The Rhetoric of (Interdisciplinary) Science:

Visuals and the Construction of Facts in Nanotechnology

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Since Jeanne Fahnestock's challenge in 2007 for increased attention to the role of visuals in science, interest in the relationship between images and rhetoric has grown, both generally and in rhetoric of science (Hope, 2006; Fleckenstein et al, 2007; Edwards and Richards, 2008, and others). Rhetoricians of science including Alan Gross (2007; 2014) and Don Idhe (2007), among others, have responded, generating insight into the function of visuals in science research. Some of this work has explored the contributions of visuals in specific disciplines (for example, Gross has looked at visuals in biology, chemistry, and geology); other work has explored the function of visuals across disciplines (for example, Idhe has drawn examples from medicine and physics to theorize the degree of complexity in the relationship between visual representations and "reality").

This work has enabled a better understanding of how images contribute to knowledge generation in science. While this work draws from published images from historical scientific discoveries, it also focuses on disciplinary science such as biology (including medical images) or physics. So far researchers have not explored how interdisciplinary fields in science such as nanotechnology employ visuals. The newly emerging field of nanotechnology brings together expertise from a range of areas. For example, studying prion (protein misfolding) diseases such as Alzheimer's disease and Creutzfeldt-Jakob disease [CJD] in humans; bovine spongiform encephalitis [BSE] in mice, sheep, and cows; and chronic wasting disease [CWD] in cervids [deer, elk, and caribou] combines expertise from physics, chemistry, biology, medicine, veterinary medicine and engineering. Research on third generation solar cells requires expertise from chemistry, physics, and engineering. The methods used to answer research questions about scientific phenomena at the nanoscale (smaller than 100 nm or 10^{-9}m) are interdisciplinary, and the data derived from these methods

combine aspects from multiple disciplines to create an interdisciplinary discourse. The data is predominantly visual, taking the form of graphs, tables, charts, electron micrographs, and illustrations.

In this article, I examine the relationship between visuals and text in nanotechnology to show how images and data displays contribute to the argument in experimental work to create knowledge in science. Through the analysis of two journal articles, I propose some answers to these two questions:

1) What characterizes the types of visuals used in nanotechnology?

2) What role do visuals play in argument and the creation of knowledge in nanotechnology?

From the articles under analysis, I offer some tentative observations about nanotechnology as an interdisciplinary field that is still developing the norms of its discourse.

I analyze the relationship between the text and visuals in two articles published in *Biochimica et Biophysica Acta* journal, one on gold nanoparticles (GNPs) in cancer cells (hereafter referred to as BB1) in 2013 and the other on the binding mechanism between phthalocyanine tetrasulfonate (PcTS) and natively (healthy) folded prion protein (PrP^C) (hereafter referred to as BB2) in 2012. The experiments being reported on in these articles were part of a research project I conducted as the Scholar in Residence for Arts Research in Nanotechnology at the National Institute for Nanotechnology in Edmonton, Alberta in 2011.

This essay moves in four stages: First, I review relevant theory associated with the functions of visuals in disciplines in science. In the next section, I show how the combination of disciplinary methodology and equipment yield the research questions and the results/visuals used in these articles. With a firmer sense of the derivation of the visuals, I analyze their role in *BB1* and *BB2* in building the arguments to create the contributions to knowledge in each article. Finally, I conclude that in nanotechnology an interdisciplinary (textual as well as visual) discourse is still emerging from the combination (or clash) of disciplines.

Theory, 'Mathematization,' Representation, and Disciplinary Use of Visuals

Alan Gross argues that visuals in 19th century science evolved from representing real phenomena, for example, the actual mountains resulting from real volcanic activity, to representing a theory—that is, how mountains in general are formed from volcanic eruption (Gross, 2007, 61). Gross notes that words and pictures together served to reveal and explain scientific phenomena better than either did alone. In detailing how visual-textual representations came to depict theory over, for example, species identification, he argues that the former representations included details salient to the point. Gross argues that by combining verbal argument, visual presentation, and metaphorical representation, Darwin uses his diagram of the divergence of species as both a "depiction of evolutionary theory" and "an argument in favor of that theory" (Gross, 2007, 67). Gross goes on to argue that scientific diagrams can "be viewed as units of selection in conceptual evolution," that is, when visuals embody a theory they serve as evidence in support of its validity (Gross, 2007, 72). Gross and Joseph Harmon argue that diagrams in science are "not a means of looking *at* the world, but a means of looking *through* it to its causal structure" (Gross and Harmon, 2014, 1392, italics in original). Gross and Harmon also make the important point that the interaction between text and visual in science is a "semiotic transformation from the iconic to the symbolic and the indexical" (Gross and Harmon, 2014, 3385); that is, the visual first is iconic, "representing the world", then symbolic, "standing for some aspect of the world," and then indexical, "pointing to causal relationships in the world" (Gross and Harmon, 2014, 613). Gross and Harmon propose a model (enhanced dual coding theory (EDCT)) to describe how visuals in science interact with text to create scientific argument. This research enables us to see how visuals—specific pieces of data—in science connect with the theory that forms a foundation for knowledge in the field.

Various uses for visuals in science have been theorized (Brasseur, 2003; Hope, 2006; Kostelnick, 2007; Wickman, 2011; and others). Lynch identifies "selection" and "mathematization" as the central "practices used to constitute the visible scientific object" (Lynch, 1990, 162). The activity of pairing a photograph and illustration represents the 'selection' process as the one type of evidence is transformed into the other. Goodwin notes that "crucial to this process is the fact that different selective/shaping practices, including filtering, uniforming, upgrading and definition, can be repetitively applied creating not just a single image, but a linked, direction chain of representations" (Goodwin, 2001, 163). Goodwin

defines 'mathematization' as "not simply . . . the use of numbers, but instead . . . the host of practices used to transform recalcitrant events into mathematically tractable visual and graphic displays, for example graphs, charts, and diagrams" (Goodwin, 2001, 163). Goodwin notes that "the contextually based practices of the participants" (who transform a series of experiments into a chart or graph) as a group serve to "accomplish the work that defines their profession" (Goodwin, 2001, 163). Here Goodwin seems to conceptualize professional practice in terms of disciplinary perspective.

Visuals have also been characterized as typifying as well as reflecting specific disciplinary practices. For example, Mishra notes three characteristics of scientific illustrations: first, they rely on "artistic conventions" that give them meaning; second, they are products of the theory or assumptions that they represent, assumptions grounded in ideology; and, finally, that disciplinary knowledge not only shapes but constitutes the nature of scientific illustration: he emphasizes that scientific illustration cannot be understood "in a generalized manner, it must be grounded in the dynamics of a specific discipline" (Mishra, 1999/2004, 193). This last point is intriguing in the context of examining illustration in an interdisciplinary field such as nanotechnology because it suggests that any use of illustration in this field must be negotiated among the discursive conventions of multiple disciplines.

Disciplinary Perspectives Shape Visual Data in Nanotechnology

Both of the research projects reported in *BB1* and *BB2* draw on knowledge, methods, and results from several disciplines—biology, chemistry, and physics and study phenomena at the nanoscale. In the service of exploring these phenomena in this realm, the researchers employ a range of equipment, methods, and expertise from these disciplines, resulting in contributions to knowledge that arise from the interdisciplinary nature of nanotechnology.

Disciplinary perspectives come together in interesting ways to shape how physical evidence is understood in this area. In the case of *BB1*, micrographs make up 3/4 of the evidence (n = 47 separate images) and the calculations (n=6), table (n=1), and graphs (n = 6) make up the remaining 13 visuals. Most of the images are cells and/or GNPs, showing the strong influence of what constitutes evidence in biology. Most of the mathematical visuals support the images by confirming or adding information about the cells, the GNPs or their association. The micrograph images, by virtue of their 'unmediated' presentation of reality, strengthen the claim that the cancer cells internalize the GNPs (and all the claims that follow)

and simultaneously strengthen viewer presumption that the association between the GNPs and the cells exists and in the manner argued.

In the case of *BB2*, the visuals consist of two drawings (because images of the 'real' are unavailable), one table, and 10 graphs, the latter presenting highly processed statistical data. The illustrations are artists' rendering of the concepts meant to communicate simplified information, while the table and charts present complex, highly mediated information that require significant viewer background knowledge and engagement to communicate meaning. The graphs demonstrate the strong influence of what constitutes evidence in physics; the illustrations reflect the focus on molecular structure (of PcTS) from chemistry and the DNA structure (the aromatic residues on the PrP^C) from biology or proteomics. At the same time, the objects of study (using physics methods) are the prion proteins (nanobiology) and their binding mechanism with PcTS (chemistry). *BB2*, in particular, combines methods and visual evidence from across these disciplines to generate an interdisciplinary answer to the binding mechanism question. Clearly, what constitutes evidence in nanotechnology is somewhat broader and more complex than within any of the single disciplines upon which it draws.

BB1 and *BB2* demonstrate how disciplinary thinking shapes both the nature and conceptualization of the research questions, the methods used to answer the questions, and the types of answers that are proposed. Both articles share a biological basis as they explore disease-related agents (A549 cancer cells and misfolded prion proteins) with the long-term goal of potential treatment. The authors of *BB1* explore first, how coating GNPs (which are toxic) with a lipid improves their biocompatibility and then, how they interact with the cancer cells. These cells must be cultured, the coated GNPs introduced into the cancer cell environment, and the process recorded and measured whereby the cancer cells internalize the GNPs. This research uses living organisms, so methods from biology are used to grow the cells and to study and record the interaction process. Methods from chemistry are used to encapsulate the GNPs and then verify the coating. These methods then yield the visuals used to support the proposed interpretation. The activities that create the results presented in *BB1* resemble those described by Chad Wickman: "This bringing-forth [of the result] is less a mode of revealing or discovery than it is a process of invention through which scientists generate meaning and persuade themselves and others that the artifacts they have created offer a legitimate contribution to existing knowledge" (Wickman, 2012, 38). In a different article, Wickman further describes this ontological process: "The scientist . . . literally brings new materials

into the world—ones that do not occur in nature—while confirming their material and conceptual 'reality' through a series of technical procedures and textual documentation practices" (Wickman, 2010, 284).

The authors of *BB2* use the perspective of physics to study the binding mechanism between PcTS and PrP^C, a topic of interest to biologists and prion researchers. In doing so, they use physics methods to measure the thermal energy generated by biological (the prion protein) and chemical (the PcTS) phenomena. The graphs generated are typical of physics research, but the focus and the broader context for this work are entirely outside the disciplinary boundaries of "physics."

While the nature of the research question may dictate the methods and equipment used to answer it, methods and equipment also shape not only the kinds of question that can be asked but also the nature of the data and the form of display used to represent them in the answers. When they present results generated from what are perceived by some readers to be non-traditional (because they are non-disciplinary) methods, researchers generally have to construct their argument differently (than when they write for disciplinary colleagues) to persuade readers who are unfamiliar with the methods that generated the data. One scientist notes the necessity to include additional context "and explain it in as simple a way as possible and sometimes it loses some of the subtleties." (Unpublished interview, March 16, 2011).

In the next two sections, I explore how visual representation, as manifested in *BB1* and *BB2*, can sometimes constitute the evidence that develops and supports the claims, how it can also constitute the claim itself in some circumstances, and how it can sometimes form simultaneously the foundation for and the structure of the new knowledge.

Seeing is Believing: Transforming Argument Into Scientific Fact in *BB1*

In "Lipid-coated gold nanoparticles promote lamellar body formation in A549 cells," published in *Biochimica et Biophysica Acta* (2013), or *BB1*, the authors use visual representations of their data to accomplish a complex range of activities from informational to rhetorical to ontological to epistemological.

> By "***informational***," I mean that the visual representation primarily provides an explanation or background to educate readers about a relevant method or calculation.

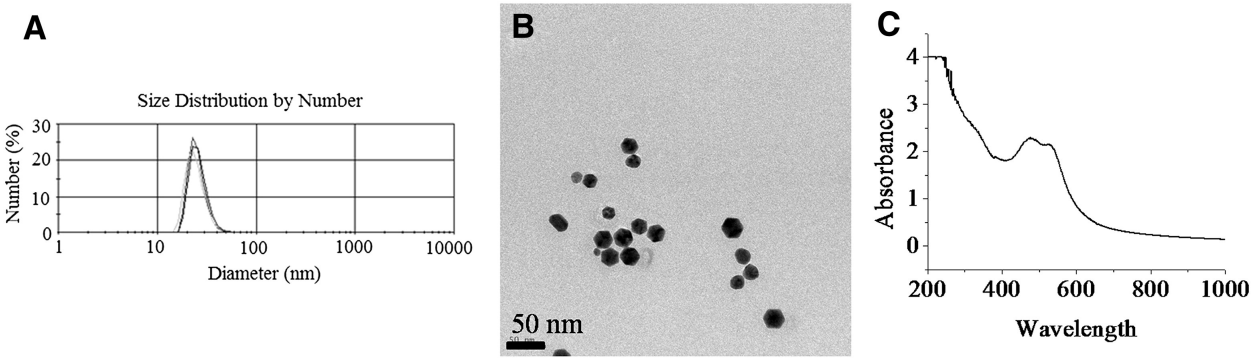
> I define "***rhetorical***" as the role visuals play as evidence supporting argumentative claims or persuading readers of the validity of the interpretation offered for the data.
>
> By "***ontological***," I refer to the visual's role in instantiating (serving as visual "proof") that the scientific phenomenon exists/is real.
>
> I use "***epistemological***" to refer to the visual's role as the argument transforms it into a knowledge claim that reciprocally strengthens the argument.

The first visual in *BB1* and all references to the visuals appear in the Results section, which is divided into four subsections. Each subsection heading is an argumentative claim—the conclusion for the results presented there. For example, the first subsection, "3.1 SOPG [the phospholipid bilayer] coated GNPs [gold nanoparticles] are internalized by A549 [cancer] cells" announces the result that the cancer cells ingested the GNPs (Wang and Petersen, 2013, 1091). First, the authors briefly describe the method used to coat the GNPs. They present evidence that the GNPs were successfully coated in *BB1* Figure 1, a triptych reporting data collected using three different methods. (See Figure 1 below.)

BB1 Panel 1A, a graph, illustrates the size of the GNPs measured using dynamic light scattering (DLS): "We reproducibly obtain a narrow size distribution of SOPG coated GNPs with a peak corresponding to 20-30 nm diameter particles" (Wang and Petersen, 2013, 1091). DLS technology enables scientists to measure the size of molecules and particles. This data, created through measuring light intensity and transforming it by mathematical calculation into the data shown in *BB1* panel 1A, exemplifies Lynch's concept of 'mathematization' (Wang and Petersen, 2013, 1990). At the same time, these data also reflect the reality of the samples that they characterize: the authors note that their "narrow size distribution" is 'reproducible' (Wang and Petersen, 2013, 1091). In addition, the data in *BB1* Figure 1 perform multiple functions beyond presentation. *BB1* Panel 1A presents DLS data that supports the argumentative claim that the researchers have created GNPs, a rhetorical function. The chart that indicates the size of the GNPs simultaneously confirms that they exist, an ontological function.

BB1 Panel 1B (central panel), a micrograph from a transmission electron microscope, supports the DLS data with photographic images of the GNPs. These images are eyewitness testimony to the

particles' shape and size, affirming their existence: readers see the hexagonal shape and estimate the size using the scale. This testimony triangulates the size calculated from the DSL data in 1A and adds to the persuasiveness of the argument. Hanson argues that microscope images allow "viewers to imagine similarities between the world they know and what the microscope images describe," a trope that she identifies as "subdivisible worlds" that lend "authenticity" to "descriptions of objects unverifiable by the unaided eye" (Hanson, 2012, 65). Hanson details the manipulation required to produce a micrograph images (Hanson, 2012, 68).



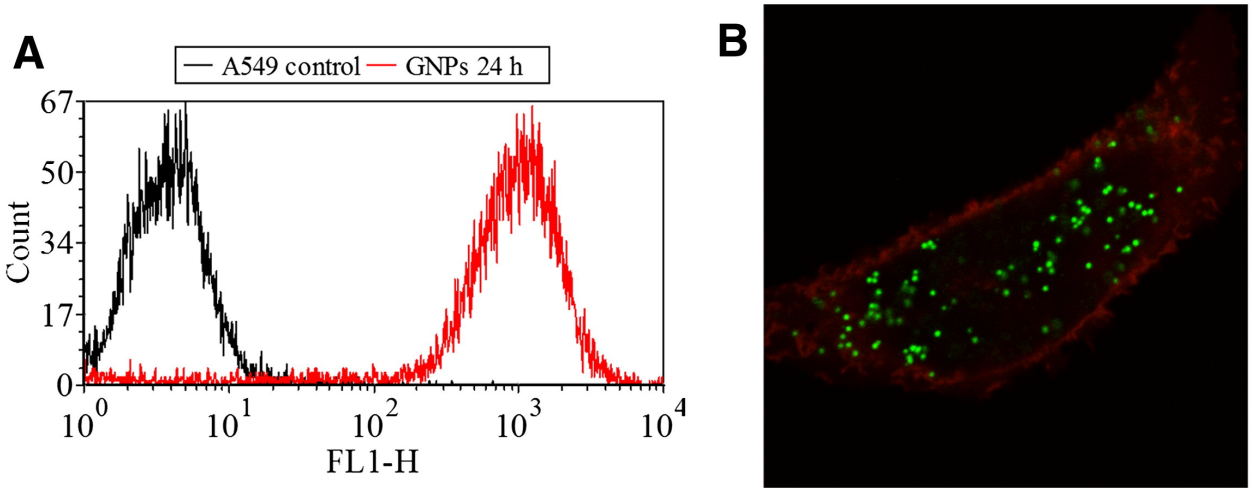
Caption (Original): Characterization of SOPG coated GNPS. (A) Size distribution of SOPG-GNPs in water from dynamic light scatting (DLS). (B) Examples of SOPG-GNPs observed by transmission electron microscopy (TEM). (C) The UV-vis absorption spectrum of SOPG-GNPs shows two absorption bands at 470 nm and 530 nm.

Figure 1 (Graves): A triptych presenting data collected using three different methods.

BB1 Panel 1C, a second graph, represents the UV [ultraviolet] visible spectrum derived from UV-vis absorption spectroscopy. These data indicate the presence of the coating (NBD) (the first peak at 470 nm) and the GNPs, the second peak at 530 nm. This graph also confirms the size (20-30 nm) of the GNPs from other tests. Each visual presents a new mode of evidence that strengthens this subsection's claim—the GNPs are lipid-coated. This tryptych highlights the image in the center, a position of emphasis where the micrograph appears larger and more important that the graphs. Since it's an image, readers can see for themselves that the GNPs exist. The mathematical data flank the image, supplying information about the size and composition of the GNPs and reinforcing that they exist. These visuals are evidence that supports the first half of the argumentative claim—that the GNPs exist and that the lipid coats the GNPs.

Evidence for the second half of the argumentative claim uses a similar strategy of combining mathematized and micrographic representation to show that the cancer cells internalized the GNPs

(See Figure 2). In the confocal micrographs, viewers can see for themselves that the green GNPs are contained wholly within the cell wall—the red outline of which is clearly visible.



Caption (Original): The interaction of SOPG coated GNPs with A549 cells. (A) Histogram of the number of A549 cells with a particular fluorescence count for untreated cells (black) and cells treated with NBD-SOPG-GNPs (red). The histogram shows that the mean fluorescence increased nearly 1000 times after 24 hour treatment. (B) Confocal image of NBD-SOPG-GNPs (green) showing that the nanoparticles were readily taken up by the A549 cells and at 24 h none were associated with the surrounding the cell membrane (stained by DiI in red).

Figure 2 (Graves): BB1 Panel A presents statistical data to support the claim that the cancer cells internalized the GNPs; Panel B is a metonym that *shows* this 'fact.'

These representational images are "isomorphic" in that, with some clarification of what viewers are looking at, they can "see" for themselves—both the shape and size of the GNPs in Figure 2B and inside the cell in Figure 2B (Idhe, 2007). This representation is powerful because viewers tend to believe what they see with their own eyes. In fact, observations from my study of research in nanotechnology suggest that many readers will be so firmly immersed in the technology and methods that generate the data that they tend to experience the micrograph images as *unmediated* representations of reality. In contrast, mathematized displays require understanding the "hermeneutic techniques" that yield this data, but for readers who understand it, the graph data and the image create a synergistic persuasive process (Idhe, 2007). At the same time, Wickman has pointed out that these activities (interpreting both micrographs and mathematized data displays) are, in fact, *reading*, which he notes is "a highly trained skill that few people outside the scientific community would be able to understand" (Wickman, 2010, 276).

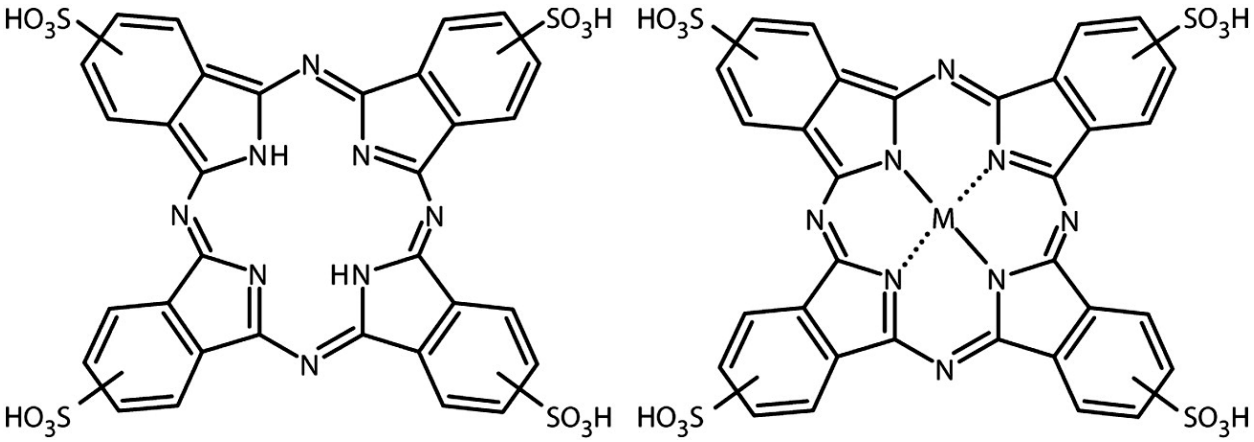
In discussing the modality of visuals in science, Jewitt and Oyama note that photographs are often seen as reflecting reality (as in 'what the eye can see') (Jewitt and Oyama, 2001). The micrograph in Figure 2 is an example of this modality, presenting as it does an individual cancer cell that has internalized GNPs. Jewitt and Oyama distinguish between the reality of photographs and that of figures and charts, which reflect a different type of reality—one that represents "how things are in general, or regularly, or according to some deeper 'hidden' truth" (Jewitt and Oyama, 2001, 151). They point out that scientific images generally omit details including background, irrelevant details, and texture or color. The more detailed and naturalistic a diagram is in science the less it is seen as reflecting reality, according to Jewitt and Oyama. The micrograph in the GNPs article might be argued to combine these two types of reality. It depicts the specific (i.e., a single cancer cell) but it also represents the general: this metonymic cell signifies that lipid-coated GNPs are non-toxic to cancer cells. This image was produced through skillful laboratory work involving multiple steps, so it is not the reality commonly captured in photographs: it lacks background, irrelevant details, texture, and color. Instead, it more closely resembles the complex calculations that yield graphs and is more akin to their "deeper, 'hidden' truth" than photographs; this combination of representational and "scientifically real" gives the micrographs their ontological and epistemological (and ultimately) rhetorical force.

The headings in the Results section are stated as argumentative claims and then transformed into knowledge claims through skillful arguments forged out of data. Each piece of evidence presented connects to the argument claim—the GNPs are coated with the lipid; the A549 cells internalize the coated GNPs. The evidence, both visual and textual, transforms the claim from argument (a contingent proposition about a natural phenomenon) to knowledge (a statement of fact about a natural phenomenon). From one subsection to the next, the argument claims become knowledge claims, and the knowledge claims become a convincing interpretation of the data—the knowledge claims become scientific facts (i.e., new knowledge). In *BB1*, the argument takes place largely in the 'Results' section through the presentation and discussion of the visuals. Consequently, the 'Discussion' deals not with the meaning of the results but with their larger significance in the field, directions for future work, and their potential for improving future cancer diagnoses and treatment.

In contrast, the second article, *BB2*, uses a different argument structure. Instead of working out the argument through the 'Results' section, the authors of *BB2* assemble their argument in the 'Discussion' section from the discrete results already presented.

Assembling Puzzle Pieces: Hermeneutics and Transformation of Data Into Argument in *BB2*

In *BB2*, "Phthalocyanine tetrasulfonates bind to multiple sites on natively-folded prion protein," the visuals perform similar functions but are distributed across three of the five sections rather than being presented in a single section (as in *BB1*). The 'Introduction' contains the first figure, a line drawing depicting the molecular structure of free-base (contains no metal) and metallated forms of PcTS (See Figure 3). This drawing supports a discussion in the 'Introduction' that summarizes published research investigating forms of PcTS as agents for preventing and treating prion disease in sheep (scrapie). Of these forms, the research found that free-base PcTS has "anti-scrapie effects" in live mice (Dee *et al*, 2012, 826). The drawing depicts the bonding structure of PcTS: at the center of each structure are, respectively, an empty space and a metal ion. The two structures are relevant to this study that explores the binding mechanism of PcTS and PrP^{C}(90-232) native-folded prion protein. This illustration is primarily informational,



Caption (Original): Structure of phthalocyanine tetrasulfonic acid, in free-base (left) and metallated (right) forms.

Figure 3 (Graves): Line drawing depicts the molecular structure of free-base and metallated forms of PcTS, the focus of the results reported in the article.

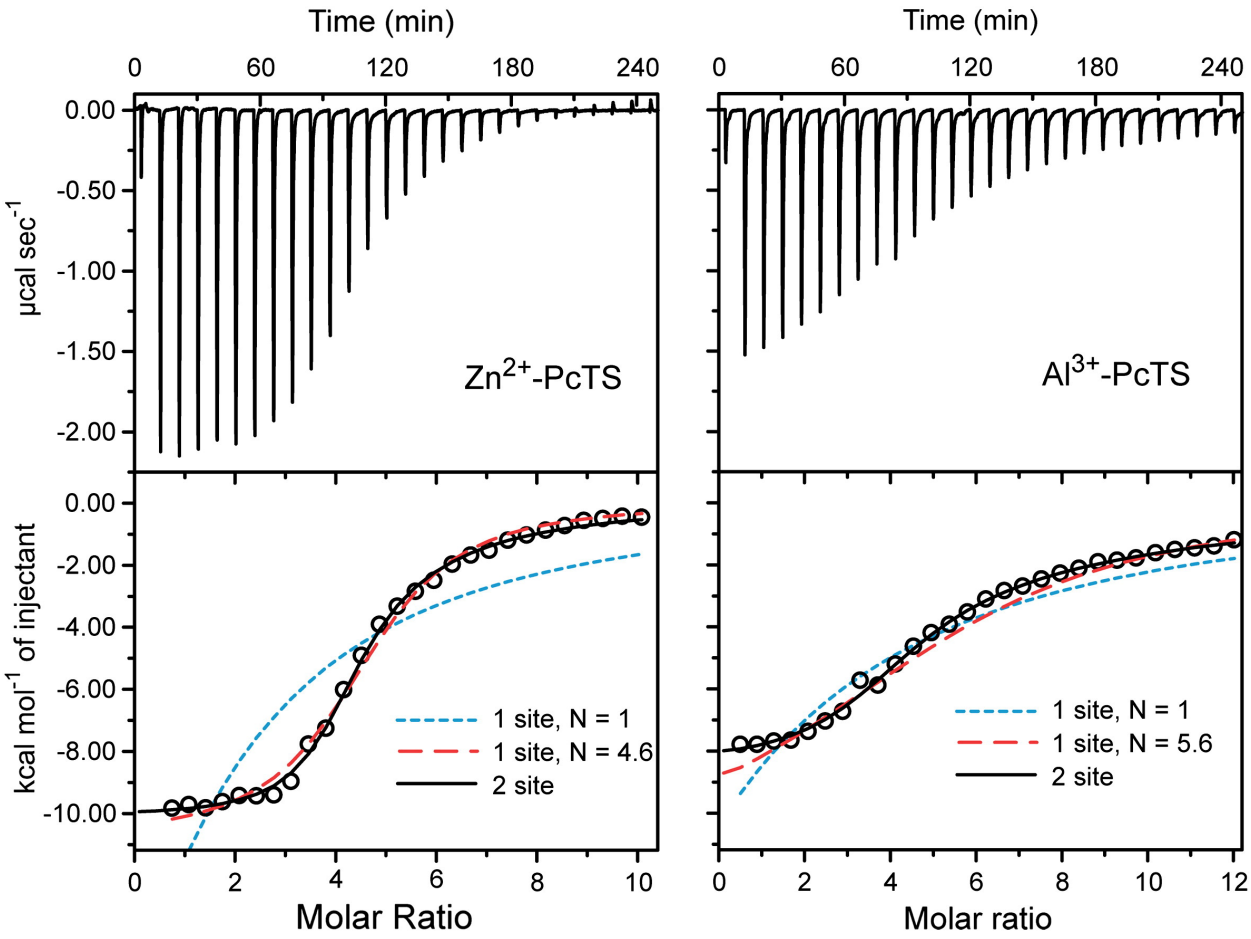
educating readers by showing the structural differences between the two molecules. It also reflects the interdisciplinary nature of this work and its readership because neither biologists nor physicists may be as familiar as chemists with the bonding structure -- but that structure is relevant to the article's argument.

Most of the visuals in this article are mathematical, generated through measurements using sophisticated equipment and complex calculations. Thus, the data do not create the same experience for

readers of 'unmediated' images of the 'real' as did the micrographs in *BB1*. In contrast, the visuals in *BB2* serve as facts or 'signs' that do not, in and of themselves, point explicitly to the conclusion. Instead the authors discuss the broader context for their data more extensively, bringing in specialized knowledge of biological and physical concepts related to prion research to explain the data's meaning and the implications of each piece of data for understanding the binding mechanism.

The 'Results' section in *BB2* has descriptive (not argumentative) headings. Its argument relies heavily on the text. Each visual contributes evidence or knowledge/facts measured by the equipment during experiments, but in each sub-section the result basically stands alone. For example, subsection 3.4, "Isothermal titration calorimetry," discusses the data presented in *BB2* Figure 4. The first sentence describes one step of the experiment (results from measuring the heat produced as the PcTS bonded to the PrP^C). The second sentence identifies the contents of and refers readers to the figure. The authors then comment on the graphs: "Interestingly, the heat produced per mole of ligand has an asymmetric shape rather than the symmetric, sigmoidal shape which would be expected for a single type of binding site" (Dee *et al*, 2012, 829). This statement alerts readers that the data are not as expected, and most of the rest of the section then explains the authors' efforts to fit the data to a model. The data had made them rethink their assumption of a single binding site because a two-site binding model fit better (the solid black line in the bottom graphs).

In the 'Discussion' section of *BB2*, the authors discuss the binding site data in a broader context. They discuss the multiple binding sites on the type of prion protein in their study, and they explain how this knowledge relates to other research on PrP binding. They then summarize several possible explanations that have been published to explain the binding mechanism, including "the hypothesis that the binding is mediated by aromatic residues" (Dee *et al,* 2012, 831). At this point, they discuss the specific biology of the Syrian hamster PrP^C that they have used to show how the theory connects to their data: "SHPrP(90-232) does indeed contain many aromatic groups . . .. Intriguingly the aromatic



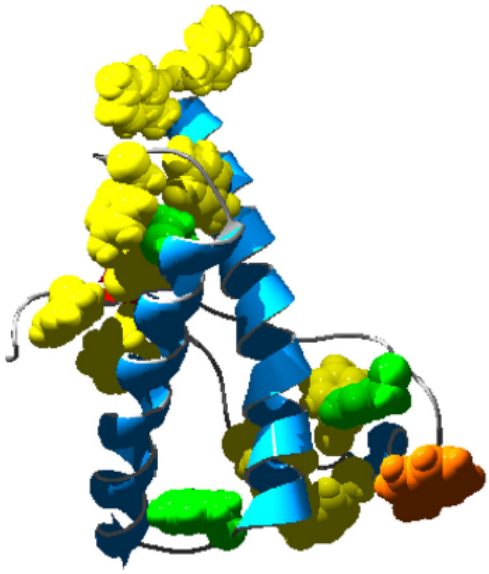
Caption (Original): Binding of PcTS to PrP^C measured by ITC. PrP^C was titrated with either Zn^{2+}-PcTS or Al^{3+}-PcTS in 10 mM phosphate buffer, pH 7.0. Top panels indicate the baseline-subtracted heats of injection. The corresponding integrated heat of injection is shown in the bottom panels, along with fits to different models: 1 binding site with stoichiometry of 1 (blue, short-dashed line), 1 binding site with variable stoichiometry (red, long-dashed line), and 2 binding sites with stoichiometries of 4 and 1 respectively (solid black line).

Figure 4 (Graves): In the lower two graphs, the blue dotted line shows the 'expected' curve if a single-site binding model is applied to PcTS and the PrP^C; the black solid line shows the curve if a two-site binding model is applied to their data.

residues located within the structured domain of SHPrP(90-232) (residues 125-228) happen to be positioned in roughly four clusters around the protein . . .." (Dee et al., 2012,831). The data as discussed in the results section indicated at least four binding sites. Here the biology of Syrian hamster PrP^C supports both using a multi-site binding model and the hypothesis that the aromatic residues on the proteins are associated with binding between PcTS and healthy prion protein. This discussion, then, shows how their proposed multi-site binding model fits theoretically as well as numerically the data presented earlier in the 'Results.'

A drawing accompanies this explanation (see Figure 5) of the structure of Syrian hamster PrP^C to illustrate for readers the location of these potential binding sites. The image functions as a metonym, depicting a single prion protein to represent the structure of all Syrian hamster PrP^C, and invoking current theory of aromatic residues. This illustration, like the earlier drawing of the structure of PcTS in Figure 3, serves an informational function that is not directly linked to the authors' experimental results. It shows multiple locations of aromatic residues on the protein, locations that the authors note have been suggested previously as somehow involved in the binding mechanisms with PcTS. It is important to note that this illustration is an artist's rendering of the DNA: no one knows what this DNA looks like yet.

This image also serves as additional evidence, albeit circumstantial, to support the authors' argument that multiple binding sites exist between the PcTS and PrP^C in their samples. They emphasize that the presence of multiple sites as depicted in the drawing fits with the their data, "leading us to speculate that these four regions could be candidates for the four high-affinity sites characterized by ITC" (Dee *et al,* 2012,831). This drawing also strengthens the claim for multiple binding sites because readers can themselves count the numerous sites where binding may occur.



Caption (Original): The structure of Syrian hamster PrP^C (residues 125–228) (PDB ID: 1B10), showing the location of aromatic residues possibly involved in PcTS binding. The aromatic side chains are shown in space-filling form, coloured according to type: Trp (orange), Tyr (yellow), Phe (green).

Figure 5 (Graves): This drawing illustrates the location of aromatic residues that may participate in binding between PcTS and Syrian Hamster PrP^C. It is an artist's rendering of researcher speculation on what this section of the DNA of this molecule might look like.

This illustration is also intended to isomorphically represent the prion protein (Ihde, 2007). However, this drawing differs from the earlier one of PcTS structure (Fig. 3); in fact, it is almost incommensurate with the earlier drawing, although the two visuals are linked. Fig. 3 is a traditional illustration of the chemical structure of the PcTS molecule, while Fig. 5 is a conventional biology illustration of $SHPrP^{C}$. It is unclear how these two drawings could be combined to illustrate the bound state of the two molecules. If we compare the media of these illustrations, we see evidence of a collision between the conceptual framework of chemistry (as it represents molecular structure) and biology (as it represents prion protein structure). This disciplinary gulf would need to be bridged to create a drawing that integrates these two phenomena.

To discuss alternative explanations for the multiple binding sites, the authors introduce background about the chemistry of PcTS to show its complexity. Then they summarize the literature to explain how their results fit into current theory of hamster prion protein structure. They note that the theory "suggests that additional binding of PcTS should take place in the full-length [not truncated] unstructured region [of the hamster prion protein]" and then conclude their results have "confirmed this hypothesis" (Dee *et al,* 2012, 831). This extended discussion brings together the central pieces of evidence (from the data displays and the illustrations) to create a coherent interpretation of the data. It did not emerge from the summary of results but rather from the 'Discussion,' as details from theory and published research were assembled to explain the broader context into which the individual results must be placed to explain what they "mean."

The authors in *BB2* use visuals in ways that differ from those in *BB1*; in both cases the visuals function as critical pieces of evidence that support the argument. While the authors of *BB1* constructed a series of argumentative claims each predicated on the strength of the previous claims, the authors of *BB2* construct an argument that resembles a jigsaw puzzle. The hermeneutic and mathematical nature of the data means that they have to assemble an argument based not only on their data but also existing research and theory from chemistry, biology, and physics to fill out readers' understanding of the phenomena and to explain the nuances of the results within the broader context. The results from the individual graphs and tables are not self-explanatory, nor do they provide a sense of unmediated perception for readers. Instead the authors consider the various alternatives that have been suggested and rule out the ones that their data discount so that the proposed explanation appears the most probable.

When researchers from other disciplines take up some of the central questions of a discipline (for example, biologists' interest in killing cancer cells without harming healthy cells), their disciplinary perspectives and methods afford new viewpoints and insights in response to those questions. Clearly, the background and training of the researchers can facilitate the direction and extent of the inquiry. This is clearly the case in *BB2* where physicists and chemists bring new methods and conceptual paradigms to the study of protein folding. Using these methods, they determine the relationship between the PcTS and the PrP^C to be four or five PcTS molecules to one PrP molecule, an insight that could not be made using traditional biology methods. But it is arguably true of any nascent interdisciplinary field that the direction and extent of the inquiry is transformed by the disciplinary training of the researchers.

Conclusion: An Emerging Field, An Emerging Visual Rhetoric

In this article, I examined how visuals were used in two published research articles in nanotechnology to support the writers' arguments for the data and to argue for the validity of their knowledge claims. The authors of *BB1* used visuals to support the incremental argument they constructed to show that the lipid-coated GNPs were internalized by the cancer cells and then over time eliminated from the cells. The bulk of these visuals were micrographs that purport to present unmediated images of the cells and the GNPs so that readers can verify the authors' claims with their own eyes and experience. In contrast, the authors of *BB2* present data through highly mediated graphs that appear as discrete summaries in the 'Results' section. In the 'Discussion' section, however, the authors place these discrete results into the broader context of existing knowledge in related areas so that the interpretation of the data and what they mean come together through this process in this section. In this analysis I showed how the data displays and visual representations were used for a range of purposes including that of educating the reader, supporting argumentative claims about what the data mean, establishing the existence of the phenomena being studied, and transforming the argument into new contributions to knowledge in these areas. Often, the visuals performed these functions simultaneously. Notably, the informational function is critically important in this interdisciplinary field for readers to grasp the significance of an unfamiliar data display or calculation.

I also demonstrate some of the ways in which the nature of the data displays and the media selected for images arise sometimes out of disciplinary approaches, equipment, and conceptual

frameworks and sometimes out of cross- or inter-disciplinary perspectives. (Inter)disciplinary methods, equipment, and conceptual frameworks can also shape the research questions posed, the experimental methods used to explore these questions and the forms of the answers that are found. However, when the disciplinary conceptual frameworks of readers collide with the interdisciplinary (or cross-disciplinary) methods, equipment, and data displays, authors must make strategic decisions about how best to explain to these readers the nature and significance of their contribution to knowledge. In such cases, writers in nanotechnology are often acutely aware of the necessity to persuade readers of the validity of their methods to authorize the validity of the results and interpretation that they present.

Interestingly, while Mishra noted that scientific illustration "must be grounded in the dynamics of a specific discipline," the examples in *BB1* and *BB2* present visuals that have been associated primarily with a specific discipline yet they stand in sequence with visuals that are in general use in other specific disciplines (Mishra, 1999/2004,193). The act of incorporating these different visual media into a single research article on a topic that spans disciplines can be argued to contribute to an emerging (inter)discipline that produces and is populated by researchers who bring perspectives, understanding, and conceptual/theoretical frameworks from across disciplines. At the same time, the incommensurate drawings in *BB2* highlight the lack of development, at least at this point, of a truly interdisciplinary discourse of visuals in nanotechnology that would enable an illustration of the binding mechanism between PcTS and $SHPrP^{C}$.

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