

# Knowledge hidden in Nuances: From Molecules to Society

## Authors

Michelle Anderson (michelle.anderson@umwestern.edu)  
Katherine Crocker (kcc2153@cumc.columbia.edu)  
Shuchismita Dutta (shuchi.dutta@rcsb.org)  
Neena Grover (ngrover@coloradocollege.edu )  
Angela Horner (ahorner@csusb.edu )  
Loren Hough (hough@colorado.edu)  
Lisa Mangiamele (lmangiamele@smith.edu)  
Talia Moore (taliaym@umich.edu)  
Gail Rosen (gail.l.rosen@gmail.com)  
Kaitlin Stack Whitney (kxwsbi@rit.edu)  
Adam Summers (fishguy@uw.edu)  
Richelle Tanner (richelle.tanner@wsu.edu)

All authors contributed to the discussion below, with individuals listed in headings taking leading roles in disseminating those ideas.

## Introduction

**The Goal:** We have discussed the theme of reintegrating biology several times at the national level over several decades (ex. A New Biology for the 21st Century, National Academy of Sciences, 2009). While these discussions are fruitful and certainly the topic may require an adaptive framework, we suggest a fundamental change in how the scientific community approaches this topic. In particular, we propose that biology can only be integrated when the structural, societal and methodological barriers to participation in biology are alleviated. A focus on the average or most prevalent approach or system - whether it is the structure of a protein, a biological process or pathway, or the average scientist - they all end up excluding observations, people, and ideas. In contrast, we propose a focus on and inclusion of nuances will enable us to examine the boundaries and rarer instances whether of topic or of people, enable us to explore, and learn from diversity that is currently unnoticed and may provide new perspectives, insights about the range of possibilities, and solutions to current challenges. By extending this paradigm to our society, including diverse perspectives and experiences may shed light on how we can learn about new ideas, tools, and resources to enhance our collective toolkits and approach solutions for problems we are addressing.

The paper will compare the benefits of applying a **nuanced** approach at a molecular, cellular, organismal, and population levels and then extend this thinking to science and society. We think

that including individuals and perspectives that are beyond the current majority/mainstream will enhance our understanding and ability to approach/address problems. **Adding nuance to our understanding of science can come from better inclusion and integration.**

The intended audience for our Vision paper includes the National Science Foundation (NSF), academic and research institutions, and society at large. We hope that NSF has the potential to create and support opportunities for multiscale scientific explorations at the edge of the boundary (outside the averages). Knowledge derived from these observations and analyses can inspire new perspectives and/or solutions that are universally usable. Additionally, other Vision groups in the Reintegrating Biology meetings include topics that could benefit from the vision presented here (space, time, resilience, modelling, communication/signalling, networks, animal learning, biocomplexity). Academic and research institutions may utilize the proposed framework to review their institutional policies that directly or indirectly (via access to resources, opportunities etc..) restrict collaborations based on interests and expertise. Our hope for society at large is to consider including, sharing, and respecting diverse perspectives and experiences.

**Broad vision for the vignettes:** The process of doing science relies on existing structural constraints upheld by institutions, funding agencies, and cultural practices established long ago. However, we continue to grow in our understanding of how these structural constraints limit our science - and those who participate in it. In thinking about structure and function in academic biology, our group identified multiple levels on which increasing nuanced understanding and practice can result in more robust, inclusive science. Understanding the **nuances** of structure-function relationships will benefit from fostering inclusivity in language, approaches, scales, study organisms, and cultural backgrounds. While we do not often address the “science of doing science”, it is important to step back and look at who is involved in our community, their contributions, and more importantly who is excluded. Here we outline in a series of vignettes the key limitations (i.e. systemic barriers), our proposed strategies for overcoming them (which may include seeking community perspective), and the resulting benefits the community will gain. These vignettes cover three main topics: what do we value as biology (science), how do we structure education to reflect these values, and how are resources allocated to reflect these values.

**1: Structure and function in research:** Considering multiple perspectives in designing studies and interpreting the data they generate. These vignettes focus on **the practice of research** and ways in which broadening and integrating our academic perspectives can strengthen and revolutionize our work.

- a. Vignette 1.1: Role of Methods in Molecular Science
- b. Vignette 1.2: Role of Culture in Molecular Science
- c. Vignette 1.3: Role of Language in Biology
- d. Vignette 1.4: Role of Ethics in Biology

**2: Structure and function of research:** Considering how institutional structures perpetuate/incentivize/reward the production of particular types of scientists and science. These vignettes focus on how **research, teaching, publishing, and funding institutional structures and cultures ~inside~ science** affect which people and ideas are able to succeed as biologists.

- a. Vignette 2.1: What types of systemic changes are needed at the level of individual institutions to create an integrative biological sciences program?
- b. Vignette 2.2: Teaching - How to train students from heterogeneous backgrounds to tackle big questions in complex biological systems?
- c. Vignette 2.3: What does open access mean? What are the consequences?
- d. Vignette 2.4: Cultural shifts required in funding and their role in professional success

**3: The function of the structure of research:** Considering how the structure of society that biologists are part of ultimately shapes the types of knowledge we seek and the mechanisms of generating knowledge that we perceive as valid. These vignettes focus on how **systemic bias in the cultures ~outside~ of science** affects what we consider to be science.

- a. Vignette 3.1: Research in the mirror maze: epistemological bias limits our understanding of the world
- b. Vignette 3.2: Cultural barriers to interdisciplinary research

**4: Looking forward:** Some ideas for how to try to improve the system.

## **LINKED OUTLINE:**

### [Introduction](#)

#### [Theme 1: Structure and function in research](#)

[Vignette 1.1: Role of Methods in Molecular Science](#)

[Vignette 1.2: Role of Culture in Molecular Science](#)

[Vignette 1.3: Role of Language in Biology](#)

[Vignette 1.4: Role of Ethics in Biology](#)

[References \(Theme 1\)](#)

#### [Theme 2: Structure and function of research](#)

[Vignette 2.1: What types of systemic changes are needed at the level of individual institutions to create an integrative biological sciences program?](#)

[Vignette 2.2: How to train students from heterogenous backgrounds to tackle big questions in complex biological systems?](#)

[Michelle Anderson & Gail Rosen](#)

[References \(Vignette 2.2\)](#)

[Vignette 2.3: What does open-access mean? What are the consequences?](#)

[References \(Vignette 2.3\)](#)

[Vignette 2.4: Cultural shifts required in funding and their role in professional success](#)

[References \(Vignette 2.4\)](#)

#### [Theme 3: The function of the structure of research](#)

[Vignette 3.1: Research in the mirror maze: epistemological bias limits our understanding of the world](#)

[References \(Vignette 3.1\)](#)

[Vignette 3.2: Cultural barriers to interdisciplinary research](#)

[References \(Vignette 3.2\)](#)

#### [Theme 4: Looking forward](#)

#### [Additional Original Notes & Ideas](#)

[What do we value as biology](#)

[How do we structure research and education to reflect these values](#)

[How are resources allocated to reflect these values](#)

[Rather than focus only on model systems, maybe we can benefit from valuing non-model systems? We are seeking nuance. Looking beyond means LEAD WRITERS: Shuchi Dutta - this part is done, at the bottom of the document](#)

[Structure and function in research: \(LEAD WRITERS: Shuchi, Neena, Loren, Richelle\)](#)

# Theme 1: Structure and function in research

*Shuchismita Dutta, Neena Grover, Loren Hough, & Richelle Tanner*

## Vignette 1.1: Role of Methods in Molecular Science

A fundamental feature of biology is that the number of systems to study, and questions to ask of those systems far exceeds the number of researchers. One way the scientific community makes sense of this overwhelming situation is to rely on the data that can be derived using samples, tools, and methods at hand. This has significant benefits, applying developed methods to established systems is typically productive in that knowledge is gained. In contrast, it can be easy to lose sight of the fact that methodological limitations become cultural expectations and values.

For example, consider x-ray crystallography and electron microscopy. These primary structural tools are routinely used to examine the molecular structures of biological macromolecules, their complexes, and assemblies. Because of low contrast in the data collected, meaningful results can only be obtained when either the physical process of scattering or the computational process of image alignment is used to average the data over many molecules. The result is a necessary focus on the average structure. More dynamic domains, that may occur in different conformations during the experiment are typically invisible in these techniques, and macromolecules which are more dynamic overall are seen as non amenable to such structural studies. From a practical perspective, it is true that atomic-level structural information is currently inaccessible for a wide range of dynamic entities. However, the lense given by our averaging techniques suggests that more dynamic regions are less visible and perhaps are also less important. Intrinsically disordered domains were often considered as scaffolds or spacers to be ignored. Methods, such as limited proteolysis that could have been used to systematically identify these regions were used to systematically exclude these regions. Of course, there is no use in trying to crystalize an intrinsically disordered protein, and much to be gained from crystallizing a wide range of amenable proteins. Today we understand that many of these regions play critical roles in protein function and may adopt one or more different conformations in the presence of relevant partner molecules/ ligands/ conditions. Currently, disordered proteins are frequently interpreted through the lense of their potential to phase separate. This perspective is both very productive, and can be excluding of disordered protein behaviors or features that do not fall into this paradigm.

Similarly, our thinking about cells, organisms, and populations are often generalized based on a few samplings. For example, if a biochemical reaction or pathway proceeds in a specific way in one cell/ tissue/ organism it is likely to be the same in other cells/ tissues/ organisms too. More generally, the reductionist approach necessitated by limited time, resources, and methods can be seen in our emphasis on model systems - where the “average” organism is a yeast, fly, worm, or mouse, the “average” biochemical condition is that of an isolated macromolecule in buffer. While this approach may be necessary to begin understanding particular macromolecules, tissues, or biological function in depth, limiting our explorations to only these methods has led to silos in biology and our understanding to be fragmented (because they are based on specific conditions or boundaries).

To overcome these limitations, we propose specifically using the lense of methods development to identify how cultural silos are erected. Specifically identifying the limitations of our methods and technologies can be used to identify conceptual traps that currently constrain our thinking. We propose that we carefully examine these boundaries/ constraints and challenge ourselves to ask questions that transcend these limitations. If we can think beyond the value system that emphasises materials obtained through any particular specialization, and focus on a more systematic approach that acknowledges the weaknesses and limitations of our techniques, we may be able to consider a more holistic picture and reintegrate biology.

## Vignette 1.2: Role of Culture in Molecular Science

In biology, the single gene leads to a single protein with a single function theory corresponds to a time when the society was more hierarchical. The views of a few individuals shaped the way science was conducted, and influenced new directions undertaken by the field as a whole. By training all types of researchers, not just students, to value broad and multidisciplinary perspectives, we can open the previously hierarchical way of conducting science so that there is not just one way to understand mechanisms and process, or structure and function, in biology. For example, as our views have changed, we come to see DNA as a non-linear information that undergoes splicing or alternate splicing to produce the appropriate messenger RNA, a fraction of this RNA can undergo editing (A-to-I or C-to-U or U insertions) to produce increased diversity of proteins (among other things), and the proteins that get produced may have more than one function. Proteins themselves can have unstructured regions that form a defined structure in the presence of specific ligands, whether in signaling, immune function, etc. RNA can have multiple conformers that can be selected to bind to specific ligands and alter downstream functions.

## Vignette 1.3: Role of Language in Biology

The language we use has implication for hypothesis building, experimental design, and data analysis. When we label DNA as a master switch, we may lose perspective regarding the importance of various other molecules involved in the formation of an organism. When we ask students if we could put the genetic material from sperm and egg on a plate with all the necessary nutrients, would an organism form, most undergraduate students think that it would. This is the problem with the way biology is taught, presented in the media and in our popular culture. We can take DNA from a dinosaur and create Jurassic Park. The role of the egg and all the other molecules is undervalued beyond being a bag of nutrients. What aspects of biology are being limited if molecular biologists are not thinking about all the levels at which the molecules play a role. We should think about molecules in the context of cells, tissues, organisms, and ecosystems. With increasing amount of evidence that organisms are interacting with each other in myriad ways and influencing each others' evolution, it requires that the biologist think about and study organisms in a more complex community rather than as individual species. Not only does language have consequences in simplifying concepts in popular culture and basic education, it also creates barriers between sub-disciplines. While we may not consider the use of words like “stress”, “adaptation”, and “resilience” to be metaphors, they mean different things to different audiences. Arguing on semantics of terminology has the potential to hold back clear comprehension and true collaboration in biology, as well as multidisciplinary understanding of diverse topics.

## Vignette 1.4: Role of Ethics in Biology

If molecular sciences are done in isolation without the context of the organism, society and culture then the impact of the research remains out of our grasp. With the revolution in CRISPR-Cas technology, molecular tool of gene editing is now readily available, so much so that organisms can be edited in our garages. If we as biologist do science in isolation it may lead to it being incomplete or worse unethical. We need to continue to learn ethics, more specifically bioethics, to value a broad range of questions, include a large number of perspectives, make our study sample be representative of the populations being examined, and allow room for feedback and speculation to see multiple dimensions of a given problem. The ethical framework should emphasize cultural and societal inequalities. Scientists need to have broad visions and training, have sufficiently diverse collaborations (including non-scientists and non-specialists), and work from a collective learning perspective. Our goals should include to

“do no harm”. Our current model of hyper-competitiveness may not lead to the most ethical modes of conducting science.

## References (Theme 1)

“Science of Science” DOI: 10.1126/science.aao0185

“Atypical Combinations and Scientific Impact” DOI: 10.1126/science.1240474

Kimmerer, Robin. Braiding sweetgrass: Indigenous wisdom, scientific knowledge and the teachings of plants. Milkweed Editions, 2013.

Family values: Maternal care in rattlesnakes is more than mere attendance.

<https://doi.org/10.1038/npre.2011.6671.1>

“An alternative hypothesis for the evolution of same-sex sexual behaviour in animals”

doi:10.1038/s41559-019-1019-7

<https://www.nature.com/articles/465690a>

<https://www.sciencedirect.com/science/article/pii/S0149763410001156>

<https://science.sciencemag.org/content/364/6443/825>

<https://royalsocietypublishing.org/doi/10.1098/rspb.2019.2047>

Stevenson TJ, Alward BA, Ebling FJP, Fernald, RD, KellyAM, Ophir AG. (2018) The value of comparative animal research: Krogh’s principle facilitates scientific discoveries. Policy Insights from the Brain and Behavioral Sciences. 5, 118-125.

<https://www.sciencedirect.com/science/article/pii/S0166223615000053>

<https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019WR025080>

<https://www.lifescied.org/doi/10.1187/cbe.18-11-0226>

Egginton, W. (1997). The English language metaphors we plan by. Language Policy: Dominant English, Pluralist Challenges, 29–46.

Gentner, D., & Jeziorski, M. (1993). The shift from metaphor to analogy in Western science.

Giannoni, D. S. (2009). Disciplinary values in English academic metaphors.

Kuhn, T. S. (1979). Metaphor in science. *Metaphor and Thought*, 2, 533–542.

Raad, B. (1989). Modern trends in scientific terminology: morphology and metaphor. *American Speech*, 64(2), 128–136.

## Theme 2: Structure and function of research

### Vignette 2.1: What types of systemic changes are needed at the level of individual institutions to create an integrative biological sciences program?

*Talia Moore*

**Departments were split for what seemed like good reasons.** These include, but are not limited to funding, expectations of trainees, group resource needs, and administrative needs. The divisions between the major funding institutions can cause philosophical difference in research approaches within a department. For example, the differing expectations between subfields may affect the training expectations within a department, such as whether students should rotate or be recruited directly into a lab, how a qualifying exam is performed, whether a PI or postdoc mentors graduate students, how long trainees should expect to work as postdocs, and publication strategy. A diverse department would necessarily use a wide variety of resources, which may not all be available in a single building. For instance, molecular, genetic, and cellular techniques require rows of wet benches, specialized imaging techniques. Paleontology and museum specimen preparation requires specialized ventilation and storage facilities. Finally, some subfields would benefit from increased administrative overhead. For example, some researchers benefit more from shared instrumentation which can be supported from overhead.

**Unfortunately, artificial barriers to integration result from split biology departments (Molecular and Cellular Biosciences (MCB) + Evolution/Ecology (EE), vs Integrative Departments) and hamper hiring, education, mentoring, and research.** Here we list a few common barriers to integrative research that result from institutional separation. Some systems can be put in place as temporary fixes that encourage integration, but **the long term solution to many of these barriers would be lumping siloed departments into integrative biology departments.** (Like UC Berkeley or University of Washington). However, increasing size can make departments less functional.

With any division, it can be unclear where the lines should be drawn. If the way the

subfields were divided between departments forms barriers within a department, it may increase polarization, moving away from integration, For example: If department A includes ecosystem ecology and evolution, but department B includes neuroethology, developmental biology, and physiology, this could lead to two very separate factions within department A such that they tend to hire and train more siloed experts. For departments that already have strong factions, there must be a convincing argument to work towards integration. This can be done by featuring renowned integrative biologists in a seminar series dedicated to integration. The department or college could create funding initiatives for inter- and intra-departmental collaboration and integration (like the MCubed grants at the University of Michigan <https://mcubed.umich.edu/>). These integrative partnerships can be reinforced through the collaborative teaching of interdisciplinary courses. Administrators should ensure that professors from different departments to co-teach broad/integrative courses and receive equitable credit for their efforts.

Hiring can be difficult for any department, but closely aligned or related departments may compete for the same candidates. For instance, if a job candidate who is motivated by Evolution/Ecology questions but uses mainly molecular techniques, should they apply to the EE or the MCB department at an institution? The UC Berkeley Life Sciences job posting provides a potential short-term solution. Cluster/group hires can be proposed in which all aspects of biology are welcome, then the departments identify candidates that align well. This can help facilitate co-recruitment with multiple departments and encourage integrative biologists to apply. The NSF can fund studies into hiring practices that enhance integrative science.

For integrative researchers, it is often tricky to balance efforts to earn recognition for their integrative approach with the responsibilities of multiple departments. Co-appointments or affiliations across departments can come with negative repercussions, such as mismatched expectations for tenure, service, and mentorship. The NSF can work towards addressing this problem by funding the formation of interdisciplinary institutes or working groups. Such groups would be non-tenure-granting, can include researchers from multiple departments, and require less service, yet enable researchers from multiple departments to form a community together and receive recognition for their integrative perspective.

Specialized resources designed for specialized departments may not be able to provide the types of infrastructure required for interdisciplinary work. For example, biomechanics, neuroethology, and behavior science require a lot of open/versatile space with ample electrical outlets, capacity for construction and electronics, and specialized sensors, which are not frequently available in buildings specialized for either microbiology or museum-based research. The NSF can help address this issue by providing funding opportunities for universities to invest in multi-disciplinary research facilities that can be used for short periods of time for large experiments. For example, the Concord Field Station at Harvard primarily facilitates

biomechanical experiments, but has enabled large-scale research from the School for Engineering and Applied Sciences, Human Evolutionary Biology, and the Museum of Comparative Zoology, as well as several evolution and behavioral experiments performed by members of the Organismic and Evolutionary Biology department. Researchers come from all over the world to use the shared resources and wide-open spaces available at the Concord Field Station.

Departmental purchasing agreements enable direct billing (or even an in-school “store”) without tax to university accounts, but only for “standard” products. Integrative biology frequently requires non-standard equipment, which puts the onus on the researcher to purchase the equipment (often with tax) and submit a reimbursement (which does not cover tax). If there is a delay in reimbursement, the researcher must live without that money for an extended period of time and may incur credit card interest or overdraft fees. These logistical hardships disincentivize researchers from pursuing ideas that require materials that lie outside of their department’s standard paraphernalia. Potential short-term solutions include make purchasing cards available to students who use non-standard equipment. Funding agencies should also make grant funding available directly to students.

Activity-based budgeting makes it difficult for equitable teaching collaborations between disciplines. For example, because department B ‘owns’ a course and gets credit for the seats filled, Department A may not reward a professor for co-teaching an integrative course with professors in Department B. Departments can address this issue by making it easier to cross-list courses between departments. Departments can also enable professors to fulfill their teaching requirements by co-teaching with another professor. Finally, it should be possible for the departments both to get credit for interdisciplinary courses.

**Giving grad students independent and sufficient funding (without requiring winning fellowships) enables integrative and collaborative research.** When students do not depend on their PI to provide salary (or a supplement to the salary to account for the cost of living in the area), they have more freedom to choose with whom they work. This makes coadvising easier (no arguments about who is paying for the student), and facilitates shifts towards integrative research. This has the side benefit of helping students leave abusive advisors.

To this end, TAs and department level RAships need to be fungible across departments. When an offer is made it has to include the ability to swap departments seamlessly. This requires negotiation among departments because bad mentoring will lead to admissions that leave.

## Vignette 2.2: How to train students from heterogenous backgrounds to tackle big questions in complex biological systems?

*Michelle Anderson & Gail Rosen*

“I teach students, not subjects” - Bryan Dewsbury

Discovery and progress in the life and social sciences increasingly rely on analysis of a staggering accumulation of data by large and complex teams of scientists (Wuchty et al 2007, Borner et al 2010, Marx 2013). However, very few scientists have been trained to work where computation, math, and statistics intersect with life and social science applications, let alone in critical “soft skills” for effective collaboration such as communication, leadership, and teamwork. In addition, the multiplicity of diverse human perspectives have historically been excluded from the practice of research and learning. This robs both practicing and in-training scientists of the enormous possibility presented by ‘community cultural wealth’ (Yosso 2005) in the form of resiliency, multilingual fluency, communal bonds, social capital, navigating past challenges, and challenges to the status quo. Therefore, there is an unmet demand for scientists who are well-versed in the collection, organization, interpretation, and synthesis of data from multiple disciplinary and cultural perspectives (see Vignettes 2.1, 2.4, and Theme 3). These scientists will be the leaders and enablers of personalized medicine, improving environmental monitoring and remediation strategies, understanding global economic and sustainability trends, and interpreting the large volumes of streaming data from these applications. This is increasingly important when confronting the theoretical and ethical challenges presented by big data studies. To meet the growing demand for scientists capable of working in interdisciplinary and transdisciplinary arenas, it is critically important to prepare the next generation of students with focused training at the intersection of the domain discipline and information/computer science, math, statistics, and cultural studies.

NSF’s Vision and Change in Undergraduate Education in Biology initiative provides context for improvements and remaining challenges to undergraduate interdisciplinary training. Recommendations from Vision and Change emphasized depth over breadth in disciplinary content coverage, which could influence specialization, but also sought to impact equity, diversity, and inclusion and promote networks and collaboration. However, “The sections in V&C pertaining to inclusion and diversity are the least referenced. Overall, parity still does not

exist in undergraduate biology education.” (pg. 17, *Vision and Change: Unpacking a Movement and Sharing Lessons Learned*, 2018).

Interdisciplinarity and transdisciplinarity does mean a bigger investment from students, faculty and institutions. Most undergraduate and graduate programs promote early specialization and reinforce disciplinary and cultural barriers, which inhibits integrated student training in life sciences, data analysis, and cultural systems. Programs should allow a student to specialize but be able to understand how different disciplines can help their problem and how to communicate with researchers in those areas to come up with a solution. For computation/ math/ engineering backgrounds, students should take molecular, cellular, systems biology courses, a wetlab, and even a special biology journal club to learn how concepts are spoken about and for interactive discussion. For biology backgrounds, students should take courses in computation and “math for data science” (numerical linear algebra and statistics). Courses that both students can take are Machine Learning/ Math Modeling, grad-level statistics, databases and group courses where students work to solve problems like learning to work with biodata -- “Intro to Bio Data Science”, and learn to use computation at scale -- “High-throughput Computation for Biological Data”, seminars, and an ethics course. While certain graduate and post-doctoral training programs address inadequate integrative training, these approaches have not taken equal root at the undergraduate level. As a bridge to graduate studies there should be post-baccalaureate classes to address inadequate preparation at the undergraduate level.

The key aspects of such programs are courses that teach through collaborative group projects, where each team can have at least one student specializing in the application domain and one in the computation/math aspects. Through such courses, they can learn to communicate with each other (although they start with different languages) and design solutions together. Such courses will be pivotal. In addition, collaborative PhD theses are extremely important and counterintuitive to the current individualized PhD programs that we have today.

All of these suggestions could add to the length of undergraduate and graduate programs, which costs more money and uses more resources. In addition, research shows that interdisciplinary researchers are penalized (see Vignette 2.4). How do we shift the value system? How do we get universities to invest in these areas that may not have immediate payoffs/rewards or commit to large-scale structural shifts in programs? Motivation for faculty to participate in ongoing professional development and openness to new ways of doing research and teaching should be prioritized. Truly interdisciplinary programs that must be university-wide are difficult to manage and go against some universities budget models like responsibility-centered management (RCM). If not well-managed, it has been shown that ``

interdisciplinary teaching and research being hindered”

(<https://www.luminafoundation.org/files/resources/obf-and-responsibility-center-management-full.pdf>), due to units competing for funding. In this case, funding agencies should give clear incentives to universities to provide support for these programs. With the low funding rates of NSF’s Research Training (NRT) program and no more BD2K training initiatives at NIH, there is little funding that researchers can ask for to accomplish these initiatives. The role of professional societies and meetings in providing educational and professional development to students and faculty may help address some critical training needs, if greater connections with university systems were made.

Broader Impact: Integrated Life/Social Data Science curricula will advance research on several Natural Academy of Engineering's grand challenges, e.g., engineering tools of scientific discovery, restoring and improving urban infrastructure, advancing health informatics, engineering better medicines, providing access to clean water, personalized education, and managing the carbon/nitrogen cycle, as well as address the disciplinary integration demanded for Growing Convergence Research from the 10 Big Ideas for Future NSF Investment (NSF 18-058, NRC 2014)

## References (Vignette 2.2)

S. Wuchty, B. F. Jones, B. Uzzi, The increasing dominance of teams in production of knowledge. *Science* 316, 1036–1039 (2007).

Borner et al. 2010. A Multi-Level Systems Perspective for the Science of Team Science. *Science translational medicine*. Vol 2 Issue 49 49cm24

Marx, V 2013 . The big challenges of big data. 13 JUNE 2013 | VOL 498 | NATURE | 255 - 260.

Yosso, TJ (2005) Whose culture has capital? A critical race theory discussion of community cultural wealth. *Race Ethnicity and Education* Vol. 8, No. 1, March 2005, pp. 69–91

NSF 18-058 Dear Colleague Letter: Growing Convergence Research  
<https://www.nsf.gov/pubs/2018/nsf18058/nsf18058.jsp>

National Research Council (2014) *Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond*

## Vignette 2.3: What does open-access mean? What are the consequences?

*Talia Moore with contributions from Kaitlin Stack Whitney & Richelle Tanner*

Over the past 100 years, advances in communication technology have enabled more rapid and effective collaboration and dissemination of ideas. Until recently, the formal academic pursuit of ideas has generally been limited to those affiliated with universities. A philosophy of “open-access” has developed in response to this classist “Ivory Tower” model of research (<https://www.cs.cornell.edu/~ginsparg/physics/blurb/pg96unesco.html>) in an effort to make scholarly research available to those outside of elite academic institutions. This has resulted in a monumental and rapid shift in the way research is performed and disseminated, which has had both positive and negative consequences. Here, we discuss the nuances of the “open-access” movement as it relates to biological research and integration across disciplines.

Open-Access **publications** make research available to more viewers, but the burden placed on the researchers and institutions to fund the access is not always equitable. Although the NSF and NIH are funded by taxpayer money, there are no requirements to make the resulting research available to those taxpayers. When journals charge university libraries for access to content there is no benefit to publishing more papers. Conversely, when open-access fees are charged for each individual paper, for-profit journals are incentivized to accept more manuscripts to make more money. This could result in lower quality research being accepted (<http://www.asbmb.org/asbmbtoday/201912/PresidentsMessage/>). When for-profit journals expand to increase the number of papers they can accept, the articles are accepted by professional editors who are not currently engaging in discovery. They have incentives to accept research which improves the journal’s impact factor (measured over the previous 2 years), rather than long-term impact on the field (<https://www.biophysics.org/bps-bulletin/scientific-publishing-past-present-and-future>).

Open-access fees to make publications freely available exclude many from publishing in those journals. Adjusting or waiving fees for developing countries is a step in the right direction. Even in developed countries, R1 institutions likely have more resources available to pay these fees than SLAC or M1 institutions. Some journals have standard fees that differ based on currency in which they are paid (<https://www.nature.com/ncomms/about/article-processing-charges>), regardless of the current exchange rates between the countries, which disadvantages researchers in less economically stable economies. BioRxiv is free, but is difficult to sort for topic or quality. Most are posted

pre-revision, so the content may not exactly match the final version. One example of a partial solution to this is the Digital Access to Scholarship at Harvard database (<https://dash.harvard.edu/pages/FAQ>), where revised and accepted pre-publication manuscripts are posted and freely available online (without violating copyright law).

Open-access **datasets** enable collaboration and application of different perspectives to ideas, but we must be sensitive to adverse consequences of sharing some forms of data. Benefits of publishing a dataset can include more independent tests that the data analyses yielded the published results. For example, a student found the mistake in the raw data that claimed austerity was a sound economic policy (<https://www.bbc.com/news/magazine-22223190>). Shared datasets also enabling downstream meta-analyses and more effective training on real datasets. Complementary analyses that provide a richer understanding of the system can also result from shared data.

However, open-ness is not inherently good and can carry risks, often for the subjects/objects of study and not the researcher. Human subjects should be informed about what data will be taken, *and how the data will be shared*, before they can give their consent (see Vignette 3.2). Henrietta Lacks had no idea that her cells would be sent away to other laboratories for experimentation, which is an extreme violation and caused great distress to her descendents (<https://www.washingtonpost.com/news/retropolis/wp/2018/06/25/can-the-immortal-cells-of-henrietta-lacks-sue-for-their-own-rights/>).

Open access data can also be extractive, especially for remotely based scientists studying communities of which they are not a part. For many communities underrepresented in health research, it is important to incorporate data from these communities in order to serve them better. However, researchers should make every effort to inform the communities they study and seek their guidance in how they handle the data collected.

Members of indigenous communities have come up with guidelines to help researchers engage ethically with indigenous communities: “understand existing regulations, foster collaboration, build cultural competency, improve research transparency, support capacity building, and disseminate research findings” (<https://www.nature.com/articles/s41467-018-05188-3>) (see Vignette 3.1). Tribal communities must be informed about the research being performed so that they can help identify potentially adverse consequences for their own communities (<https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.1103904>). Incorporating tribal communities in the review process helps mutual understanding of the ethical and clinical impact of the research (<https://www.nature.com/articles/gim201447>). If a study incorporates data from tribal members living outside of their communities, individual-based consent may not be sufficient.

<https://www.nature.com/articles/s41576-019-0161-z>)

How much “open access” is necessary when we break down barriers to collaboration? Can we restore the power to communities often marginalized by freely available data (without knowledge of consequences) by allowing this sharing of data to happen through collaborative networks instead of in a database without connections to people? “Community rights of refusal” exemplified by Dr Liboiron and CLEAR’s work in Newfoundland demonstrate how research can be done in ways that respect indigenous people

(<https://civiclaboratory.nl/2017/12/29/feminist-anti-colonial-science/>). We can do things like help a community organize and become informed so that the members can collect data and control how they are shared on their own terms (<https://www.nature.com/articles/gim2016111>).

Even for remotely sensed imagery and forest conservation/deforestation, people affected by these studies may be in places/communities far away from scientists (and with less power/resources). If researchers from a developed country travel to remote community to do research, the researcher should find out how to contribute to the members of that community so they benefit an equitable amount. This can happen by forming collaborations with local scientists, hiring students from the region, donating a portion of all collected specimens to a local museum, training in new techniques, etc.

For endangered animals, publishing the locations where they were observed/collected can make them vulnerable to poaching. Museums can store these data and contact the collector to determine whether the information can be shared with other researchers on a case-by-case basis. The curators/collections managers must be careful to omit precise locality data from public databases, but other aspects of the specimen’s information can be shared.

The high cost of specialized equipment can hinder the advance of research in economically disadvantaged communities. Sharing the tools of science at a lower cost can make science more equitable, minimize the opportunity cost of interdisciplinary research, and encourage the invention of new and customized scientific methods.

Arduino, Raspberry PI and many other open source microcontroller and electronic devices have sparked a revolution in electronic development. Initially designed to appeal to electronic hobbyists, such devices have now formed a global community of "Makers" and inventors with accelerating use in industries and professional research. Novel and innovative research requires customised experiments, but it is often hampered by the lack of readily available equipment or sufficient funding. This research need can be addressed with open electronics devices and electronic Do-It-Yourself skills, which provide very flexible low-cost solutions in the lab and field that can be easily maintained and shared among labs, researchers and students. They can further automatise time-consuming tasks in the lab, improve repeatability of experiments and lead to novel and creative applications. Setting up extensive

experimental designs in the field or lab can be a large financial barrier to early career researchers and/or researchers from emerging nations. Open technology can reduce this barrier, but only if researchers have access to support in starting these new endeavors.

Biological equipment may frequently be prohibitively expensive to purchase from standard manufacturers. If designs can be shared online, labs may be able to cut costs, and increase customization, of lab equipment by gaining access to a 3D printer (<https://www.nature.com/articles/d41586-019-01590-z>).

Teaching and developing tools using free software enables researchers with few resources to try out new methods with low opportunity cost. While much of engineering research depends on subscription-based programming languages, such as Matlab, biological programming is generally performed in freely available programming languages, such as R or python. R has become the standard for phylogenetic analyses, in part due to the NSF-funded National Evolutionary Synthesis Center ([https://www.nescent.org/cal/calendar\\_detail.php-id=70.html](https://www.nescent.org/cal/calendar_detail.php-id=70.html)).

Accessibility (meaning disability accessibility) is also an important axis to consider when disseminating information. Often even the US federal government and scientific agencies do not make materials or platforms compliant with ADA or WC3 guidance / best practices. This webinar we're all on isn't very accessible! Google Hangouts has recently introduced simultaneous captioning for group meetings. Perhaps the NSF can fund the formation of best practice guides for conferences and dissemination. A key source of information is "Nothing about us without us" Charlton, James I (1998). University of California Press. ISBN 0-520-22481-7. The NSF should also provide funding for conferences to provide simultaneous captioning and headsets services (The Robotics: Science and Systems conference has recently incorporated simultaneous captioning)

Finally, open-access is not always sufficient: interoperability is key to integrative research. Although data may be public, they may only be available to those with field-specific expertise. This could be due to the way in which they were collected, the way in which they were reported, or the platforms in which they are shared. The iDigBio community seeks to facilitate data sharing and address these issues. For example: Video data have been collected in many different formats over the years. Recently, researchers have been developing a rubric for standardizing the metadata that are reported for such data and providing stable repositories (<https://academic.oup.com/icb/article/57/1/33/3964476>).

## References (Vignette 2.3)

<https://www.cs.cornell.edu/~ginsparg/physics/blurp/pg96unesco.html>

<http://www.asbmb.org/asbmbtoday/201912/PresidentsMessage/>  
<https://www.biophysics.org/bps-bulletin/scientific-publishing-past-present-and-future>  
<https://www.nature.com/ncomms/about/article-processing-charges>  
<https://dash.harvard.edu/pages/FAQ>  
<https://www.bbc.com/news/magazine-22223190>  
<https://www.washingtonpost.com/news/retropolis/wp/2018/06/25/can-the-immortal-cells-of-henrietta-lacks-sue-for-their-own-rights/>  
<https://www.nature.com/articles/s41467-018-05188-3>  
<https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.1103904>  
<https://www.nature.com/articles/gim201447>  
<https://www.nature.com/articles/s41576-019-0161-z>  
<https://civillaboratory.nl/2017/12/29/feminist-anti-colonial-science/>  
<https://www.nature.com/articles/gim2016111>  
<https://www.nature.com/articles/d41586-019-01590-z>  
[https://www.nescent.org/cal/calendar\\_detail.php-id=70.html](https://www.nescent.org/cal/calendar_detail.php-id=70.html)

“Nothing about us without us” Charlton, James I (1998). University of California Press.  
ISBN 0-520-22481-7

<https://academic.oup.com/icb/article/57/1/33/3964476>

## Vignette 2.4: Cultural shifts required in funding and their role in professional success

*Richelle Tanner & Angela Horner*

Funding opportunities in the US (specifically focusing on the NSF here) are often awarded to a select few individuals and continue to support the success of these few members of our community. The perceived and real bias towards favoring large, existing collaborative networks of established PIs is a problem we have yet to solve. There is a bias against topics favored by groups outside of this selective network, specifically topics undertaken by minority groups that may be outside of the traditional fundamental science focus or pertaining to the lives of these minority groups. Additionally, we want to highlight an underlying theme of unsuccessful grant applications across the graduate student, postdoctoral, and faculty levels: interdisciplinary proposals are rarely rewarded, especially when being undertaken by a single or few PI(s). We believe that promoting collaboration across disciplines, institutions, and all levels of academic rank and status will naturally promote fresh approaches to integrating biology.

### *Proposal initiation process:*

The end goal of reintegrating biology relies on funding granted to groups being more prevalent, but we need to restructure the playing field for collaboration in order to facilitate equitable and diverse allocation of funds. Additionally, collaborative grants need to hold a greater benefit for PIs' promotion packages; typically co-authorship of grants is counted less, or not at all for R1 tenure. One methodology that promotes equitable participation by grouping people based on interests, rather than experience (real or perceived), is by opening virtual "playgrounds" in the same manner this NSF Jumpstart meeting was planned. Organizing online meeting places assists PIs in making connections outside of their immediate circles of influence, while also promoting collaboration of *ideas* rather than particular people and institutions. This could also serve to broaden proposals, as many have different interpretations of topics that may be posed as a "playground". In this scenario, PIs could add themselves to a project - or make a new one - in a collaborative virtual space that is hosted by NSF, and post what they feel their contribution/value to the proposal might be. Initial organization could allow PIs to remain anonymous until collaboration is agreed upon to prevent bias. A more radical suggestion is to disrupt the current status quo of collaborative networks that currently get funding. Researchers within like-minded communities (whether grouped by scientific topic or by personal background - education, institution type, socioeconomic background, etc.) collaborate more often, and within a group a select few develop highly-funded research labs. By placing a premium on previous grant collaborations and success, funding agencies like the NSF are creating additional barriers for new, isolated, and/or minority researchers. Grants agencies should not award a "token minority" member, but rather reward novel collaborations, especially those made outside of the PIs' existing community. This could be facilitated by the previously mentioned virtual playgrounds, passively, or by a blind machine learning approach (designed with an inclusive perspective in mind) that actively places PIs in contact with each other based on topic alone - disregarding current funding status, institutional type, and career stage.

### *Review process:*

Taking the risk of a collaborative grant will only be worth it if the review process is restructured to be more friendly and open to such ideas. The review process is plagued by the same problems as grant collaborations; reviewers are biased towards topics/researchers they are already familiar with. Additionally, reviewers often do not reward interdisciplinary work because it is outside of their perceived expertise; thus, truly innovative and cross-disciplinary collaborative grants are not likely to be funded if the review process remains unchanged. A double blind review process for grants based on content alone would alleviate some, but not all of the biases mentioned here. In order to support novel collaborations and ideas, integrative

grants should be reviewed by broadly applied reviewers; that is, researchers who have some expertise in several fields, rather than several researchers each with individual expertise in a single field (the 'silo' effect). Moreover, some researchers who do broad, interdisciplinary work are not being tapped as reviewers potentially because the depth of their knowledge is not seen as sufficient in any one area.

### *Redesign of fellowship opportunities*

There are fewer grant opportunities than ever for students and postdoctoral trainees, yet their perceived value has not changed among academic and research institutions in reviewing applications for jobs and/or tenure. Early success in obtaining fellowship support is often correlated with later success, but some groups are excluded from these prospects because of limited disciplinary topics. Pre- and post-doctoral support before full grant proposals fosters fresh, new scientific ideas essential to the growth of our scientific community, but again the opportunities are lacking. The inability for postdoctoral fellows to serve as PIs on full NSF grants hinders our ability to support new science and promotes a culture of hierarchy, where postdocs are routinely taken advantage of for their ideas and funding potential by PIs. We recommend alleviating the pressure on these fellowship opportunities by allowing any applicant with a PhD to apply for a full NSF grant as PI. Challenges outlined here are in addition to all challenges posed by cultural and systemic barriers in the traditional grant process (see Vignette 3.2). We briefly outline three NSF fellowships (past and present) and their limitations.

- Graduate Research Fellowship: Recent years have seen rules put in place to promote awards to earlier career students (current undergraduates and first year graduate students). However, interdisciplinary proposals are still penalized in the same way that standard grants are by reviewer selection. The difference between grant proposals and this fellowship, however, are in placing barriers to entering higher education and the research field, which is arguably more impactful on our field's progress.
- Doctoral Dissertation Improvement Grant: While this no longer is a viable funding opportunity, it had significant limitations while active. Most notably, some subject areas (e.g. marine sciences) were barred from application as their discipline's directorate ceased funding ahead of other programs. As all predoctoral grants provide, the DDIG was a significant opportunity for an early career scientist to establish their own ideas with support from outside of their PI's lab. In this grant opportunity and the following postdoctoral opportunity, letters from the PhD advisor are compulsory, which can disadvantage students who are discriminated against by their own labs or have an otherwise toxic relationship with particular individuals that have disproportionate control

over their success.

- Postdoctoral Research Fellowship: Even more restricted than the preceding two opportunities, there are often three or fewer subject areas within the biological sciences that are eligible for this fellowship. None of these areas address interdisciplinary themes. These subject areas do not rotate quickly and serve to severely limit the imaginations of early career researchers as they prepare to establish their own labs. Establishing their research programs as faculty members requires existing support and/or a publication record indicative of success in this subject area, which is increasingly difficult as pre-faculty grants are diminishing and restrictive. Additionally, these fellowships are only offered to postdoctoral researchers able to secure their next steps while still in graduate school or in the six months after graduation. This is a disadvantage to students that face barriers in their graduate educational experiences, whether it be perpetuated by toxic lab environments, lack of connections (and mentorship), or personal life choices penalized in the academic environment (e.g. having a baby). The current Broadening Participation opportunity for the PRF is also vague in its implementation of concrete benefits to URMs. Many members of this Jumpstart meeting shared their personal experiences applying for or advising a fellow for this proposal, where they were told that NSF does not review the social impact of these proposals with the same critical reviewer lens as the unrelated research aspect of the proposal. This diminishes the potential impact of the social aspects of these proposals, and continues to enforce the narrative that NSF is only interested in broadening participation if it does not disrupt the status quo and remains secondary to fundamental science research. We recommend incorporating interdisciplinary reviewers in social science to evaluate the ability of these proposals to actively broaden participation in our field and taking into account outside-academia experience in social justice for applicants in this particular category.

## References (Vignette 2.4)

- Bark, R. H., Kragt, M. E., & Robson, B. J. (2016). Evaluating an interdisciplinary research project: Lessons learned for organisations, researchers and funders. *International Journal of Project Management*, 34(8), 1449–1459.
- Bol, T., de Vaan, M., & van de Rijt, A. (2018). The Matthew effect in science funding. *Proceedings of the National Academy of Sciences*, 115(19), 4887–4890.
- Bromham, L. (2017). Curiously the same: swapping tools between linguistics and evolutionary biology. *Biology & Philosophy*, 32(6), 855–886.
- Bromham, L., Dinnage, R., & Hua, X. (2016). Interdisciplinary research has consistently lower funding success. *Nature*, 534(7609), 684.

- Fleischman, R. K., & Schuele, K. (2009). Co-authorship in accounting history: advantages and pitfalls. *Accounting, Business & Financial History*, 19(3), 287–303.
- Freeman, R. B., Chang, T., & Chiang, H. (2009). Supporting "The Best and Brightest" in Science and Engineering: NSF Graduate Research Fellowships. In *Science and engineering careers in the United States: An analysis of markets and employment*(pp. 19–57). University of Chicago Press.
- Gallo, S. A., Sullivan, J. H., & Glisson, S. R. (2016). The influence of peer reviewer expertise on the evaluation of research funding applications. *PLoS One*, 11(10), e0165147.
- Langfeldt, L. (2006). The policy challenges of peer review: managing bias, conflict of interests and interdisciplinary assessments. *Research Evaluation*, 15(1), 31–41.
- Laudel, G. (2006). Conclave in the Tower of Babel: how peers review interdisciplinary research proposals. *Research Evaluation*, 15(1), 57–68.
- Li, E. Y., Liao, C. H., & Yen, H. R. (2013). Co-authorship networks and research impact: A social capital perspective. *Research Policy*, 42(9), 1515–1530.
- Lungeanu, A., Huang, Y., & Contractor, N. S. (2014). Understanding the assembly of interdisciplinary teams and its impact on performance. *Journal of Informetrics*, 8(1), 59–70.
- McLeish, T., & Strang, V. (2016). Evaluating interdisciplinary research: the elephant in the peer-reviewers' room. *Palgrave Communications*, 2(1), 16055.
- Newman, M. E. (2004). Coauthorship networks and patterns of scientific collaboration. *Proceedings of the National Academy of Sciences*, 101(suppl 1), 5200–5205.
- Parish, A. J., Boyack, K. W., & Ioannidis, J. P. (2018). Dynamics of co-authorship and productivity across different fields of scientific research. *PloS One*, 13(1), e0189742.
- Perper, T., Bailis, S., & Klein, J. T. (1989). The loss of innovation: Peer review in multi-and interdisciplinary research. *Issues in Interdisciplinary Studies*.
- Tebes, J. K., & Thai, N. D. (2018). Interdisciplinary team science and the public: Steps toward a participatory team science. *American Psychologist*, 73(4), 549.
- Zagonari, F. (2019). Coping with the Inequity and Inefficiency of the H-index: A Cross-Disciplinary Analytical Model. *Publishing Research Quarterly*, 35(2), 285–300.

## Theme 3: The function of the structure of research

### Vignette 3.1: Research in the mirror maze: epistemological bias limits our understanding of the world

*Kaitlin Stack Whitney & Katherine Crocker*

The practice of academic science in its current form derives from European cultural values. Charles Darwin, for example, is (along with a handful of other men from his era) hailed

as the father of evolutionary biology. While preserving the knowledge generated by their activities, academic biologists have also preserved many of the social mores of that era: this is not necessary, nor is it inescapable, but as with any culturally enshrined habit, it takes active intervention to replace.

Academic biology is not the only approach by which knowledge can be gained. Non-European civilizations across the world have generated knowledge concerning the environments in which they exist. This knowledge is often what allows them to survive, culturally intact, for thousands of years. In fact, these cultures--though only 5% of the total global population--are responsible for safeguarding 80% of biodiversity, and for curating their environments so well that an entire academic discipline (restoration ecology) exists in order to restore ecosystems to the intact form and function they had before European intervention.

Nevertheless, our custom and practice are largely preserved from the unapologetically racist, jingoistic eras of European global conquest. These customs teach us to exclude or infantilize all other knowledge systems that purport to make conclusions about the workings of the natural world (see Theme 1). However, European-tradition scientists regularly recapitulate as “new findings” the knowledge that is common everyday cultural certainty of other cultures. For example, the hashtag #NativesToldYouSo on Twitter is regularly updated by various members of indigenous communities across the planet, whenever a long-known fact is hailed as new science.

These other knowledge systems often predate the practice of academic biology. Kanaka Maoli knowledge records predate Aristotle, and the majority of continental North American Indigenous cultures predate medieval scientists such as Rhazes and al-Jahiz. Many of these knowledge systems come from cultures that are still extant today--and which have survived by dint of relying on their knowledge of biological systems. The survival--and thriving--of an entire culture across thousands of years is a much higher standard of proof than  $p < 0.05$ , and yet disciplines like restoration ecology rarely if ever consult Indigenous knowledge keepers of any continent. For example, Robin Wall Kimmerer's work on Traditional Ecological knowledge provides a rigorous set of suggestions of how to do this (e.g. Kimmerer 2013), yet TEK remains a niche pursuit that is rarely, if ever, included as more than an afterthought.

It is no accident in a colonial-mindset driven culture that people from many of these still-extant cultures are dramatically underrepresented in academic biology, especially in the United States. Active racism in the academy persists--virulently, in the case of biology.

However, making room inside the academy for other knowledge systems to communicate their frameworks for understanding the world can only strengthen current efforts. While Broader Impacts are an excellent move in this direction, more needs to be done. PIs currently are able to claim that they have done, or will do, actions in their Broader Impacts sections, that they are not held to. Nor are blatantly racist behaviors penalized within the academy: not by funders, nor by departments. As a result, people who are overrepresented in the US academy (European Americans) often do not take seriously the extent to which 1800s-normative bigotry shapes who can be a member of the academy. Until this is rectified, the cultural exclusion will continue and science will be the weaker for it. However, the change is worth making, and the first step is to reframe research approaches in ways that show gaps in academic understanding and adding additional dimensions of data previously (largely) unconsidered by academic biologists.

A striking example of the knowledge that can be gained by removing some of the bias enshrined in the culture of academic biology is of how bringing a feminist lens to academic biology has already yielded dramatic insights about animal behavior that were previously not merely ignored, but outside the dimensions of our conceptual framework. In the light of these findings, the patriarchal values that shaped our academic understanding of animal behavior are clear. However, before additional perspectives were considered, these clearly biased interpretations of data were accepted as objective truth.

Integrating biology necessitates addressing who is seen as - and gets to call themselves - biologists (see Vignette 3.2). An inclusive integrative biology should thus learn from sociology of science scholarship. Specifically, the concept of boundary object theory (Star and Griesemer 1989) can be applied, meaning that the boundaries of biology - and biologists - are socially defined and enforced. An inclusive integrative biology must thus be more open to who is a “real” biologist, rather than using previous, socially agreed upon definitions, to prevent the exclusion of trainees and scholars from diverse backgrounds and career paths. This would include and value community science (sometimes referred to as “citizen science”), as well as other academic disciplines. Community scientists are by definition not professional scientists by vocation (in this case, biologists), but the deep history of outstanding contributions by community scientists in biology demonstrates that specialists are not the only experts. In turn, this is a reminder that expertise in integrative biology is not only held by specialists. An inclusive integrative biology would welcome the contributions and lived experiences of non-specialists and also train them (in research, teaching, and service) with the work of non-specialists. This could also include training that doesn’t ask or require trainees to specialize so quickly. Rather than de-valuing specialization, this would increase the value of generalization. In doing this though, we must

make sure to expand our frame of reference far beyond community science, which is still within the majoritarian experience of science and biology.

## References (Vignette 3.1)

Kimmerer, Robin Wall. *Braiding Sweetgrass: Indigenous Wisdom, Scientific Knowledge and the Teachings of Plants*. Minneapolis, MN: Milkweed Editions, 2013.

Star, S. L. and J. R. Griesemer. 1989. "Institutional Ecology, 'Translations,' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907 – 1939." *Social Studies of Science* 19: 387-420.

<https://eos.org/opinions/understanding-our-environment-requires-an-indigenous-worldview>

## Vignette 3.2: Cultural barriers to interdisciplinary research

*Richelle Tanner*

The barriers to engaging in research and being considered "high impact" research stem from cultural norms ingrained in academia. First, we must acknowledge the status quo of academia: Euro-centric (white and/or English-dominated), male, R1-conducted research ideas are most often funded. This is not reflective of the quality of research ideas, rather how they fit into the cultural manifestation of our field. There are a number of barriers - both invisible and distinct - in academic communities that hold our field back both in inclusivity and the advancement of science. We posit that addressing inclusivity barriers will produce a natural diversification and integration of biological sciences.

### *Barriers*

The first major barrier that gets little attention in the US is language. English is the default language for all science, and having this requirement greatly limits participation from nationalities that do not have English as their primary language. Additionally, researchers with English as a learned language are at a disadvantage in the peer review process, often subject to discriminatory behavior by reviewers who assume research is of a lower quality if not expressed succinctly in their primary language. One current solution to this is editorial support for manuscripts self-identified as needing English language support, although this burden falls on the authors (often financially as well, see Elsevier Language Editing Service).

Another barrier at the forefront of many students' minds is bias in training. First, in order to achieve entry to graduate school, students must have high standardized test scores and grades, the former of which has been shown to be uninformative about student success and the latter of which is highly dependent on undergraduate university (whether this be perceived value by university type and/or program-specific grading standards). The graduate school that a student attends also matters on the job market - students from "elite" universities have a massive advantage based on reputation alone independent of actual skills.

A major barrier for PIs is location, whether that be physical location or in relation to a school's ranking. Labs and researchers in rural areas, at community colleges, or at primarily undergraduate institutions are at an instant disadvantage in securing funding and students because of the cultural norms in academia - if everyone views the R1 experience as optimal success, what does that say about our other highly valuable (but not highly-valued) institutions? This barrier leads to research being concentrated at high performing institutions, even when the research question is better suited to other demographics. For example, studies done on societal problems are often conducted with a sample population of college students at an Ivy League school, just because the researcher was able to secure the funding there. This is not helpful to our science or to our researchers at other institutions better suited to ask specific questions that are crowded out of the funding race because of their systemic disadvantage. This contributes to a negative feedback loop, where we as a scientific community are less aware of systemic problems because research is not being done in the most effective way to address these issues. Placing less importance on "who you know" in the review process will greatly facilitate change in this area, perhaps by blind review of proposals only (sans CV).

Self-sorting communities in science pose a barrier to the dominant culture of research (and therefore what is valued, funded, etc. - see Theme 1). Women and minorities have trouble finding like-minded mentors, and face unconscious bias in recommendations from their superiors. While high impact collaborations may exclude whole other communities because of self-sorting (see Vignette 2.4 for proposed solutions), there is also the problem of traditionally minority communities' ideas being viewed as low impact and non-fundable. Questions asked by minority researchers are more likely to be undervalued, whether that be because of subject area (i.e. their own communities) or non-traditional approach. In this way, racism and misogyny are mirrored from society onto our academic community. Diversifying reviewer panels will directly address this issue, which includes diversifying career stage, institution type, personal background, etc.

Interdisciplinary research is punished in the current promotion and funding structure of academia. This issue stems back to how science is siloed by specialty early in training and how collaborative networks in science do not promote cross-disciplinary work (see Theme 2). Organizing review panels - whether that be for hiring or grant proposals - around a diversity of viewpoints, specifically focused on rewarding interdisciplinary research is extremely important for our goal of reintegrating biology.

### *Respecting communities in research practices*

One major cultural distinction is between “the researched” and “the researchers”. Very often ivory tower studies are done on communities - either of lower socioeconomic status or in foreign nations - that the researchers do not belong to. This ties into the above barrier in location, where researchers best suited to the question are not the successfully funded individuals. We need to move away from this practice and actively award grants to individuals with unique knowledge - not necessarily a publication record - demonstrated in their proposals, whether this be because of community belonging or historical ties to a study system (i.e. with indigenous knowledge of natural systems). Placing more importance on the human aspect of research will foster inclusivity, reduce harm to marginalized communities, and increase the diversity of research approaches (see Vignette 3.1). It is also very important to consider the impact of research on communities in the grant proposal process, as proposals almost never detail the consent or potential consequences of doing research on communities that the researcher is not a part of, especially in the dissemination of research outcomes (i.e. with open access data). Prioritizing grants to individuals invested in their own communities will greatly reduce the harm on this front.

### *Lessons learned from interdisciplinary departments and networks*

Some departments and collaborative institutes already mitigate some of these barriers, especially to interdisciplinary research. For example, Environmental Studies departments engage in social, biological, physical, and chemical sciences to achieve common goals of informing policy and management. Nonprofit science organizations organize around the idea of a collaborative network, where staying within a subdiscipline goes hand-in-hand with reaching out to other expert parties regularly for collaboration. In both of these approaches, interdisciplinary ideas are more readily exchanged because of the non-competitive nature inherent in the structure (see Vignette 2.4). Additionally, perspectives from all types of groups are valued because there are no dominant threads of ideas. We need to stop approaching the scientific process as linear, fueled by high impact labs at primarily R1 university, and instead

value all types of approaches that achieve the same goal of advancing our field (see Theme 1).

## References (Vignette 3.2)

- Balazs, C. L., & Morello-Frosch, R. (2013). The Three Rs: How Community-Based Participatory Research Strengthens the Rigor, Relevance, and Reach of Science. *Environmental Justice*, 6(1), 9–16. doi: [10.1089/env.2012.0017](https://doi.org/10.1089/env.2012.0017)
- Bedeian, A. G., & Feild, H. S. (1980). Academic Stratification In Graduate Management Programs: Departmental Prestige and Faculty Hiring Patterns. *Journal of Management*, 6(2), 99–115. doi: [10.1177/014920638000600201](https://doi.org/10.1177/014920638000600201)
- Bradshaw, H. K., Mengelkoch, S., & Hill, S. E. (2020). Hormonal contraceptive use predicts decreased perseverance and therefore performance on some simple and challenging cognitive tasks. *Hormones and Behavior*, 119, 104652. doi: [10.1016/j.yhbeh.2019.104652](https://doi.org/10.1016/j.yhbeh.2019.104652)
- Buchwald, D., & Dick, R. W. (2011). Weaving the native web: using social network analysis to demonstrate the value of a minority career development program. *Academic Medicine : Journal of the Association of American Medical Colleges*, 86(6), 778–786. doi: [10.1097/ACM.0b013e318217e824](https://doi.org/10.1097/ACM.0b013e318217e824)
- Cochran, C., & O'Connor, C. (2019). Inequality and inequity in the emergence of conventions. *Politics, Philosophy & Economics*, 1470594X19828371.
- Crouch, M. A. (2012). Implicit bias and gender (and other sorts of) diversity in philosophy and the academy in the context of the corporatized university. *Journal of Social Philosophy*, 43(3), 212–226.
- Dempsey, S. E. (2009). Critiquing Community Engagement. *Management Communication Quarterly*, 24(3), 359–390. doi: [10.1177/0893318909352247](https://doi.org/10.1177/0893318909352247)
- Hoenen, S., & Kolympiris, C. (2019). The Value of Insiders as Mentors: Evidence from the Effects of NSF Rotators on Early Career Scientists. *The Review of Economics and Statistics*, 1–50. doi: [10.1162/rest\\_a\\_00859](https://doi.org/10.1162/rest_a_00859)
- Kameny, R. R., DeRosier, M. E., Taylor, L. C., McMillen, J. S., Knowles, M. M., & Pifer, K. (2013). Barriers to Career Success for Minority Researchers in the Behavioral Sciences. *Journal of Career Development*, 41(1), 43–61. doi: [10.1177/0894845312472254](https://doi.org/10.1177/0894845312472254)
- LaCroix, T., & O'Connor, C. (2018). *Power by association*.
- Moneta-Koehler, L., Brown, A. M., Petrie, K. A., Evans, B. J., & Chalkley, R. (2017). The Limitations of the GRE in Predicting Success in Biomedical Graduate School. *PLOS ONE*, 12(1), e0166742. doi: [10.1371/journal.pone.0166742](https://doi.org/10.1371/journal.pone.0166742)
- Morello-Frosch, R., Brody, J. G., Brown, P., Altman, R. G., Rudel, R. A., & Pérez, C. (2009). Toxic ignorance and right-to-know in biomonitoring results communication: a survey of scientists and study participants. *Environmental Health*, 8(1), 6. doi: [10.1186/1476-069X-8-6](https://doi.org/10.1186/1476-069X-8-6)
- Petersen, S. L., Erenrich, E. S., Levine, D. L., Vigoreaux, J., & Gile, K. (2018). Multi-institutional study of GRE scores as predictors of STEM PhD degree completion: GRE gets a low mark. *PLOS ONE*, 13(10), e0206570. doi: [10.1371/journal.pone.0206570](https://doi.org/10.1371/journal.pone.0206570)

- Shavers, V. L., Fagan, P., Lawrence, D., McCaskill-Stevens, W., McDonald, P., Browne, D., ... Trimble, E. (2005). Barriers to racial/ethnic minority application and competition for NIH research funding. *Journal of the National Medical Association*, 97(8), 1063–1077. Retrieved from PubMed. (16173321)
- Stoff, D. M., Forsyth, A., Marquez, E. D., & McClure, S. (2009). Introduction: The Case for Diversity in Research on Mental Health and HIV/AIDS. *American Journal of Public Health*, 99(S1), S8–S15. doi: [10.2105/AJPH.2008.153536](https://doi.org/10.2105/AJPH.2008.153536)
- Sullivan, M., Kone, A., Senturia, K. D., Chrisman, N. J., Ciske, S. J., & Krieger, J. W. (2001). Researcher and Researched-Community Perspectives: Toward Bridging the Gap. *Health Education & Behavior*, 28(2), 130–149. doi: [10.1177/109019810102800202](https://doi.org/10.1177/109019810102800202)
- Sydnor, K. D., Hawkins, A. S., & Edwards, L. V. (2010). Expanding research opportunities: Making the argument for the fit between HBCUs and community-based participatory research. *Journal of Negro Education*, 79(1).
- Terviö, M. (2011). Divisions within academia: Evidence from faculty hiring and placement. *Review of Economics and Statistics*, 93(3), 1053–1062.
- Tock, J. L., & Ericsson, K. A. (2019). Effects of curricular emphasis in college on the GRE and its impact on the gender gap in performance. *Contemporary Educational Psychology*, 56, 40–54. doi: [10.1016/j.cedpsych.2018.11.003](https://doi.org/10.1016/j.cedpsych.2018.11.003)
- Wei-Skillern, J., & Marciano, S. (2008). The networked nonprofit. *Stanford Social Innovation Review*, 6(2), 38–43.
- Wei-Skillern, J., Silver, N., & Heitz, E. (2013). Cracking the network code: Four principles for grantmakers. *Washington, DC: Grantmakers for Effective Organizations*.
- Wilson, M. A., DePass, A. L., & Bean, A. J. (2018). Institutional Interventions That Remove Barriers to Recruit and Retain Diverse Biomedical PhD Students. *CBE—Life Sciences Education*, 17(2), ar27. doi: [10.1187/cbe.17-09-0210](https://doi.org/10.1187/cbe.17-09-0210)

## Theme 4: Looking forward

Focusing on nuance and those ideas, structures and people historically excluded from biology has the potential to provide a framework to integrate biology and catalyze advances. Some ideas for how to try to improve the system have been presented above. Here we summarize and provide broad suggestions that span across the themes to encourage integration and inclusion in science.

- Best practices for data use, control, disability accessibility, interoperability, and sharing that are built with the knowledge of institutional inequalities.
- Approaches to restructure the expectations and logistics of collaboration to promote a diversity of approaches - new methods of collaborative incentives set up by funding agencies
  - Multiple levels of academic structure can be used to facilitate integrative science - institutes can provide shared resources and collaborative communities until integrative departments can be formed.

- Explicitly address reviewer bias with training and/or recruitment of interdisciplinary reviewers
  - Specifically match proposals to reviewers with appropriate expertise
- Culture shift away from high value R1 research
  - Valuing ideas outside of the strongest-supported line of research
  - Many smaller grants funded rather than only funding a few number
  - Improve our appreciation and evaluation of research done at non-R1 institutions, including non-academic experts from community organizations, indigenous groups, and undergraduate focused institutions.
  - Allow non-faculty to serve as PI on grant (students or non-academic experts)
  - Recognize and give appropriate credit to all authors of collaborative research
- Funding and infrastructure must be flexible to support self-guided interdisciplinary endeavors
- Training.
  - While students are the future of this field, they will not be able to accomplish these integrative goals unless we change the system to make it possible. We also have a responsibility to model this interdisciplinary behavior as supervisors since students do not have the ability to affect change on their own.

# Additional Original Notes & Ideas

*\*\*\*Below is content from our collective notes that has been integrated into the outline above, but perhaps re-organized or re-worded, so the original writing is preserved below to preserve the original thoughts\*\*\**

**These are related ideas and we are happy to include others in this discussion and potentially break this into multiple visions**

-Understanding the **nuances** of structure-function relationships will benefit from fostering inclusivity in language, approaches, scales, study organisms, and cultural backgrounds

-What systemic changes are needed to create an integrative biological sciences program?

-Cultural barriers to interdisciplinary research

-Structural and societal barriers to reintegrating biology

-Research in the echo chambers, **epistemological bias** drives academic insularity

-How to train students from heterogenous backgrounds to tackle big questions in complex biological systems?

-How can we restructure the expectations and logistics of collaboration to promote a diversity of approaches? [Increasing data accessibility and collaborative capacity across agencies and disciplines]

-An intergenerational, distributed and coordinated model of research: many labs, one question

Introduction:

## What do we value as biology

- Research in the echo chambers, **epistemological bias** drives academic insularity (i.e. when you are narrowly defining who is a scientist and how we do science, you are limiting your knowledge)

- Specialists are not the only experts (more focused on scientists)
- Cultural barriers to interdisciplinary research (who do we value as scientists)

## How do we structure research and education to reflect these values

- How to train students from heterogenous backgrounds to tackle big questions in complex biological systems?
- What's systematic at the level of individual institutions? changes are needed to create an integrative biological sciences program?
- Rather than focus only on model systems, maybe we can benefit from valuing non-model systems?

## How are resources allocated to reflect these values

- What does open-access mean? What are the consequences?

Cultural shifts required in funding and its role in professional success

We are thinking about metalevels of science. That is, How do we do science? How do we think about doing science? How do we think about our process of doing science?

Example: Doing = collecting data according to how we were taught? Thinking about doing = Should we think of 5 hypotheses instead of 2? Why do we collect those data using that method? Thinking about process = Why do we think that this relationship should be binary? Are we placing value judgements on things because we come from confrontational/hierarchical cultures?

Who is the audience for this paper? Hopefully NSF and departmental bigwigs who want to make meaningful change

Evidence strategy: Maybe we can cite literature to help identify existing problems, then bring in hypothetical or personal-ish anecdotes to demonstrate the benefit of making the changes we suggest. \*No need to include personal anecdotes that will reflect badly on us\* positive tone; 'value', 'cultural capital'. NOT; don't do this, but DO this. We have discussed the theme of reintegrating biology several times at the national level over several decades (ex. A New Biology for the 21st Century, National Academy of Sciences, 2009), yet we are having the discussion again. While these discussions are fruitful and certainly the topic may require an adaptive framework, perhaps it is time to consider a fundamental change to how the scientific community approaches this topic?

Tell us a good story about a problem that is important to solve. How would you solve it and what else would it enable? You might consider:

- What's the big question? What's the exciting science?  
Paying attention to nuances - in molecules, cells, organisms, populations, and society
- What's the potential impact?  
We get a chance to see, explore, and learn from diversity that is currently unnoticed and may provide new perspectives and solutions to current problems.
- Why now?  
We are talking about reintegrating biology so we should consider all features/traits and perspectives - not just the averaged, dominant, or easily accessible one(s). Perhaps they were the low-hanging fruits and we got started in our explorations using the averages. However examining the boundaries and rarer instances provide insights about the range of possibilities. By extending this paradigm to our society, including diverse perspectives and experiences may shed light on how we can learn about new ideas, tools, and resources to enhance our collective toolkits to approach problems we are addressing.
- What are the state-of-the-art technologies, applications, etc ...?

Molecular -

- techniques to observe/record molecules in the context of cells and detect minor variations in states/interactions of molecules to describe their roles in the function of the molecule.
- computational tools, algorithms, and approaches to simulate transitions between observed states

Being aware of the biases in creating algorithms and programs

Cellular -

- techniques to study cellular function at multiscales - single-cell, tissue, and organismal levels - including intracellular interfaces and their communications under various conditions
- computational tools, algorithms, and approaches to compare and analyze similarities and differences in their constitutions, interactions, and functions

Organismal -

- Strategies to comprehensively explore various organisms that have been recently described (including genes, proteins, metabolisms, distinct products and their functions)
- computational tools, algorithms, and approaches to compare and analyze similarities and differences between organisms in the context of their habitat, behaviors, and interactions (between other organisms of same and different species)

Societal -

- Collaborative environments and core facilities that can be accessed broadly to participate in research described above
- Opportunities to identify, discuss, record, and synthesize the interests, experiences, concerns, and perspectives of diverse communities/populations?

- Elaborate the key barriers and challenges that will need to be overcome.
  - Molecular, Cellular, and organismal -
    - Technical - access to tools and technologies
    - Infrastructural - collaborative platforms to integrate various types of data to derive new knowledge
    - Personnel - suitable training of “scientists” and machines to operate and use data and information collected; inclusion of “non-scientists” in data collection where appropriate and asking questions based on their experiences and observations
    - Broad view of the field - beyond molecular; understanding various organismal level implication; incorporating more bioethics training; non-invasive language; non-dominant language; non-binary language
  - Societal -
    - Technical - inclusion and respect of diverse and minority communities and ideas
    - Infrastructural - qualified individuals freely collaborate based on interest and expertise without concerns about their salary and position
    - Personnel - an environment of openness and acceptance
- 
- What might be broader impacts?
 

New knowledge about diverse molecules, cells, and organisms is likely to provide insights and inspirations for designing new tools, and products. Also, lessons learned from exploring nuances in biological systems and organisms may be transferable to societal organizations and interactions.
- How does it reintegrate biology?
 

This approach enables us to achieve a more comprehensive picture. Requires knowing beyond molecular-level to larger levels and to think about implications of the work on population- and societal-level.

To value careful experimentation and analysis over speed and other competitive metrics for determining good science

]Using multiple languages to express ideas - not depend on English as the only language of science. Using multiple ways of speaking may allow us to process ideas in interesting and new ways. And not exclude those who think and write in different languages.
- What disciplines might be needed?
 

Subdisciplines of biology, chemistry, physics, math, computational analysis, bioethics
- Intended audience of the paper.
  - NSF - to potentially create opportunities for scientific multiscale explorations that at the edge of the boundary (outside the averages). New knowledge derived from these observations and analyses can inspire new perspectives and/or solutions that are universally usable.
  - Academic and Research institutions - to review their institutional policies that directly or indirectly (via access to resources, opportunities etc.,) restrict collaborations based on interests and expertise

- Society at large - to consider including, sharing, and respecting diverse perspectives and experiences.
- What institutional changes are needed to make this vision a reality?  
See above

#### Potential Solutions (Neena)

1. Integrative biology “institutes” at schools (at all levels: R01 to community college) that want funding through integrative biology program.
  - a) This would biology departments to collaborate across departmental boundaries without physically moving anyone.
  - b) The institutes should also have bioethicists and social scientists who study science included.
  - c) The goals should be to do broad, collaborative, innovative, integrative research that is currently limited by focus on individuals doing research. It might require funding agencies to push the institutions to examine various levels of impact the science would have if it were funded - both real and speculative impact so we trying looking at possibilities long before they become a reality.
  - d) The outcomes of a research project need to be present more broadly than research publications. The language of science will get examined by the larger community of scholars who are part of the institute.
  - e) community engagement might be necessary both for input into the questions but also for input into who is doing the research and if they are qualified to do such research (e.g: researching the genome of native americans would require native american presence in the design, implementation and impact process as there are very few native american biologist).
2. Review process at all levels should be done with anonymous coding rather than as currently done?
3. Publications should perhaps be from institutes rather than individuals?
4. Student researchers, undergraduate (and perhaps younger students), should be included in the integrative research process as early as possible so that the fresh perspectives of those not biased by the field are visible and we are training younger generation to do integrative science.

#### Under the education/training section:

- “I teach students, not subjects” - Bryan Dewsbury; students develop as researchers from where they are as individuals
- Tara J. Yosso’s “community cultural wealth framework” (Yosso 2005) - not just about training students in a particular way, it’s about people in power / teachers + mentors valuing what they bring to their learning and collaborations
- From KSW, research shows that interdisciplinary researchers are penalized. How do we

shift the value system? (need reference) (GR: responsibility centered management (RCM) fiscal systems only reward “home departments”)

- Promote a system where students look to others to help solve problems (GR: This is the key -- breadth helps but people need to specialize and if two specialists can work together and speak each others languages to solve a complex problem, then interdisciplinarity is working)
  - Students need to learn what others can offer -- GR: speak each others' languages
  - Curriculum changes - more inclusive of outside disciplines
  - A program should allow a student to specialize but be able to understand how different disciplines can help their problem and how to communicate with researchers in those areas to come up with a solution
  - Interdepartmental programs - students don't have a home dept so they are organically multidisciplinary (GR: there are barriers to interdepartment programs at some schools)
    - But this still doesn't address the distinction of “department” - not to say this is a bad thing, but again their mentors must engage in this same interdisciplinary behavior instead of staying in their discipline
- 
- Currently we jump into specialized systems too soon?
- Needs to be structural change - students are the most transient in the education system compared to faculty, staff, admins, etc
- Need motivation for faculty to participate in ongoing PD and open their minds to new ways of doing research and teaching
- Educational opportunities are often lacking locally for students - how do you get a proper training in other areas without delving very deeply into those disciplines
  - The role of professional societies and meetings in providing educational and professional development to students and faculty
  - Courses across universities so people can get an informal/introductory training?
    - Breadth vs depth - needs to be a balance still. Maybe, NSF might be able to support and provide some guidelines or suggestions.
    - Bootcamps

- Rather than focus only on model systems, maybe we can benefit from valuing non-model systems? We are seeking nuance. Looking beyond means **LEAD WRITERS: Shuchi Dutta - this part is done, at the bottom of the document**
  - Are there tools or incentives that we can introduce to encourage the use of non-model systems or the establishment of new model systems?
    - Tools for using new model systems are already here. Many useful alternative model systems are already here. But, need to pioneer new (comparative) modes of analysis. Need to encourage/incentivize crossing of organizational and disciplinary boundaries to get research done.
  - Non-model system being an example of the mindset - there are 1000 people studying tau, but less work on other proteins
  - Example: Non-model systems being used to understand the diversity and complexity of social behaviors
  
- From section on teaching - has this been well covered? Transparency about the metrics in different fields/departments
  - Importance of independence vs. assigned project
  - Oral vs poster presentations
  - Papers vs abstracts
  - Expectations for independent funding
    - Not NSF/NIH but rather small grants to grad students
  
- Structure and function in research: **(LEAD WRITERS: Shuchi, Neena, Loren, Richelle)**

Thoughts on incorporating the molecular structure-function piece  
(Neena)

As we look back at the biological science over the past one-hundred years, it provides us with guidance on how we move forward. Predominant ideas are hard to change (ref: Alfred Chalmers book - What is

this thing called science?). Proteins were considered to be the original genetic molecules and it took almost forty years to see the role of nucleic acids in inheritance. It is important to identify what are the current paradigms that are limited by the way we structure biology in the classroom, in our research laboratories, and how we see its relevance to the society. The stories below tell us that culture has an impact on science as we scientists are steeped in it.

One way that the overwhelming breath and depth th

- What are we studying - non-model systems (just the idea that using a model system allows us to assume the function behaves the same across taxa/contexts, which is usually not true), focusing on variance in addition to means in response)
  - Examples of “model”
    - Isolated protein in buffer
    - Organisms vs microbiome vs community
    - Budding yeast vs wider range of organisms
    - Certain proteins - ribosome vs transiently associated proteins
    - Tissue specificity
    - Range of important concentrations
  - Systems we use have assumptions that we have accepted - is this useful for progressing biology?
- How are we studying it - technology, instruments, tools
  - Each of these has limitations (and strengths), but we tend to focus on the strengths while accepting the limitations.
  - Framework/assumptions that we put around the technology that hides the limitations
  - Examples:
    - X-ray crystallography vs disordered regions
- These methods let us lose sight of anything beyond the status quo of current experimental methods
  - End up with dominant (exclusive thought)
    - IDP - ignored, now all phase separation
- Some new ideas might get less ignored biology was more integrated
  - Value in diverse ways of thinking of problem
  - Limitations of interpretation

**Below is edited writing from outside the vignette structure, important points but it is unclear yet where in the outline they belong or where in vignettes the ideas may already live. These points may also help directly some additional address issues listed by NSF as of interest to Vision papers: What are state of the art applications? What are the barriers and challenges? Institutional change? Disciplines needed (biology, chemistry, physics, math, computational analysis, bioethics, others)? Broader impacts?).**

**All original writing these points are derived from is pasted at the end of this document.**

*We are thinking about metalevels of science.* That is, How do we do science? How do we think about doing science? How do we think about our process of doing science?

Example: Doing = collecting data according to how we were taught? Thinking about doing = Should we think of 5 hypotheses instead of 2? Why do we collect those data using that method? Thinking about process = Why do we think that this relationship should be binary? Are we placing value judgements on things because we come from confrontational/hierarchical cultures?

*Inclusive metaphors* - Let's try to find metaphors other than leaky pipelines (this is harmful and a bad metaphor)

Let's try to *shape communities other than trainees*, who may be already on board\*

\*idea of additive (can imply an afterthought) vs making room or space for something that has been excluded\*

*Robustness of data and its interpretations* (cite: social science on diverse opinions in decision making) (Neena added - can be removed)

*How does it reintegrate biology?* This approach enables us to achieve a more comprehensive picture. Requires knowing beyond molecular-level to larger levels and to think about the implications of the work on population- and societal-level. To value careful experimentation and analysis over speed and other competitive metrics for determining good science. Using multiple languages to express ideas - not depend on English as the only language of science. Using multiple ways of speaking may allow us to process ideas in interesting and new ways. And not exclude those who think and write in different languages.

*What are the state-of-the-art technologies, applications, etc ...?*

At the molecular level, techniques to observe/record molecules in the context of cells and detect minor variations in states/interactions of molecules to describe their roles in the function of the molecule. These include computational tools, algorithms, and approaches to simulate transitions between observed states, with the awareness of potential biases in how algorithms and programs are constructed. At the cellular level, techniques to study cellular function at multiscales - single-cell, tissue, and organismal levels - including intracellular interfaces and their communications under various conditions. These again include computational tools, algorithms, and approaches that are now used to compare and analyze similarities and differences in their constitutions, interactions, and functions. At the organismal level, strategies to comprehensively explore various organisms that have been recently described (including genes, proteins, metabolisms, distinct products and their functions). These computational tools, algorithms, and approaches are used to compare and analyze similarities and differences between organisms in the context of their habitat, behaviors, and interactions (between other organisms of same and different species). At the societal scale, collaborative environments and core facilities that can be accessed broadly to participate in this novel research. Opportunities will be generated to identify, discuss, record, and synthesize the interests, experiences, concerns, and perspectives of diverse communities/populations?

*Elaborate the key barriers and challenges that will need to be overcome.*

Across molecular, cellular, and organismal scales, barriers include: 1) technical access to tools and technologies, 2) infrastructural collaborative platforms to integrate various types of data to derive new knowledge, 3) personnel issues such as suitable training of “scientists” and machines to operate and use data and information collected; inclusion of “non-scientists” in data collection where appropriate and asking questions based on their experiences and observations, 4) broaden the view of biology as a field - beyond molecular; understanding various organismal level implication; incorporating more bioethics training; non-invasive language; non-dominant language; non-binary language. Societal barriers include 1) inclusion and respect of diverse and minority communities and ideas, 2) creating an infrastructure for qualified individuals freely collaborate based on interest and expertise without concerns about their salary and position, and 3) personnel working in an environment of openness and acceptance.

*Potential Solutions* (adapted from Neena’s writing)

5. Integrative training - Student researchers, undergraduate (and perhaps younger students), should be included in the integrative research process as early as possible so that the fresh perspectives of those not biased by the field are visible and we are training the next generation to do integrative science.
6. Integrative biology “institutes” at schools (at all levels: R01 to community college) that want funding through integrative biology program. This would foster biology departments collaborating across departmental boundaries without physically moving anyone. The institutes should also have bioethicists and social scientists who study science included, in part to help examine the language of science by a larger community of scholars. The goals should be to do broad, collaborative, innovative, integrative research that is currently limited by focus on individuals doing research. It might require funding agencies to push the institutions to examine various levels of impact the science would have if it were funded - both real and speculative impact so we are trying to look at possibilities long before they become a reality. Community engagement might be necessary both for input into the questions but also for input into who is doing the research and if they are qualified to do such research (e.g: researching the genome of native americans would require native american involvement in the design, implementation and impact processes).
7. The review process - Should the review process at all levels should be done with anonymous coding rather than as currently done? Publications should perhaps be from institutes rather than individuals? Integrative biology institutes should support outcomes of a research project being presented more broadly than just through research publications.