PHYSICAL REVIEW FLUIDS **7**, 120501 (2022)

Invited Articles

Some thoughts on style in science

David Quéré
Physique et Mécanique des Milieux Hétérogènes, UMR 7636 du CNRS, PSL Research University, ESPCI, 75005 Paris, France

(Received 26 July 2022; accepted 1 November 2022; published 26 December 2022)

DOI: 10.1103/PhysRevFluids.7.120501

This paper is a modified version of the Otto Laporte lecture I delivered at the DFD conference in Phoenix, in November 2021. I focus here on the first part of this talk, which I have expanded through a discussion of why we should care about style in science. My thoughts sometimes follow the accidents of a reverie, but they also hang on a few concrete examples related to scaling laws, my favorite way of tackling scientific questions. I hope I do not overestimate the role of style in science, but I would be happy if I can convince my readers not to underestimate it. It is nothing more (but nothing less) than a string to our bow …

Here we have a unique opportunity to depart for a few days (the time I needed to write this paper) or a few minutes (the time you will need to read it) the conventional frame for a paper published in a scientific journal. Such an excursion results from the generous invitation I received from the editors of *Physical Review Fluids* to provide a written version (possibly expanded, according to their wishes) of a talk given at the 2021 DFD meeting in Phoenix, when I had the privilege of accepting the Fluid Dynamics Prize of the American Physical Society. *How do we compose a talk?* would be a good and perhaps useful subject in itself, but I will only allude to it by recalling how I suddenly realized, on my way to the United States, that my audience in Phoenix would probably be not so enthusiastic, in such festive circumstances, to hear technical details about my past research—as we are generally not so happy to endure an interminable pseudophilosophical speech given by a wise (yet drunk) uncle at the end of a Christmas dinner. Instead, I imagined that the singular character of the event would allow me to think (aloud) about something more general, something that we all share, for instance how we do research, and more specifically, because we have no other option than being specific, how it can be fruitful to think of it in terms of style.

Working in physical or engineering sciences, we generally build our investigations on observations, so that our first mission is to frame and to order what we see, just as writers or photographers do, and for the same reason: we need to extract from the jungle of reality an object pure enough, delineated enough, to become an object of thought—characterizable, autonomous, and ideally designed to become a toy model in itself, or even better an archetype, with sufficient aura to retain some potentiality, or mystery, beyond whatever description we have made of it. As we shall see here but already in Fig. 1, I came to the conclusion that one way to approach this ambitious goal is to go as far as we can in the direction of simplicity, and perhaps even arrive there.

Hence, what I must discuss has indeed to do with the search for a style. We might first imagine that there is no real style involved in scientific research, or, more precisely, that whatever style there is has been predefined with a number of codes that must be obeyed. It would seem to be something preformatted, left for us to fill as if it were some sort of administrative form. But, this would be like saying that the constraint of fourteen lines makes all sonnets equivalent. In my view, however, constraints rather open the door to imagination. We thus have to question the very nature of style,

FIG. 1. An object of science. A water droplet placed on a textured, hydrophobic surface adopts the shape of a pearl. The texture is micrometric but its regularity makes it "visible," owing to the structural colours it generates on the solid surface. (Photo: Mathilde Reyssat.)

to define its ambiguous meaning, and we will follow here Marcel Proust, who designated it as *the quality of a vision* [1]. This definition implicitly includes the framing of reality, but it goes further, despite its simplicity and concision. Five people looking at the same object do not see it identically, and style can be seen as the accentuation of the singularity of one's eye. Proust of course had art in mind, but his proposition is amazingly relevant in science. He even concluded that *The pleasure given by an artist is to make us discover a new universe*—which is indeed precisely what we expect from a scientist.

As an essential first remark, let me emphasize that the complexity of reality and its multidimensional character (space, time) often make different eyes complementary to one another. Hence, there is not a unique or a better means of expression, quite the opposite: it is necessary that distinct styles coexist, and sometimes confront one another. Indeed, describing the same object with different eyes will reveal the multiple facets of this object. We know from experience that we can deeply understand a scientific problem only if it has been examined from diverse angles—each providing a kind of projection. A projection is useful to simplify the question, but it is also likely to impoverish it, so that the problem itself is accessible only through a reconstruction from various images. Think of a sculpture, which similarly cannot be comprehended from a single point of view; rather, we need to circle it in a process that allows us to gradually perceive its various aspects (Fig. 2). A sculpture, in a sense, is unreachable, but we can approach its reality if we recompose the piece from an ensemble made up of split images. As a consequence, any style may frustrate us (by us, I mean the person who receives a style but even the agent who puts it forth). As it is, the rigorous mathematical resolution of a problem of hydrodynamics sometimes makes us lose the key features, while its impressionistic treatment with scaling laws can disappoint (and sometimes irritate) the followers of a rigorous doctrine. Having the vision of a statue from a single angle offers the same feeling of incompletion.

However, we often choose, deliberately or not, to develop a certain stylistic idiom, driven by the feeling that to do so will increase our chances of having an original view on reality. I will try here to describe my own path, keeping in mind that I obviously do not consider my own particular idiom (if it exists) as ideal. However, I think it is interesting to understand why, and under which circumstances, we have tried to dig for something that would personalize science, and what we have discovered on this path—which I will illustrate by a few examples drawn from my research. I am happy for this opportunity to express myself on a point we rarely discuss, first in a personal capacity, as if I were taking stock of my situation in the middle of an ocean, but also to raise young colleagues' awareness of the interest there is in thinking about it.

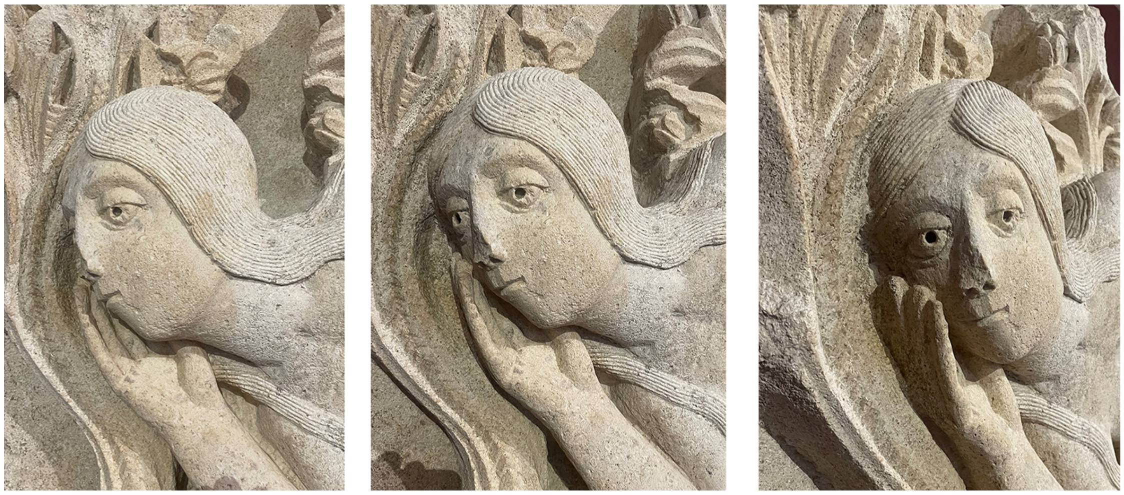

FIG. 2. Unreachable nature of statues. Even for a bas-relief, here the Eve of the Romanesque sculptor Gislebertus, in Autun, France (circa 1130), varying the point of view produces different visions of the model. The artist has exploited this property to make Eve's character ambiguous, at once attractive and treacherous. By the way, it is not insignificant in our context to remember that Eve is supposed to have provided us with the fruit of knowledge … (Photo: Merinda Vadian.)

I often try to present the main finding of a paper in its Fig. 1. Similarly, I will start here by the main point, admitting that I am driven by a taste for minimalism—for something that is simple to express and readily explicable (Fig. 3). To look at the lines of force in a work of art, and to accept that these lines of force alone constitute the essence of the artwork: these are highly instructive lessons that one may learn in museums or galleries [2]. Whatever our scientific activity involves (designing an experiment, modeling its results), I always find it important to extract its core or its essence, which can be justified in different ways.

(1) Research in soft matter is multidisciplinary in two distinct ways – being at the intersection of physics, chemistry, fluid mechanics, and sometimes biology on the one hand, but also at the frontier between basic and industrial research on the other hand. This status generates difficulties for communication, the backgrounds of the various actors being quite different. In this tower of Babel, it seems necessary to elaborate a kind of Esperanto, and the language of scaling laws, which can be thought of as the core of a more sophisticated theory, seems especially appropriate for this task. In addition, minimization of the mathematical treatment is accompanied by a reduction in the number of steps needed to establish a law, which not only simplifies the language but also helps us concentrate on the heart of phenomena—relevant parameters and orders of magnitude.

FIG. 3. An object of art. Water drops by Kim Tschang-Yeul (1929–2021), a Korean painter who spent fifty years painting drops in various situations and configurations, always doing so in a minimalistic way. Among other things, we can remember, looking at this painting, that "meniscus" comes from the Greek *meniskos*, crescent moon. (Photo: Charlotte Herr.)

(2) While this first argument is regrettably mundane, I would now like to discuss antithetically the beauty of the thing. I confess to being sensitive to the compactness of the language of scaling laws, but I also understand that others can think differently—after all, we can be sensitive to the allure of someone without being particularly attracted by that person's skeleton. As a matter of fact, the beauty lies rather in the journey we took before reaching a rather elementary, simplistic-looking result. Simplicity is not "simplism," and the road to genuine simplicity is long and arduous. We have glorious examples: the successive manuscripts of certain sublime adagios in Beethoven's string quartets evolve slowly but surely from black (many notes) to white (a few chords). But, the way remains hidden, and this so true that lectures based on scaling laws are difficult to give: if we just align dry equations, the audience quickly feels it to be a purely random, arbitrary game where we do what we do out of sheer convenience, because, for instance, we know the result in advance. Teaching (with) scaling laws rather consists of *slowly* (the important word here) accompanying our students, and pointing out the surprises and multiple branches of the route. Fluid mechanics, more specifically, often attracts us by its own splendor, which, when we look closer at it, is often revealed to be the result of a complex entanglement. The path we have to trace (when we are able to do it) superimposes upon the intrinsic charm of fluid mechanics another sort of elegance, that of a gradual simplification leading to simple, general ideas.

(3) The latter remark leads me to my final, and what I feel is the most crucial, point in this regard. It is expressed in a mere three words: *less is more,* the short, powerful, and famous dictum of Mies van der Rohe, the father of modern architecture and a promotor of minimalism [3]. Very often, going to the less (the essence) allows us to reach the more (the generic, that is, the capacity of generating ideas rather than closing up a problem). Here we must make clear what we mean by *less*. Less does not mean nothing; it just means the minimum (decanted, clarified) form that contains quantitative information. In my view, it opposes popularization, another scientific language but one that is oversimplified. Popularization is necessary but it does not belong to our toolbox; it vaguely tells us what our colleagues are doing, but, seen from a professional point of view, it fails twice over: first, because it does not produce operational tools that would be usable in our research; second, because it cannot describe the way itself and its allure, whatever its nature (mathematical, numerical, minimalistic, etc.). As the poet Louis Zukofsky wrote (attributing generously the phrase to Einstein), *Everything should be as simple as it can be, but not simpler* [4].

These thoughts naturally lead us to what de Gennes called *the melancholy of our science*, namely the difficulty of sharing what we do. The mathematical language of physics, known for Galilean ages, unfortunately makes our reasoning impossible to share with a large audience, and sometimes even with our colleagues—but we must accept this condition, and even realize that the aura of creation (now at large, including art) comes at least in part from the fact that we only access the final product, with very little information about the trajectory to this product. But, there is a second reason for melancholy in science, which is specific to this field: unlike art, which is enduring owing to the absence of a measurable "progress" (we cannot compare Manet to Chardin in such terms), the fate of scientific findings is to be made opaque by subsequent discoveries—as a plot of ground overgrowing gradually hides the remains of earlier times. (Yes, an archaeologist might excavate this piece of ground and unearth relics, but even these relics will appear to us as covered by the dust of time.) We cannot oppose this sinking process, which is the *raison d'être* of science, but glancing sideways at art, where style is precisely the recipe for immortality, we can think of style as a way of slowing down the irresistible decay, ultimately to oblivion, of what we do. Such reflections might seem naively hubristic, but my point here is more modest: we try to share the knowledge we produce not only with our contemporaries but also with colleagues not yet on the scene. Since style means the shaping of our objects, it can make what we produce slightly more resistant to the ravages of time, the kind of resistance a textbook, for instance, can have. This remark helps us to develop a scientific style: we need to find some distance from what we are doing (not an easy task), for instance by delaying publication (not an easy task either), in any case by treating what we did as if someone else had done it (we are often less indulgent and less smug when we tell a story that

FIG. 4. The charm of old ruins. In this painting by Hubert Robert (1733–1808), a preromantic amateur of Roman ruins, we notice the amateur himself, drawing the ruins—an elegant *mise en abyme*. One statue is still standing, but we suppose that it will be soon like the other ones, broken in the side of the scene—an inspiring lesson on vanity. (Photo: Jean-Gilles Berizzi.)

happened to others)—this is a way to essentialize and strengthen what we have managed to produce and may (we say with hope) slightly delay its transformation into ruins.

Natural ruins have some charm (Fig. 4), and our romantic side may accept them as the not-so-desperate fate of our constructions. In my own case (I enjoy so much the possibility of using a "I" in a scientific journal that I might have gone too far in this direction), I can even say that my taste for minimalism is a taste for ruins, which, after all, are often the skeletal remnants of buildings. Using scaling laws is a way to reduce a construction to its ruins, with indeed the aura of mystery we wished for, as well as some intrinsic robustness. I would like to illustrate this image by two examples, which will allow me to be more precise about the language of scaling laws.

In 1942, Landau and Levich published the not-yet-famous article in which they calculated the thickness of the film coating a solid drawn out of a liquid [5]. The paper is splendid, and it includes one of the first examples of what we today call asymptotic matching, a technique of paramount importance in fluid mechanics. They predict that the film thickness h should scale as the capillary length a (the size of the meniscus made by a wetting liquid contacting a vertical solid) times the two-thirds power of the capillary number $\eta V/\gamma$, a number that compares ηV, the product of viscosity by the plate velocity, with γ, the surface tension of the liquid. (Denoting the viscosity and tension by η and γ instead of the more common μ and σ is a well-known coquetry of physicists.)

A primary benefit of scaling laws is their ability to recover known formulas in a straightforward way—for the purpose of communication, education, or beauty. This case is particularly relevant owing to the subtleties of the arguments; it is also exemplary: given the Landau-Levich equation, we know in advance that it belongs to the category of scaling laws and we can take as a game the "condensation" of the theory in elementary pieces. Firstly, a liquid contacting a wall forms a meniscus, a static object by definition, with a height a on the order of a few millimeters. Secondly, when we withdraw the solid, the entrained film is thin at this scale, so that only the very top of the meniscus should be distorted by the motion, by some vertical distance ℓ. Having two dynamical unknowns, h and ℓ, we conclude that we need two equations to solve the problem.

At low Reynolds number (small withdrawal velocity), our equation (1) will be a force balance in the dynamic region. The viscous friction there scales as $\eta V/h^2$, since the flow velocity and film thickness are of order V and h, respectively. It could be opposed by gravity, but Landau and Levich rather assumed that the liquid is mainly attracted downward by the Laplace depression $-\gamma h/\ell^2$ holding in the dynamic meniscus. The balance of the corresponding pressure gradient, $\gamma h/\ell^3$, with the viscous force provides a relationship between our two unknown distances, $h \sim \ell(\eta V/\gamma)^{1/3}$, which relevantly introduces the capillary number $\eta V/\gamma$. The second equation we need expresses that the dynamic meniscus is not off ground, as it was in the preceding lines, but matches the static one, which was assumed to happen nearly at its top. Matching implies a balance of pressure that writes $-\gamma h/\ell^2 \sim -\rho g a$, denoting ρ as the liquid density and g as the gravity acceleration. The distance ℓ is thus found to be the geometric mean of h and $a = (\gamma/\rho g)^{1/2}$, from which, using the first equation, we directly deduce the Landau-Levich law.

We can be sensitive to the shortcuts pierced by such arguments, a feeling reinforced by a look at the original paper and at its 29 equations. Scaling laws do not only condense mathematics to its essence; they also reduce the number of steps to reach our goal. However, the approach preserves the skeleton of the theory, here the lubrication approximation, the key role of surface tension to oppose viscosity and the finesse of the matching. We miss the numerical coefficient in the law (it turns out to be ~0.95), but we access the by-products of scaling laws: orders of magnitude (coming out of a pool, we typically entrain 50 μm of water) and quantitative predictions (increasing the velocity by 30% thickens the film by *exactly* 20%). Last but not least, we can check all the key assumptions ($h \ll \ell,\ \ell \ll a,\ \rho g \ll \gamma h/\ell^3$), and discover that they reduce to one (unique) hypothesis, $(\eta V/\gamma)^{1/3} \ll 1$—the Landau-Levich miracle, a miracle that the authors themselves do not seem to have fully realized …

If scaling laws were limited to rederiving known theories, they would mainly be a convenient tool of communication—and I would not have written this paper. But, they can also model phenomena of a higher degree of complexity, without known solutions, as we learned from the spectacular example of polymer physics [6]. The Landau-Levich problem itself offers a formidable variation in the limit of large capillary number, where all its assumptions collapse. Physically, the dynamic meniscus then invades the static one, which renders the asymptotic matching impossible. If we like shortcuts, we have here a wonderful example: we lost our second equation, but we also lost the second unknown (the length of the dynamic meniscus, no longer relevant)—and indeed, our first equation alone, where we now consider gravity as the force restraining entrainment, $\eta V/h^2 \sim \rho g$, is enough to predict the entrained thickness! To the best of our knowledge, there is today no exact calculation of this law first proposed by Derjaguin [7].

Let me give a second example selected in our work on pearl drops—the variety of drops that hardly wet the solids on which they are deposited (Fig. 1). At impact, these droplets are simply reflected by the substrate—a surprising example where a liquid, whose dynamics is generally dictated by viscosity, in particular at small scales, acts as something elastic. There is indeed some elasticity hidden there, not *in* but *on*, when we remember that the liquid surface tension γ is measured in N/m, the unit of a spring stiffness: deforming a drop by a distance ε generates a restoring force $\gamma\varepsilon$. A drop with mass m impacting a repellent surface deforms but friction is clearly not dominant since rebounds are observed. Hence, the elastic force $\gamma\varepsilon$ can be, to the first order, simply balanced by the inertia $m\varepsilon/\tau^2$, denoting τ as the rebound time. We deduce the well-known spring formula $\tau \sim (m/\gamma)^{1/2}$, independent of ε and thus on the impact velocity. This time is typically 10 ms for a raindrop of a few millimeters, a time much larger than the microseconds observed for a bouncing steel ball—a signature of the soft character of this unusual spring.

Can we beat the time τ? This question was recently posed with the aim to generate "super-superhydrophobicity," where, for instance, a drop impacting a cold repellent surface does not have enough time to freeze at contact [8,9]. Ingenious solutions were proposed, starting with the idea of placing on the repellent solid a thin fiber of equivalent repellency [8]. A drop hitting this device takes off about twice more quickly than on the bare solid. As seen in the top view of Fig. 5, a fiber indeed dramatically affects impact. Instead of being circular, the drop transiently adopts the shape of a butterfly (a good trick to fly, by the way) and it takes off after ~8 ms, instead of ~15 ms without the fiber. How can we understand it? Well, it is embarrassing to divulge, but after six

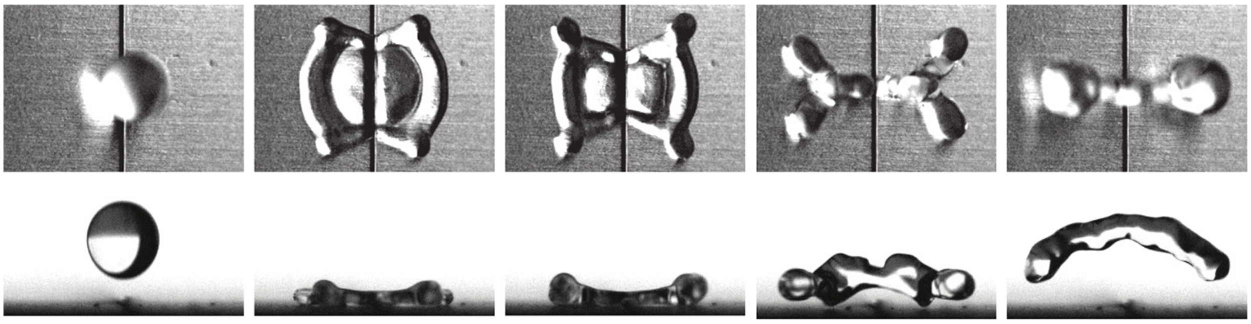

FIG. 5. Fast repellency. A millimeter-size water drop impacting a repellent solid decorated with a thin fiber (black line) bounces after a complex process, as we can see from these top and side images of the impact (shown at time −1, 3, 5, 8, and 14 ms), We discuss in the text how scaling laws capture the reduction of contact time arising from these complex shapes. (Photo: Anaïs Gauthier.)

months of pointless attempts, we just looked at the figure. Water being more repelled along the fiber than by the substrate, the drop gets recomposed in four lobes, and not in two, as we might naturally think [10]. *Four* lobes! Thinking of each of them as a subdrop with mass $m/4$ that successively spreads and recoils, our spring model, where τ scales as $m^{1/2}$, predicts a contact time reduced by a factor equal to $4^{1/2}$, that is, 2 … Importantly, when we are interested in a comparison (here without/with fibers), scaling arguments provide *exact* results, since they become then independent of any coefficient and thus fully quantitative—a surprise when we look back at the deformations in Fig. 5 whose complexity had given little hope of facile modeling. Yet, we still wait for the more exact calculations that will tell us whether we reached here the realm of true simplicity or rather accidentally crossed the frontier of the simpler …

This detour to a few concrete cases did, I hope, illustrate our initial statements. On our way, we were also tempted to use a few analogies with research in art, which, however, might have generated some ambiguity that we need to disperse. Of course, each time we face an enterprise where creation is at stake, style matters. Absolutely essential in art, it submerges all other kinds of questions, such as technique or subject, for instance. We recognize our favorite painters or writers by their inimitable expressive achievement, and we admire how it came to be only after a long and solitary quest—casting each artistic personality in its own mold and making it unforgettably unique. The situation is different in science, where the mastery of technique and the ability to select good topics play major roles. However, I have here tried to show why we should not ignore the question of style, not only for its abilities to shape our productions (papers, talks), but also because *the quality of a vision* sometimes leads to something we would not have reached without this string to our bow.

Acknowledgments. The main chance in my scientific life was the group of about 35 Ph.D. students (plus a few postdocs) with whom I interacted over the years, including for this paper. They deserve my most sincere and highest gratitude. I also benefited from wonderful industrial and academic collaborations, among which I must distinguish my long-term journey with Christophe Clanet. Jim Gibbons corrected many approximations in the text and gave me, once more, a lesson in English. Finally, I deeply thank Pierre Soulages for teaching me what is style and how it often connects to simplicity.

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