24

Performing Science

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In 1999 I became a principal investigator, a scientist with my own lab, coming like a speeding train from my postdoc. I was ambitious and wanted desperately to succeed. My colleagues wanted me to succeed. My parents wanted me to succeed.

I walked into the whitewashed rooms of my new lab and felt like the walls and ceiling were collapsing on me. I panicked, because I realized that I didn't know what to do in my new job. How to find students, how to mentor them, how to resolve conflicts, how to choose good projects, how to build motivation, how to interview, how to write papers and grants.

I had studied thousands of hours of physics and biology, but not 1 hour on how to perform the day-to-day interpersonal tasks of doing science. No wonder that I made many basic mistakes. For example, when I interviewed potential students I talked a lot, trying desperately to convince them to join my lab. What I did not do was listen – so I had little idea of what the student was like. As a result I hired people who didn't fit with me or with each other. Soon, conflict arose between students, and I was torn in mediating between them, having no concepts about conflict resolution. Finally, I had to fire two students, after many sleepless nights of deliberation.

The lack of discussion or education on the subjective aspects of science contrasts with the detailed attention we give to objective aspects. When we buy a new microscope, we make sure to give it the best optical table and filters to work optimally. But when a new person joins our lab, what do we know about how to create an environment that will enable her to reach her full potential as a scientist working with a team of other scientists trying to build narratives about the natural world?

I started looking for knowledge about how to perform science, and found rich sources of information outside of science. One source came from doing improvisation theatre – I participated in an ensemble that does an improvisation form called playback theatre.[1] Improvisation theatre takes a group of actors into the unknown by listening and building on each other's ideas. It uses rituals to build trust and flow in the group. This was powerful experience for building a research group that goes into the unknown together. I also learned concepts from humanistic psychology from my partner Galia Moran, a clinical psychologist focusing on rehabilitation of people with mental illness. This helped me to perform what may be called interaction-centred science.

Bringing these notions and practices into my scientific mentoring made my group charged with intrinsic motivation, cooperation, playful and attentive amplification of each other's ideas and mutual support. This helped us pioneer a scientific field between physics and biology. Much of our success was due to the focus on the subjective and interpersonal performance of science by us, human beings.

Why don't we professionally discuss or teach the human aspects of doing science? The reason has to do with values. As pointed out by Evelyn Fox Keller, natural science has a cultural myth, in which the doing of science is purely objective and rational.[2] Just as the knowledge we seek is objective, so is the person doing the seeking. But when we label something as objective and rational, the other side – the subjective and emotional – is labelled as non-science or even threatening to science. Scientists sometimes write about their subjective journey – a classic example is Jim Watsons 'Double Helix' – but this remains extra-curricular reading, not part of the mainstream scientific education or discourse.

Natural science thus stigmatizes discussion – discussion within professional settings, that is – of the emotional and subjective aspects of doing science, our biases, our performances as interacting storytellers. We are assumed to be smart enough to figure out how to perform on our own or through observing our mentors. Subjective and emotional problems are pushed under the table. This leads to a form of self-oppression, in which scientists are increasingly unhappy with the 'system', and at the same time feel powerless to change it.[3]

Commiseration and complaint is a mainstay of private conversations when scientists meet – the academic reader may resonate with topics such as needless aggression from anonymous reviewers, systematic waste of talent of PhD students by certain mentors, promotion systems based on publication statistics rather than merit, grants that go to the least daring and creative proposals, and so on. On a deeper level, our lack of discussion of the emotional content of scientific communication and interaction limits our ability to do science, as I will argue below. But these recurring topics are rarely discussed in the public sphere in conferences, journals, classrooms, because they are considered subjective and therefore non-science or anti-science.

When viewed as a cultural phenomenon, one can gain hope for improving the culture of science. After all, culture can be changed and ways to change culture are well researched and understood. The key is what we discuss and don't discuss in professional settings. Public discourse shapes people's behaviours. For example, 100 years ago women could not vote. Public discussion relegated women to the home, so why should they vote on public matters. Most people agreed. Except for those who didn't, and after a few generations of struggle, won the vote for women. Today, people with chauvinistic opinions still exist, but they don't say 'take back the vote' – that is no longer a conceivable option. What we talk about and the way we talk about it makes such a statement unlikely.

Peer groups of scientists create a space for culture-changing discussion

Science is in a good position to widen its focus and improve its culture. After all, discourse can be changed by education, and science extensively deals with education. In recent years, I promoted an effective way to change the culture at an institution: starting a peer group of scientists. A group forms when 10–15 scientists at the same stage (PhD students, new faculty, etc.) get together and invite a workshop on communication skills for scientists that presents simple concepts on active listening, conflict resolution and leadership (I like the workshops given by the company HFP consulting). This nucleates a core for meeting regularly, say once every 2 weeks.

The peer group creates a space for discussing the subjective and emotional aspects of science, and build leadership to make changes as the group members increasingly get involved in running the institution. The inspiration is women's empowerment groups in the 1960–70s, with their motto 'the personal is political'. In the meetings, one person presents a conflict or issue they are facing now, the others share related stories. The facilitator notes the group state, and sees that people aren't getting into modes of giving advice, preaching, joking or any of the other barriers to effective communication. Scientist peer groups are running at Harvard, Yale, the Weizmann Institute and other universities.[4] Members report that the meetings provide mindfulness about how to perform science, how to carry out the different roles of being a scientist. Bonds of solidarity are formed between group members. Established groups have helped newcomers to start second-generation peer groups. Cultural change has heredity: once a peer group is founded, it becomes part of the normal offering to scientists.

To enhance discussion and education on the subjective and emotional aspects of our craft, we need a good curriculum. In the remainder of this essay, I lay out some suggestions for how performance studies – in the wide sense encompassing literature, anthropology and theatre – can help build such a curriculum and inspire deeper understanding of how to perform science.

The scientific conversation and improvisation theatre

Scientific conversations are where many ideas are generated, motivation is gained and insight achieved. They can also be meetings that suppress ideas and lead to de-motivation.

If we consider the scientific conversation as an attempt to journey into the unknown, we can analyse it using concepts from improvisation theatre in which two actors try to build an unscripted scene. The main principle in improvisation is saying *Yes And*, as described by Keith Johnstone. This skill includes making clear offers that the other can understand, accepting the other's offer and developing it clearly. The opposite of saying *Yes And* is called blocking. Blocking sounds like this:

> Here's a pool of water.
> No, that's just the stage.
>
> The scene ends, actors are frustrated.
>
> Saying *Yes And* sounds like this:
>
> Here's a pool of water
> Let's jump in!
> Ooh- there's a whale.
> Yeah, let's grab it by the tail.
> Wow, it's pulling us to the moon!
> --------------

Scientific conversations which block ideas prematurely tend to demoralize the participants and to prevent 'stupid' ideas from combining with other ideas to become breakthroughs.

Thus, good scientific conversations require mindfulness of blocking and saying *Yes And*. Skilled improvisers are able to recover from blocks and use them as material for new turns in the scene. This skill can be taught to science students, to help them co-lead discussions.

More fundamentally, performing a scientific conversation well allows us to tap into deep sources of intuition. For this, saying *Yes And* has a crucial importance: it is a way to bypass the inner critic. Improvisation theatre recognizes an inner critic that stops us from saying things, so we won't be considered crazy, obscene or unoriginal. In science nowadays, the inner critic is strong, and we don't say things so that people won't think we are not smart. Saying *Yes And* is one way to bypass the critic to allow access to material that is sometimes surprisingly salient and deep.

When I talk about this to scientists, they sometimes object that this picture excludes criticism of errors. In fact, current education in science places a premium on criticism – finding out where the other is wrong. This objection is valid, and a balanced scientific conversation can be thought of as a diamond shape pattern – first a phase of opening of ideas, even preposterous ideas, that are played with to generate the material for discussion, followed by a stage of critical examination. Too much *Yes And* may lead to an unproductive mess of mistakes, but also too much criticism can stifle creativity and prevent new ideas from originating. More likely, with skilled performers, both modes can go on at the same time, just as improvisation actors say *Yes And* while steering the scene to meaningful unexpected directions.

Improvisation actors also use their body to help bypass the inner critic. Before stepping into the scene, they go into an upright and relaxed body stance called 'Up and Happy'[5] and they make eye contact with their partners. They take a deep breath. All of this prepares the entry into the unknown together. Other body stances, such as eyes cast down and closed posture, seem to enhance a type of planning and thinking that interferes with spontaneous flow of the scene. I have become increasingly aware of my body stance during scientific conversations. Simple awareness of whether I'm attending to the other, for example, by turning my shoulders to face my discussion partner and attempting not to slouch, seems to improve my listening and sharpens the potential for playfulness in the discussion. Such body rituals may help scientists enter the scientific conversation better prepared for good interaction.

There is much to explore in scientific conversations: How can we enhance the chance of bypassing the inner critic, and gain access to inner voices that are not normally heard – voices that may carry insights that can take our understanding forward.

Scientific articles and The Art of Dramatic Writing

We are not taught to write compelling papers in science. No wonder that writing is a painful experience for many scientists. The fruit of our labours is, all too often, equally painful to read. In this section and the next, I address the issues of clarity and narrative structure in scientific writing. I have discussed the performance aspects of oral scientific communication elsewhere.[6]

The clarity of my writing was transformed by ideas from theatre, as described in Lajos Egri's book, 'The Art of Dramatic Writing.[7] Egri's message is that a play must have a premise: a central idea – a full sentence – that unifies all choices in the play. The play Macbeth has a premise: ruthless ambition leads to its own destruction. The premise is evident in every character, and in every detail. It gives the play artistic unity, the sense that all things hang together with nothing arbitrary.

AQ: Please provide the closing quote for the quotation starting "The Art of Dramatic Writing...

The same applies to a good scientific article. Clear writing starts before a single word is written, by the effort to find a premise. The premise is a full sentence, conveying the main message. If one sets out without a premise, or with more than one premise, the result is difficult for readers to comprehend. A single premise can guide the writer and reader, and is the unifying principle for the paper. Include only material that relates to the premise. Drop the rest – even if it means dropping work that took much time.

Finding a premise takes effort. It is hard to boil down our work into a single sentence, and to commit to it. I start with a session of premise finding with my co-authors. A premise must be a full sentence. 'Complex networks of molecules in the cell' is not a premise; it is only a sentence fragment. 'We can understand complex networks by seeing that they are built of a small set of recurring patterns' is a premise.

My co-authors and I talk, give ourselves freedom to say stupid things, say *Yes And* and come up with several premises for our data. We then plot them out along two axes. The first axis is 'How interesting is this premise to us?' – interesting to us rather than what we imagine would be interesting to others. The second axis is: 'How well-supported is the premise by our data?' Readers tend to close up their attention if the premise is not matched by good support of the data.

Now our premises are plotted as points on a graph, defined by the two axes of interest and support. If one premise is better on both axes than the other premises, we choose it. Often, however, two premises show a trade-off – the duller premise is better supported than the intriguing one. In this case, if we have time constraints, we might choose the less interesting and better supported premise. If time and resources are available, we can see what research needs to be done to better support the more interesting premise. In this way, writing is part of research because it generates new experimental ideas.

With a premise in mind, we draw out the figures in a progression made to lead the reader step by step through our story. We try not to make big jumps, but to let each piece of description lead naturally into the next.

Science articles and the morphology of the Russian wonder tale

The scientific article, in the myth of rationality, is a technical exposition of data. The goal is to let the data speak for itself, a stream of encoded information injected into the reader's brain. To do so, we are taught the dry mechanics of writing the introduction, results and discussion sections. In reality, the quality of storytelling in an article is of central importance: papers that leave a lasting emotional impression, and tell an unexpected yet credible story (with a single well-supported and interesting premise), are the ones that make a difference.

To guide the transformation of data into a compelling story, I use an analogy to Vladimir Propp's classic structural analysis of the Russian wonder tale.[8] This is only one of many possible ways to form a narrative, suggesting a rich field for additional study.

In Propp's analysis, the Russian wonder tale is made of a series of plot modules, carried out by specific character types (hero, villain, magic donor, etc.). The modules appear in a universal order. I describe here a very simplified form of the original analysis. The Hero has a miraculous birth (born in a cabbage flower). Trouble descends on the land (sorcerer lays a curse), and the hero decides to do something about it and goes on a journey, meets a magical donor (fairy godmother) that tests him and provides a magical boon (magic sword), with which the hero combats and defeats the villain. Hero returns to the land but a false hero (the pretender) arises, and is unmasked. The hero attains the throne and marries the princess.

Here is how this maps to a scientific article. The introduction begins with the work of previous pioneers (miraculous birth), but there is a gap in our understanding (trouble), and we set out to address it (go on a journey). For that purpose we develop with some effort a technology (magical donor) and overcome technical difficulties (combat villain), to find new knowledge. We return to the land in the conclusions section and restate our main findings, but caveats and limitations are noted (false hero) and are addressed (unmasked). Marrying the princess means potential for royal offspring, and we conclude the article by suggesting the potential for new science and applications.

Hero miraculous birth	Pioneering origin of our field
Trouble descends upon land	But there is a gap in our knowledge
Hero decides to go on journey	Here, we address this
Meets magical donor	To do so, we developed a technology
That tests him and provides magical boon	And overcame technical challenges
Hero fights and defeats villain	To make new finding
Returns to land	Summary of new knowledge
False hero appears, is unmasked	Caveats and limitations are noted, and addressed
Hero marries princess, potential for royal offspring	Potential for more science, applications

As in the wonder tale, part of the appeal of an article is in the specific details (the glass slipper). Good articles provide idiosyncratic details, curiosities and specifics. But it is the overall plot modules that provide the sweep, context and timing for these details to enhance rather than obstruct the emotional experience – the narrative truth that, as Velleman[9] noted, guides the reader through a defined series of emotions. The wonder tale structure takes the reader, as in ritual structure described by van Gennep and Turner,[10] from the known, across the threshold into the unknown, and safely back transformed with new understanding. Not technical and dry, science writing can be like composing an adventure story.

Looking at an article this way opens the discussion of different ways for making narrative for conveying scientific findings. The wonder tale form, as any form, restricts us in important ways. For example, there is no scope for failure – indeed it is hard to publish negative results (lack of confirmation of hypotheses), dooming scientists to go down the blind alleys already visited by others. We also avoid non-linear and ramifying tales, without a beginning middle and end. Science can benefit from additional forms to guide readers through such non-linear accounts. In summary, widening the discussion of ways to tell scientific stories will provide better scope for scientists to communicate and enrich the kinds of stories we can tell about the natural world.

Dramatic metaphors, robust mathematical models and limitations on scientific understanding

Science is about making stories about nature. Here our subjectivity can collide with the objective goal of understanding nature. I'll use as an example the current struggle to understand the networks of molecular interactions within living cells.

How can we begin to understand how molecules interact if we never saw them with our eyes or felt them with our hands? Nanometre-sized molecules are alien to us. As noted by Fox Keller, Lakoff[11] and others, scientists wrap their ignorance by using metaphors as working tools. With metaphors we can entail properties of the known onto the unknown. Scientists use metaphors of space and visual metaphors to make abstractions. We have no choice but to use metaphors that are grounded in our bodies and our social mindset.

A class of metaphors that have long been used to understand molecules relates to drama – the way that two, three or more characters interact. Consider the words antagonist, hydrophobic, affinity. Molecule X binds molecule Y is talked about as if X loves Y (has high affinity for Y), molecule X may fear water (hydrophobic), X may be inhibited by its enemy (antagonist) and so on.

Things get more complicated when we try to understand the dynamics of circuits of molecules – how their story evolves with time. Here is an example of a story that is so enticing that it long dominated the way that biologists think of signalling in cells. It is the story of the bucket brigade. X hands a bucket to Y, which hands it to Z etc. If you know the initial conditions – X is given a bucket – you can predict the story at future times: the bucket will go step by step down the brigade. If you block the cascade – using a drug to inhibit Y, for example – you can predict exactly where the bucket will stop.

Such stories translate into mathematical models that are structurally robust: many details and parameters do not matter, and the equations give the same qualitative dynamics for many different parameters. In the model, changing the affinities of the molecules to each other may change timescales, but not the essential fact that we can feel in our bones: the bucket will reach the end of the cascade.

A bucket brigade model is an example of a story module. Other story modules are also intuitively understandable to our dramatic mindset. Three-character stories like 'the enemy of my enemy is my friend', and 'two friends agreeing about a third character', are well-known elements of social networks.[12]

But not all stories are as understandable to our minds as bucket brigades and love triangles. As all playwrights know, we can't truly understand stories with many more than three characters (unless they are arranged in a bucket brigade, in teams or other simple forms); a story with ten equally important interacting characters is beyond us, unless separated into simpler stories. The principles of Egri and Propp also relate to such limitations. In fact, we can't keep in mind more than a limited number of chunks of information and a limited number of simultaneous 'theories of mind'. This is crucially important because in order to understand an entire cell, we need to understand the story of thousands of interacting molecular characters – a feat comparable to understanding an entire village.

Thus, our limited ability to fathom drama may restrict the kinds of stories we can tell about nature. Unless biology is built of modules simple enough to understand, we won't be able to make sense of it – not in the intuitive grounded sense that I mean here. We may be able to follow through complex stories by means of computer simulations, but simulations don't lead to intuitive understanding if they can't be decomposed into parts[13] and mapped to simple metaphorical situations. It is thus conceivable that biology could be too tough for us to ever understand. Biology evolved to survive, not for scientists to understand.

Now comes a wondrous turn, or the hope of one. In 2001, we found to our surprise that complex networks of interacting molecules in the cell are much simpler than they could have been – they are made up of a small set of recurring patterns.[14] We called these recurring patterns network motifs. Each network motif is a small circuit, in which molecules interact in specific ways. Each network motif appears again and again in the network, each time with different molecules. Experiments suggest that each network motif carries out a specific dynamical function in the cell.

The network motifs found so far are built in ways that are understandable. The mathematical models that describe them have structural robustness: you don't need to know the precise parameter values in order to grasp the kind of dynamics they can display. For example, the incoherent feedforward loop is a network motif in which X does two opposite things, it activates Z directly, but also activates Y which is an inhibitor of Z. This circuit can cause a pulse of Z:X first activates Z. Then, at a delay, it activates the antagonist Y that causes Z activity to go down. If you understand this pulse, you understand what I mean by intuitive understanding. More subtle functions of this circuit can be revealed by mathematical analysis.

The same network motifs have since been discovered in every organism analysed. This raises the hope that biology may be universally built of modules simple enough to understand using stories of two and three characters, with robust math. It may be that evolution selected and kept these few circuit types because they are the simplest circuits (most economical in terms of number of components) that carry out needed functions in a way that is robust enough to work in the noisy environment of the cell. Once you understand the network motifs, you can in principle comprehend the dynamics of the entire networks out of the dynamics of each of its simple building blocks. A similar situation exists in engineering: complex electronic devices are built of a small set of recurring circuit elements, each simple enough to be understandable and to work robustly.

The understandability of biology, like that of engineering, is probably not a coincidence. It stems from three facts: (1) Systems that function in the real world apparently must be made of small, robust units, otherwise they cannot evolve to meet changing needs. (2) Thus, complex biology evolved to be built of small, robust modules. (3) These modules can be mapped to stories that our mind can understand, because we evolved the capacity to intuitively grasp stories that lead to reliable (structurally robust) predictions about the social world.

Biology may thus turn out to be more satisfying than physics, at least to scientists interested in intuitive understanding. Physics deals with non-evolved matter, which is mostly un-understandable. We can understand the harmonic oscillator, but not a meshwork of thousands, or even three, non-linearly interacting objects. Biology, on the other hand, may offer us centuries of research on systems we can deeply understand.

This optimistic conclusion for biology may of course turn out to be false. It is possible that parts of biology are built differently, more like villages not decomposable into simpler parts. Perhaps the neocortex or the immune systems are examples. In my bones, I feel these will also turn out to be understandable in terms of simple building block circuits – here is an exciting avenue for scientific research.

Conclusions

The myth of a lone scientist, purely objective and rational, suppresses discussion within the scientific professions of the subjective and emotional aspects of doing science. As a result scientists are increasingly isolated from each other, and are left without important concepts on how to do science. Our profession currently focuses on the results, not the process of science. It is rife with self-oppression and ignorance of basic communication skills, leading to loss of talent and potential.

A better metaphor for science is perhaps a group of explorers and storytellers, each resonating with some aspects of nature, trying to build increasingly rich and coherent stories. To improve science, we need to open discussions of the subjective and emotional aspects of our craft, so that both individual uniqueness and social communication can be enhanced. Through discussion, our limitations can be better addressed. The more we take into account our biases as human beings, the more objective the outcome of our science is likely to become.

In a practical way, this essay tries to touch upon topics for a future discussion of the subjective and emotional sides of science – a discussion not by outside observers of science, but rather by working scientists within the public sphere of science. Theatre can offer ways of practising and understanding scientific conversations, metaphors and scientific communication. Many more topics remain to be explored. My hope is that this grows into a living cultural change in science, rather than ending up an artificial set of self-help maxims. The thriving of peer groups that can create new culture locally, and the enthusiasm that scientists, especially of the current generation, express for these topics, gives hope.