of visual design in scientific communication

Keywords: visual communication design, scientific communication, scientific visualization, graphical abstract, table-of-contents graphic, fluency, scientific figures, visual design for scientists, data visualization, information graphics

This study examines how scientists respond to visual design in scientific communications. Specifically, we determine the impact of visual design on the Graphical Abstract (GA), an overview figure that attracts potential readers and visually summarizes what a paper is about. We show that GAs designed in accordance with classic visual design principles significantly enhance readers' first impressions of a paper. Well-designed GAs make papers seem more interesting, more clearly written and more scientifically rigorous. These results confirm that visual design enhances rather than detracts from the perception of intellectual and scientific competence.

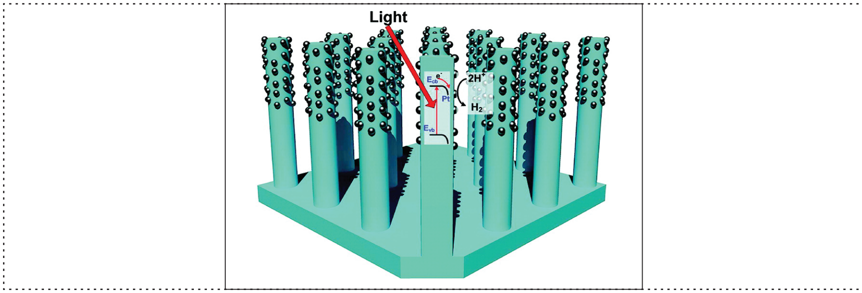
1. Introduction

Given the rapid growth of scientific publication—estimated to double each decade—scientists and engineers increasingly need ways to quickly explain and draw attention to their work (Bornmann 2015). Towards this end, several scientific journals have published editorials emphasizing the importance of the Graphical Abstract (GA), an overview figure that attracts potential readers and visually explains what a paper is about. Editors encourage scientific authors to create GAs that are simple, easy to understand and visually attractive (Wong 2011; Buriak 2011; Kamat & Schatz 2013; Buriak 2014). These criteria are based on the common observation that readers tend to browse papers by looking very briefly at the title and GA (Divoli et al. 2010). Studies show that users respond to visual images and infographics on websites in 50–500 milliseconds (Harrison et al. 2015).

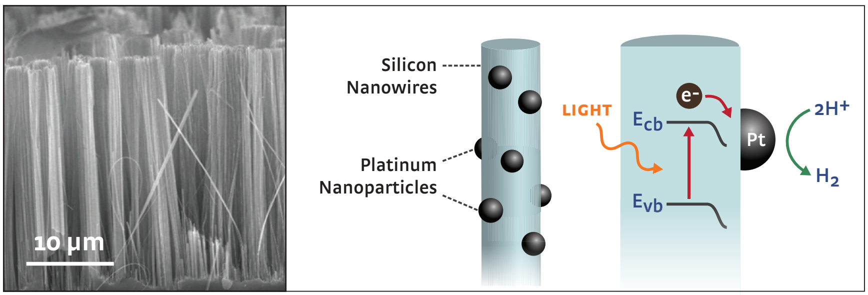
Despite the clear impact of GAs on scientific communication, there are no studies on how well-designed GAs influence a viewer's choice to read a paper. Therefore, we applied established visual design principles (Agrawala et al. 2011; Rolandi et al. 2011) to already published GAs (Figure 1, Figures S1–S6) and examined how the redesigned GAs influenced readers' initial perceptions. Our research question was: Do well-designed GAs change readers' understanding, interest and expectations of a scientific paper?

2. Experimental procedures

We selected graphical abstracts (Fang et al. 2012; Ghosh et al. 2012; Idan et al. 2012; Korten et al. 2012; Mikheev et al. 2012; Oh et al. 2012; Rewitz et al. 2012;



ORIGINAL
Too cluttered—also, interior diagram too small to be legible.



REDESIGNED
Reformatted using a series of close-up views.

Figure 1. Original and Redesigned Graphical Abstract. The original GA (Oh et al. 2012, reprinted with permission from the American Chemical Society, copyright 2012) shows a schematic of a silicon nanowire array. When exposed to light, the array photoelectrochemically generates hydrogen. In the original GA, this reaction is difficult to see, due to its small scale. The revised GA uses larger close-up views that are more legible. The larger array is still shown, but with an instrument image.

Qiu et al. 2012; Siozios et al. 2012; Smith et al. 2012) from a single issue of *Nano Letters*, a journal with high-caliber research papers (2015 impact factor = 13.779) and a long history of using GAs. From the 90 articles in the issue, we selected ten GAs (Figure 1, Figures S1–S6) based on their potential for improvement via redesign. These GAs had limited functionality due to their violation of known and tested visual design principles—for example, insufficient value contrast between text and its background, or graphics that were too small to be legible (Agrawala et al. 2011; Rolandi et al. 2011). Because it was impractical to engage and consult with the original authors for our redesign process, we avoided GAs that were exclusively instrument data or computer-simulated images. These visuals were difficult for us to modify without having greater access to the original experimental data.

We redesigned each GA according to the four-stage design process shown in Figure 2 and Figure S7. First, we read the associated scientific paper to ensure that we understood the message being communicated by the original GA. Our aim was not to alter this message, but to communicate the same information with better visual design.

Next, we considered the overall complexity of each GA. Many designers support the broad concept of making scientific visuals “as simple as possible, but no simpler” (Wong 2011; Rolandi et al. 2011). This general prinicple

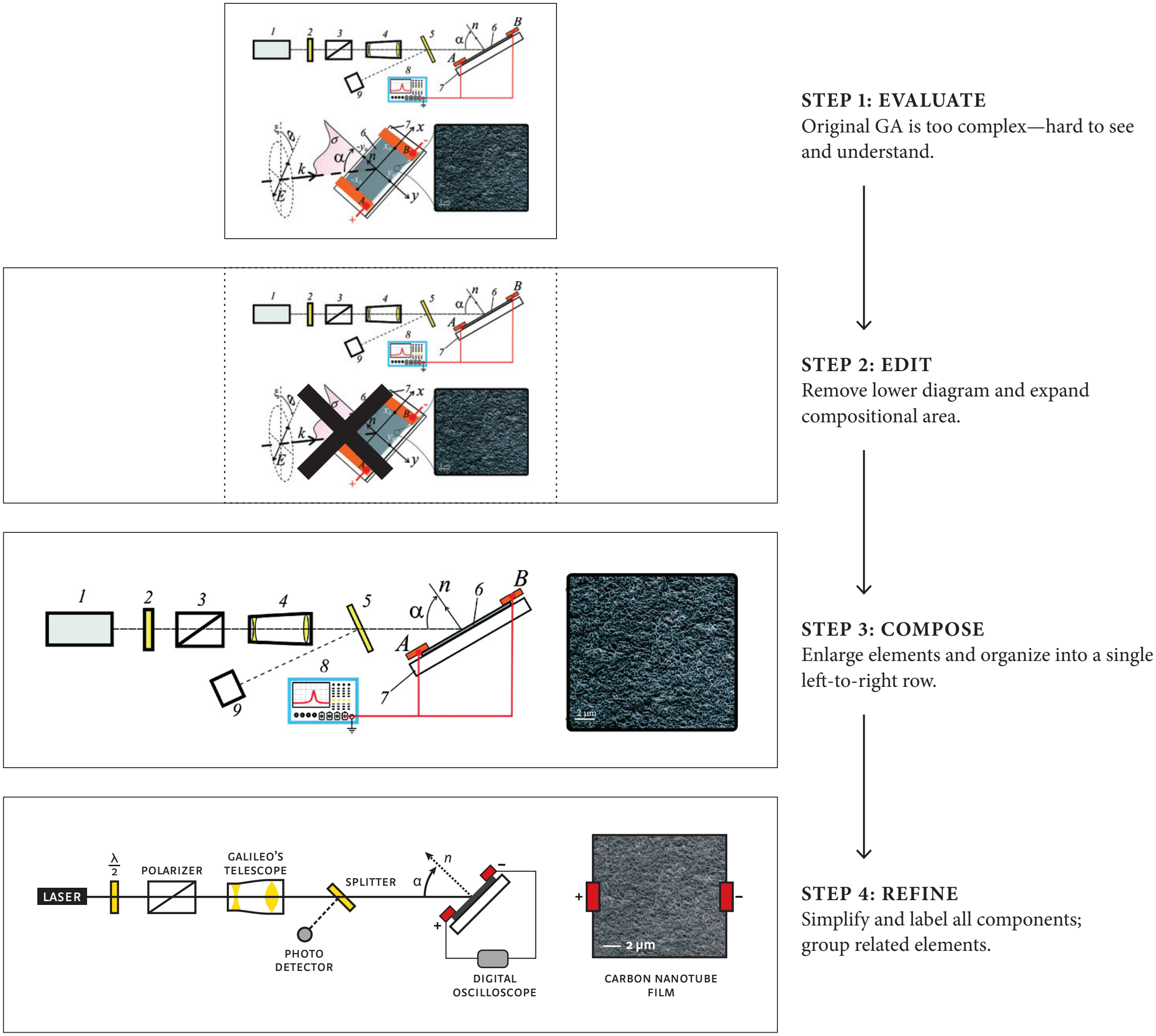


Figure 2. Redesign Process for a Graphical Abstract. The original GA (Mikheev et al. 2012, reprinted with permission from the American Chemical Society, copyright 2012) has three parts: a schematic of the experimental setup; a diagram showing specific vectors and angles of incidence; and an instrument image of the single-walled carbon nanotube film being exposed to laser radiation. Established visual design principles (Wong 2011) generally advocate inclusion of only the most essential information; therefore, the revised GA eliminates the diagram of vectors and angles of incidence.

has been validated by studies that show users to prefer visual designs with low-to-moderate complexity over high complexity (Bauerly & Liu 2006; Tuch et al. 2012). Based on this demonstrated evidence, we sought to simplify nine of the ten GAs (Figure 1, Figure S1–S5). We found the tenth GA (Figure S6) to be too simple: it lacked sufficient content. This tenth GA was cropped from a larger figure shown in the associated paper; therefore, we used the larger figure as a starting point for redesign.

Specifically, to simplify four GAs, we eliminated components we judged to be either redundant or non-essential. To simplify all ten GAs, we revised certain graphics—for example, by making arrows smaller, or by using a plainer style of arrow (Wong 2011). Additionally, in all ten GAs, we increased white space (Wong 2011) by distributing the visual elements within a larger portion of the space provided by the publisher.

Next, we reorganized the remaining visual components of each GA into a new composition with a clear starting and ending point, flowing from top-to-bottom and left-to-right, as recommended by Malamed (2009). Creating these visual flows also involved grouping: aligning and/or placing related items in visual groups and subgroups to make a visual hierarchy of content that was structured and easy to understand (Wong 2011).

Finally, we highlighted the most important information—the key findings of the research paper—with visual contrast: changes in color, position, and size. These visual attributes have been proven to draw viewers' attention during visual search processes (Wolfe & Horowitz 2004). In addition, for all ten GAs, we used short text labels to further focus readers' attention on critical elements, and to explain specific mechanisms.

We showed the original and redesigned GAs to 50 study participants who reported regularly reading scientific journals. The participants were faculty, post-doctoral researchers and graduate students from nine science and engineering departments (Applied Math, Bioengineering, Chemistry, Chemical Engineering, Electrical Engineering, Environmental and Occupational Health Sciences, Materials Science & Engineering, and Physics) affiliated with the University of Washington's Center for Nanotechnology. We recruited the participants for a study entitled "Visual Communication in Nanotechnology." The study was administered as an online web survey, which could be taken at a time of the participants' choice.

The online web survey consisted of ten webpages, each showing a screenshot of a single GA as it would appear within a Table of Contents (TOC) page on the *Nano Letters* website (Figure S8). The title and CAS section keywords were shown, but researcher names were redacted to avoid bias from known authors. The DOI identifier was also redacted to prevent participants from easily accessing and reading the full text of the actual paper.

Each participant saw five TOC items with the paper's original GA, and five TOC items with our redesigned GA. Papers were not identified as featuring an original or redesigned GA, nor was it mentioned that GAs had been altered. Our plan was to use randomized partial counter-balancing for the condition combinations and orderings because there were many more combinations than subjects. Early in our test administration, due to a programming error, eight participants had identical counterbalanced orders. We fixed the error, and ensured that each original figure and each redesigned figure appeared 25 times across the study.

Below the overview screenshot, participants were presented with a series of six statements and a Likert scale (Likert 1932) for each statement. The six statements were:

1. I have a sense of what this paper will be about.
2. The title and figure make sense together.
3. The paper will be clearly written.
4. The paper seems interesting.

5. The authors seem intelligent.
6. The science in the paper seems rigorous.

Participants rated their agreement with each of these statements on a seven-point scale marked with agree on one end of the scale and disagree on the other end of the scale. After rating all of the statements on a webpage, the participants continued to another web-page with a different overview screenshot. There was no time limit, and participants could not backtrack or skip ahead. After rating ten overview screenshots, the participants were asked to complete a brief survey providing demographic information. At the conclusion of the survey, participants were thanked for their participation and given instructions to claim their compensation (a $10 Amazon.com gift card). The median time for participants to complete the online survey was 9 minutes and 51 seconds.

3. Results

Our results (Figure 3) were calculated by first converting the seven options on the Likert scale to values from zero for the strongest disagree option to six for the strongest agree option. We then treated these values as ordinal data and compared performance on each of the six statements with the nonparametric Wilcoxon Signed-Ranks Test. Each of the statements had statistically reliable differences

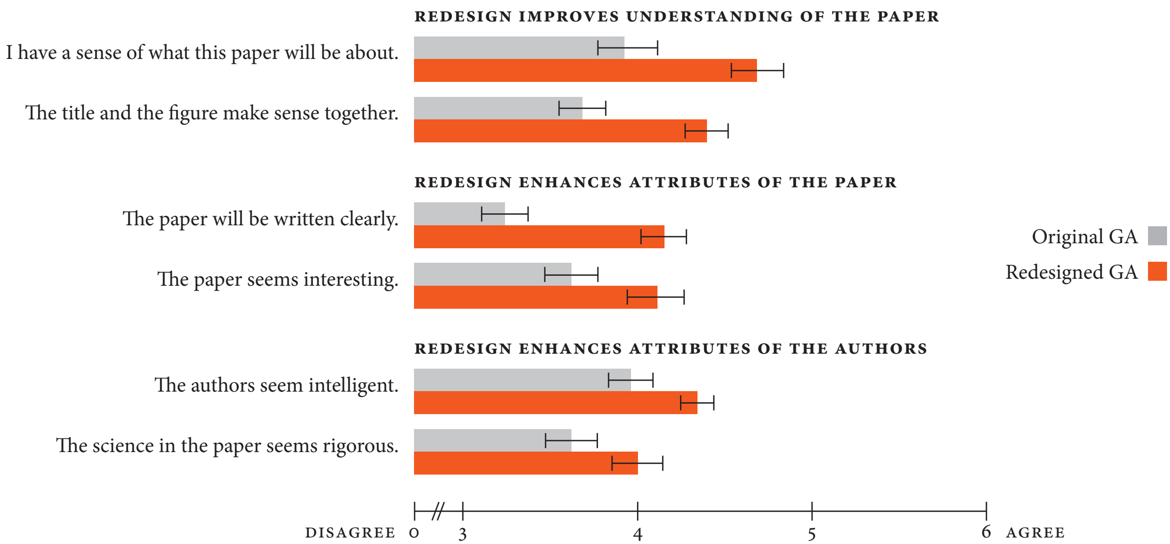


Figure 3. Initial Perceptions of Scientific Papers Before and After Redesign of the Graphical Abstract. Redesigned GAs improved scores for all six statements. Error bars are the standard error of the mean (SEM). Redesigned GAs improved readers' understanding of the paper, and made better sense with the title. Additionally, redesigned GAs enhanced the initial perception of the paper: readers believed papers with improved GAs would be more interesting and written more clearly. Finally, redesigned GAs enhanced the perception of the authors' intelligence, and the rigor of the science.

between the ratings for the original and redesigned GAs, and the effect sizes for these differences ranged from medium to large. The direction of the main findings held true for all 10 GAs.

The first two statements evaluate the reader's understanding of the paper's preview. For the statement, "I have a sense of what this paper will be about," the average rating with the original *GA* is 3.95 (SD = .90) while the average rating for the redesigned *GA* is 4.51 (SD = .81). This difference is statistically reliable, Z = 3.84, p < .0001, r = .54 (large effect size). For the statement, "The title and figure make sense together," the average rating with the original *GA* is 3.76 (SD = .80) while the average rating for the redesigned *GA* is 4.31 (SD = .67). This difference is statistically reliable, Z = 3.25, p < .001, r = .46 (medium effect size).

The next two statements evaluate the reader's expectations of the paper. For the statement, "The paper will be clearly written," the average rating with the original *GA* is 3.44 (SD = .81) while the average rating for the redesigned *GA* is 4.10 (SD = .68). This difference is statistically reliable, Z = 4.27, p < .0001, r = .60 (large effect size). For the statement, "The paper seems interesting," the average rating with the original *GA* is 3.70 (SD = .81) while the average rating for the redesigned *GA* is 4.07 (SD = .83). This difference is statistically reliable, Z = 2.16, p = .03, r = .31 (medium effect size).

The last two statements evaluate the reader's perception of the authors. For the statement, "the authors seem intelligent," the average rating with the original *GA* is 3.95 (SD = .65) while the average rating for the redesigned *GA* is 4.27 (SD = .60). This difference is statistically reliable, Z = 3.08, p = .002, r = .44 (medium effect size). For the statement, "the science in the paper seems rigorous," the average rating with the original *GA* is 3.72 (SD = .81) while the average rating for the redesigned *GA* is 4.00 (SD = .77). This difference is statistically reliable, Z = 2.87, p = .004, r = .41 (medium effect size).

4. Conclusions

We have demonstrated that redesigned GAs have substantial benefits for scientific authors. These results align with prior psychological studies of fluency (Reber and Schwarz 1999; Oppenheimer 2006). For example, a statement of fact is rated as more truthful when it is written in a more legible, high-contrast color than when it is written in a lower legibility, low-contrast color (Reber & Schwarz 1999). Similarly, an author who writes with simpler language is perceived as more intelligent than one who writes with more complex vocabulary (Oppenheimer 2006). Also, in human-computer interaction design research, interfaces designed according to classical aesthetics were better liked and considered more usable; websites perceived as visually unappealing were less likely to be trusted, and more likely to be left by visitors (Lindgaard et al. 2011).

In the future, we would like to determine which aspects of visual redesign have the greatest impact on potential readers. Future work could also investigate if the advantages of a redesigned TOC graphic continue to influence the perception of a scientific paper even after the full publication has been read.

Our results point to the benefits of interdisciplinary collaboration between scientists and visual design experts. A renewed focus on visual scientific communication, especially within graduate education, would enable future generations of scientists and engineers to communicate their research findings more effectively. Scientists that create accessible, informative and engaging images will reach larger audiences, and therefore catalyze new explorations and discoveries.

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About the authors

Karen Cheng received her Master of Design from the University of Cincinnati's College of Design, Art, Architecture and Planning. She is a Professor of Visual Communication Design at the University of Washington in Seattle, where she teaches information design and data visualization. Her research and design practice focuses on making information both more understandable and more compelling in a wide variety of contexts—in print, in environmental installations and in interactive products.

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Yeechi Chen received her Ph.D. in Physics (2009) and a certificate in Natural Science Illustration (2010), both from the University of Washington. Her graduate research examined the optical properties of fluorophores near metal nanoparticles. Her postdoctoral work explored the methods and efficacy of visual communication among nanoscience researchers. She is working on improving science education and communication between scientists and with the public using visual design and illustration.

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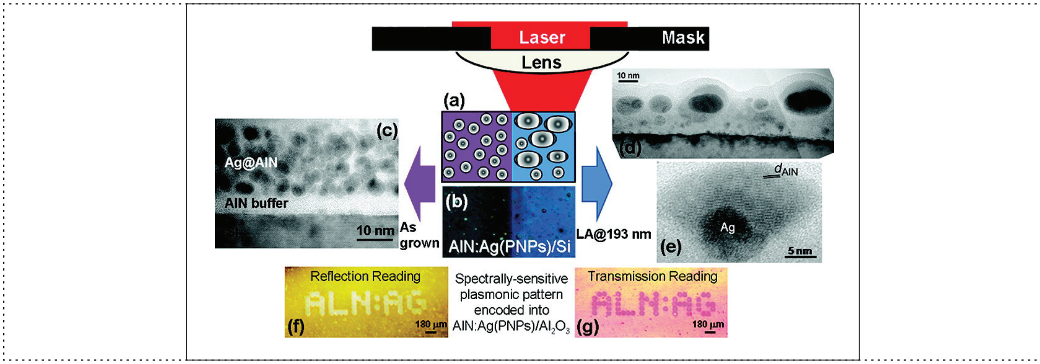
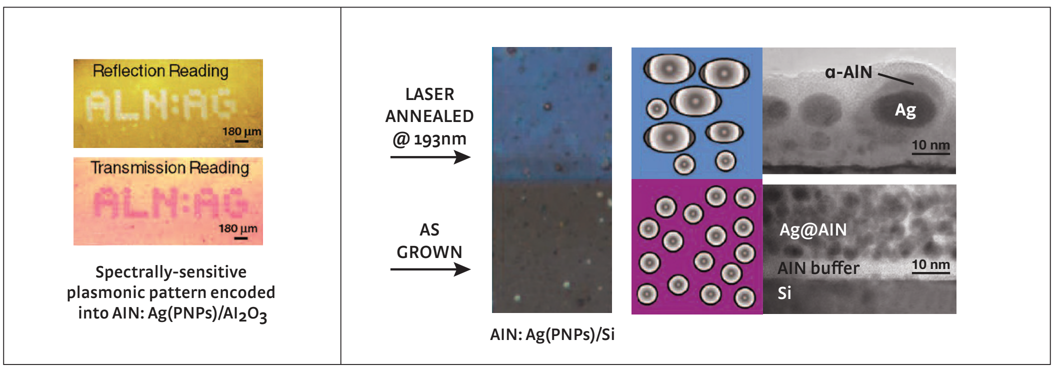
Appendix

Supplementary materials

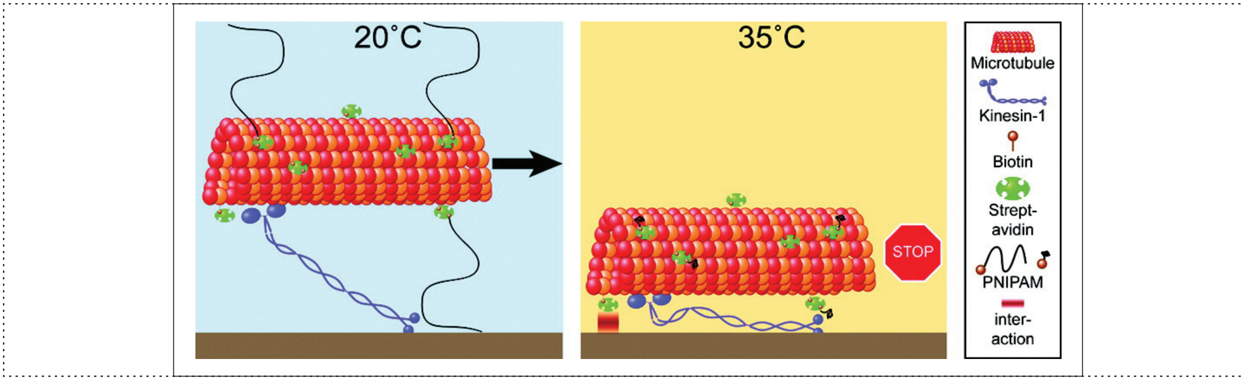


ORIGINAL
GA is too complex—lacks organization and directional flow.
Grouping is unclear; readers can't see which images belong together.



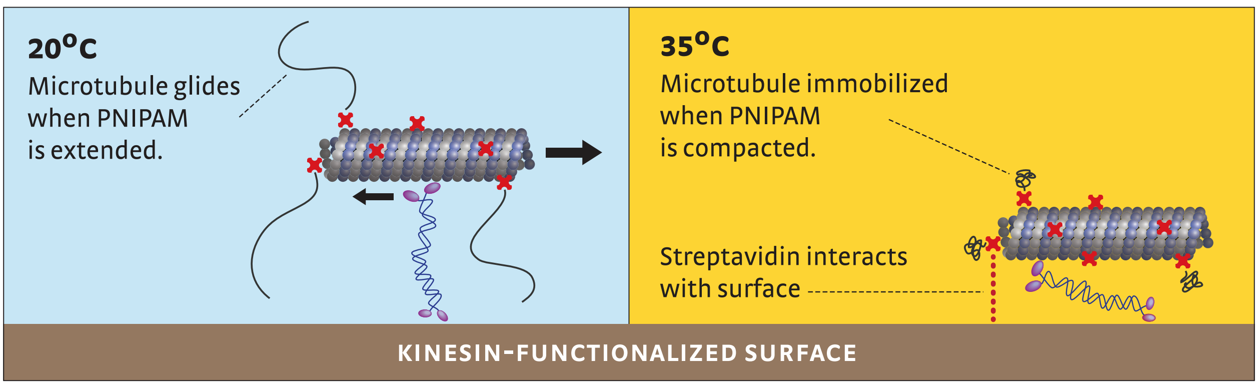
REDESIGNED
Related images were grouped and aligned, flowing from left-to-right.
The key scientific result (encoded pattern) is highlighted by being shown first.

Figure S1. *Improving Visual Flow*. The original Graphical Abstract (Siozios et al. 2012, reprinted with permission from the American Chemical Society, copyright 2012) is difficult to visually enter and follow. In the revised GA, information is consolidated into a smaller number of visual groups that proceed from top-to-bottom and left-to-right.



ORIGINAL

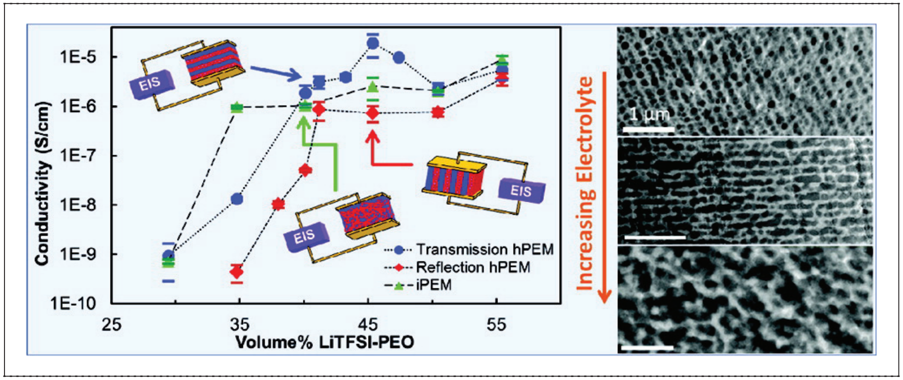
The most important information (how the molecule starts and stops moving) is not emphasized.



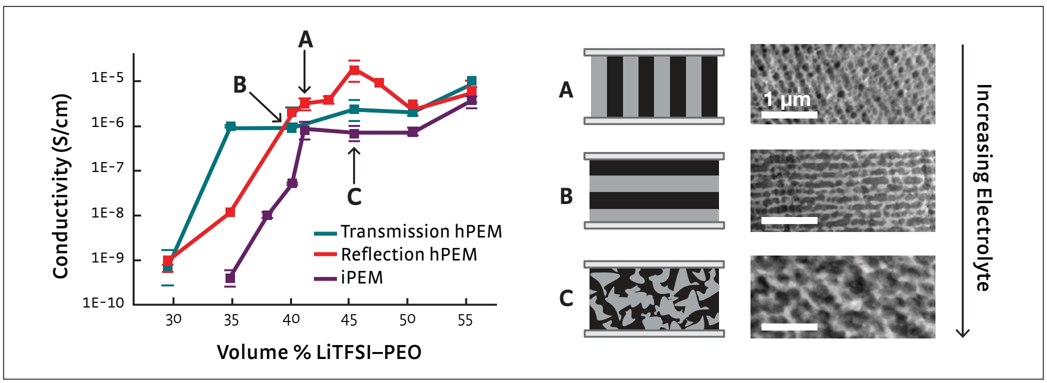
REDESIGNED

The redesign emphasizes and explains the key molecular interactions with text labels and captions.

Figure S2. *Simplifying Graphical Abstracts*. The original Graphical Abstract (Korten et al. 2012, reprinted with permission from the American Chemical Society, copyright 2012) is difficult to comprehend, because viewers must frequently refer back to the side legend in order to understand what is being shown (Kaplan et al. 1998). In the revised GA, elements are directly labeled, eliminating the need for the legend.

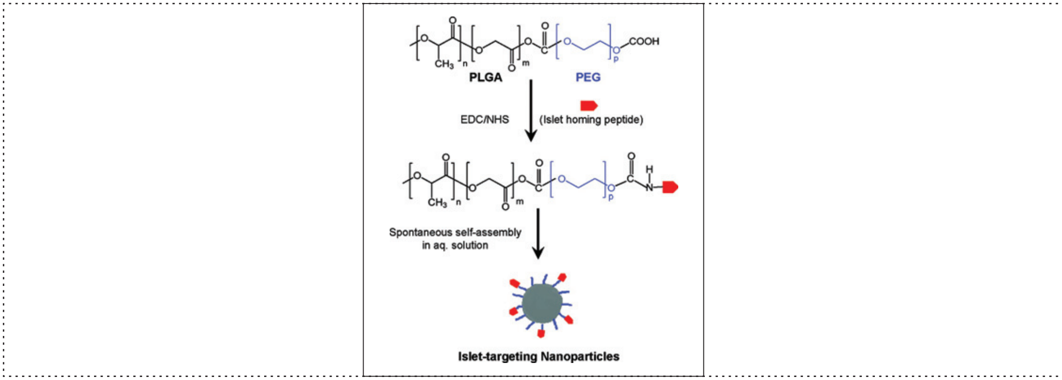


ORIGINAL
Instrument images are disconnected from schematics.
Schematics disrupt and clutter the line graph.

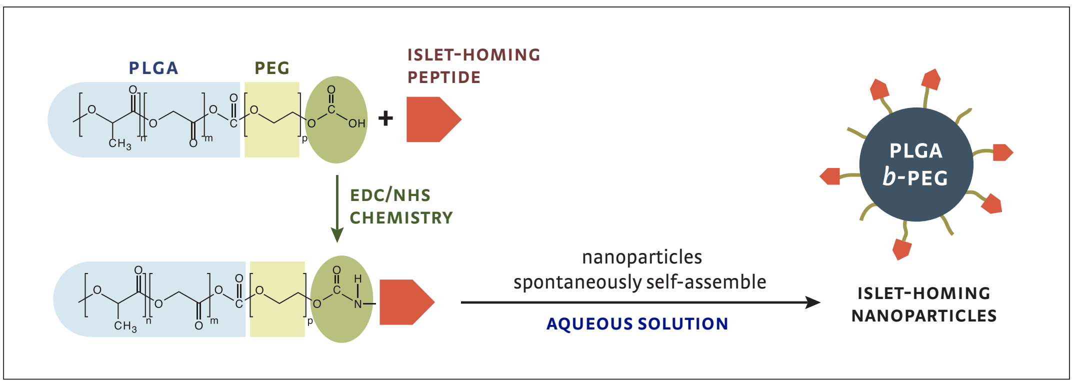


REDESIGNED
Schematics were aligned to the corresponding images.
Line graphs were simplifed, with increased color contrast for clearer coding.

Figure S3. *Reorganizing Graphical Abstracts*. In the original Graphical Abstract (Smith et al. 2012, reprinted with permission from the American Chemical Society, copyright 2012) viewers cannot easily see which material structure corresponds to a specific line graph and instrument image. By aligning the schematics and images into pairs, we can show the relationship more clearly and concisely.



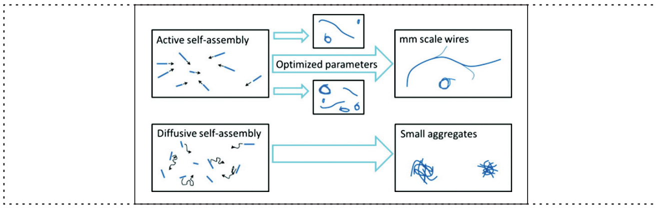
ORIGINAL
The vertical composition uses space inefficiently.
Similar components (PGLA and PEG) are difficult to identify.



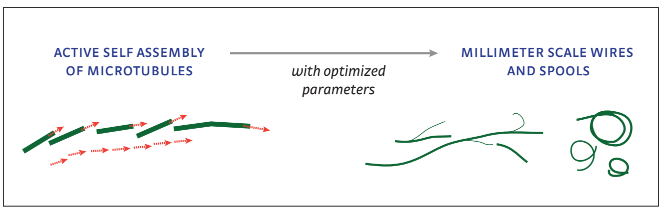
REDESIGNED
The GA was reformatted as a left-to-right row.
Graphic shapes and color were used to identify similar structures.

Figure S4. *Clarifying Graphical Abstracts with Shape*. In the original GA (Ghosh et al. 2012, reprinted with permission from the American Chemical Society, copyright 2012) the main blocks of the polymer (PLGA and PEG) are difficult to see. In the redesign, these blocks are enlarged and coded with both shape and color to enable faster visual recognition.

a

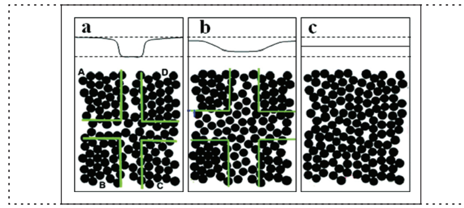


ORIGINAL
Figure is too complex to quickly scan and understand.
Too many arrows and containers clutter the layout.

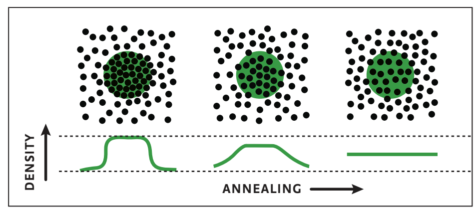


REDESIGNED
GA was edited to focus on active self-assembly in a single row.
Boxes were removed and arrows simplified.

b

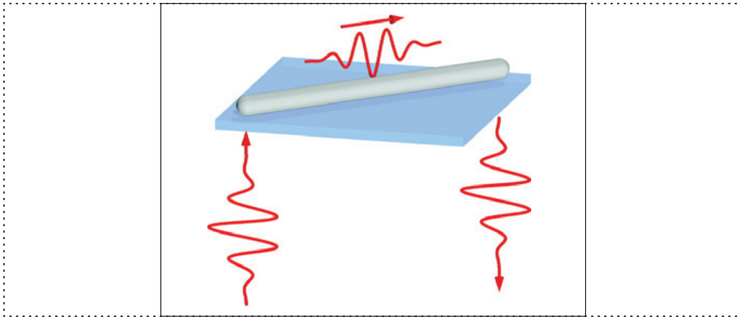


ORIGINAL
Upper graph is hard to understand without labels.
Too many interior boxes clutter the layout.



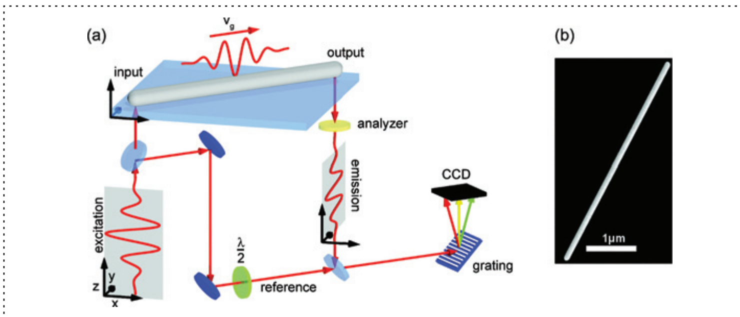
REDESIGNED
The line graph has been labelled directly.
Boxes were removed, and groups created with alignment.

Figure S5. *Removing "Chart Junk" from Graphical Abstracts*. Both of these original Graphical Abstracts (Idan et al. 2012 and Fang et al. 2012, both reprinted with permission from the American Chemical Society, copyright 2012) are cluttered with chart junk (Tufte 1983)—decorative boxes, rules and frames that are unnecessary to communication. Removing chart junk allows the actual content to be more legible and therefore, more important.



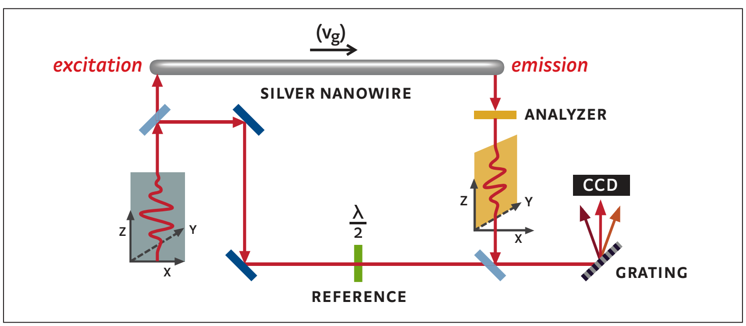
ORIGINAL

Image lacks content and context; viewers may not understand what this image means.



ALTERNATE FIGURE

The GA is a cropped version of a larger figure included in the main paper, shown above.



REDESIGNED

The final revised Graphical Abstract: A simplified version of the experimental setup.

Figure S6. *Redesign of a Graphical Abstract Lacking Content and Context*. The original GA (Rewitz et al. 2012, reprinted with permission from the American Chemical Society, copyright 2012) is a cropped version of a larger schematic. While the larger schematic is too complex to function as a GA, the cropped version (showing a single silver nanowire) fails to communicate the key finding of the paper - that far-field spectral interferometry can be employed to fully characterize ultrafast plasmon pulse propagation on silver nanowires. In the revised GA, a simplified version of the experimental setup is used to more clearly communicate this finding.

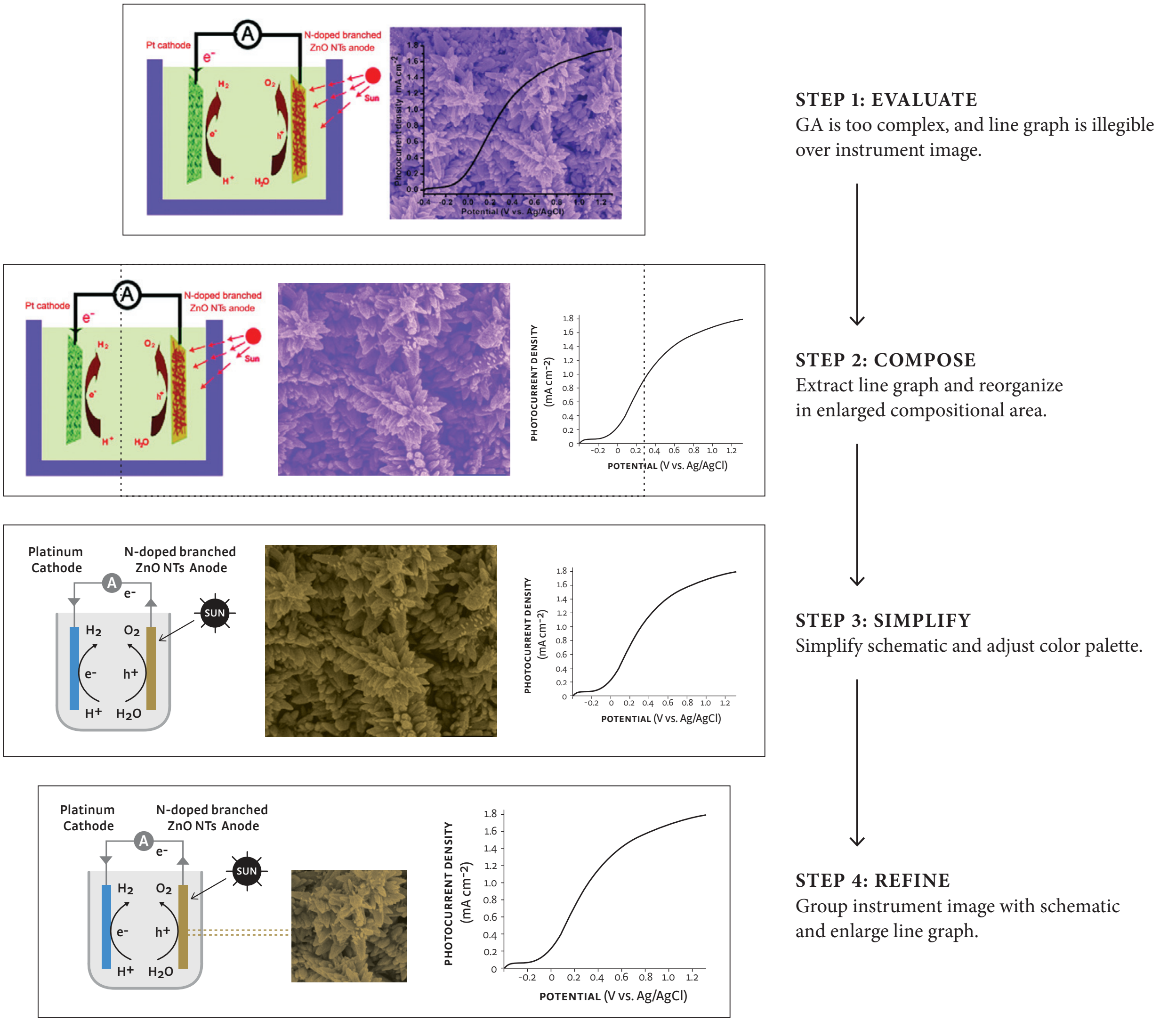


Figure S7. *Redesign Process for a Graphical Abstract*. The original GA (Qiu et al. 2012, reprinted with permission from the American Chemical Society, copyright 2012) is a schematic showing the experimental setup. However, this design fails to highlight the key result - the development of a photoanode that yields significantly increased photocurrent density. Instead, the purple container (which is inconsequential) is highlighted and uninten-tionally linked to the purple instrument image. In the redesign, the anode is made visually prominent, and is connected to the instrument image with color and graphic lines.

Selective Control of Gliding Microtubule Populations

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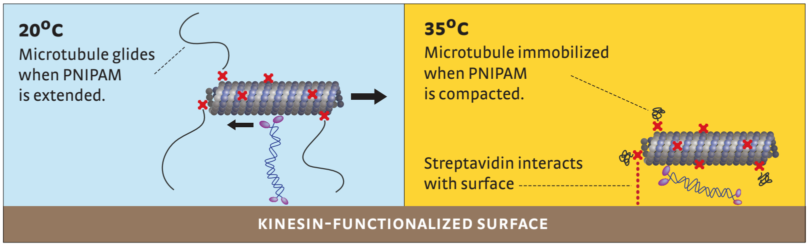

Please rate the following statements about the visual shown above:

	DISAGREE					AGREE
I have a sense of what this paper will be about.						
The paper seems interesting.						
The authors seem intelligent.						
The paper will be clearly written.						
The title and figure make sense together.						
The science in the paper is rigorous.						

Figure S8. *Table of Contents Summary Shown via Online Survey to Research Participants*. Research participants completed a survey consisting of ten webpages. Each webpage showed either the original GA or the revised GA as it would appear in a summary view on the Table of Contents page of the *Nano Letters* website. This figure shows a single survey webpage with a revised GA. Below each summary view, participants were asked to indicate their agreement with six statements on a seven point Likert scale (Likert 1932).