Narrative and epistemic positioning: the case of the dandelion pilot

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Abstract

This chapter introduces philosophers of engineering to a new research agenda currently permeating the history and philosophy of science, one concerned with the functions of narrative in science. The functions of narrative that I am here interested in contribute to two particular kinds of epistemic positioning. First, that of the individual researcher's epistemic position in relation to a field of inquiry. Second, the positioning of a community of researchers gathered around and looking at newly acquired evidence, assessing its significance. In the first, the kind of inference and hypothesis making that narrative affords stimulates and orders inquiry. In the second, narrative supplies a means of reasoning from the particulars of a case to something deeper or broader. The case analysed concerns an interdisciplinary project between engineers, applied mathematicians, and biologists dedicated to understanding how dandelion seeds fly. My analysis draws on the concepts of 'tellability' from literary study and 'synoptic judgment' from the philosophy of history. Tellability is used to explore question generation in science and engineering, in particular the making of more or less 'askable' questions. Synoptic judgement is drawn in to interrogate my own case, key elements of which resemble synoptic judgement without assimilating to it.

1. Introduction

This chapter introduces philosophers of engineering to a new research agenda currently permeating the history and philosophy of science, one concerned with the functions of narrative in science.[1] Thus far, scholars addressing narrative

[1] Morgan, Mary S. and M. Norton Wise. 2017. Narrative science and narrative knowing. Introduction to special issue on narrative science. *Studies in History and Philosophy of Science*

science have, as the name suggests, primarily focussed on the sciences, rarely touching on technological or engineering cases. There are however very clear ways in which the narrative science research agenda can be extended into the world of engineering, and to their mutual benefit. Here I focus on narrative's role in epistemic positioning, more specifically, within two particular kinds of epistemic positioning. First, the making of an epistemic position for the individual researcher (and their team) in relation to a potential field of inquiry. Second, organising a community of experts around newly acquired evidence, so that its significance might be assessed. In both such moments or processes of positioning, narrative plays a key role. The case analysed arises from a collaboration between engineers, applied mathematicians, and biologists.[2] Their project was dedicated to understanding how dandelion seeds fly. This question was of interest for a range of reasons including better understanding flow behaviours at low Reynolds numbers, the structures and means by which the head of a dandelion seed opens and closes on contact with water, how new manufactured products might utilise these aerodynamic features, optimal dispersal methods for organisms grown from seed, and evolutionary histories of methods for locomotion.

Some researchers in engineering studies and the philosophy of engineering already take narrative seriously, but this work has typically focussed on the importance of narrative for pedagogy and identity. Narrative here is not treated so much as a way of knowing, but rather as a medium for explanation and representation.[3] Bill Wimsatt provides a helpful exception, a brief section of *Re-*

62:1-5. For more on the project please visit the Narrative Science website www.narrative-science.org [last accessed 9/8/2019].

[2] My attention to interdisciplinary projects between biology and engineering was inspired by the Engineering Life project, which sponsored the empirical research analysed here. Schyfter, Pablo, Emma Frow and Jane Calvert. 2013. *Engineering Studies*. 5:1-5. For more on the project please visit the Engineering Life website http://www.stis.ed.ac.uk/engineeringlife/home [last accessed 19/12/2018].

[3] Buch, Anders and Louis L. Bucciarelli. 2015. Getting context back in engineering education. In *International Perspectives on Engineering Education*, eds. Christensen, Steen Hyldgaard, Christelle Didier, Andrew Jamison, Martin Meganck, Carl Mitcham, and Byron Newberry. Cham: Springer. Downey, Gary Lee. 2008. The Engineering Cultures syllabus as formation narrative: Critical participation in engineering education through problem definition. *St. Thomas Law journal* 5:101-130. Korte, Russell. 2013. The Formulation of Engineering Identities: Storytelling as Philosophical Inquiry. In *Philosophy and Engineering: Reflections on Practice, Principles and*

engineering Philosophy making the case that narrative knowledge is an essential part of science and engineering because it helps to deal with, and draw in, a range of different kinds of evidence and different perspectives regarding that evidence, as will also be seen in my case.[4] Louis Bucciarelli also makes repeated reference to the importance of narrative in his *Engineering Philosophy*, but what narrative is taken to mean is not developed, and again his examples often lean towards teaching.[5] Pedagogy and identity are clearly important, and there is no need to view them in isolation of research, experimentation, and everything else that makes up engineering. For example, in a recent seminar series dedicated to narrative science, Caitlin Donahue Wylie argued that engineering educators make use of narratives, particularly failure narratives, to acclimatise their students to some of the realities of engineering in the world, all the while building particular kinds of engineering identity and epistemology.[6] Through Wylie's example, we can acknowledge that pedagogy matters, that there is more to pedagogy than pedagogy, and likewise, that narrative has a much broader epistemic significance. Wylie's concept of 'vicarious learning' helped shape my own thoughts, because vicarious learning recognises potential differences between two people's epistemic positions, and puts those differences to work.[7]

The case study is unpacked over two sections dedicated in turn to starting points and interpretation. I first explain narrative's role in positioning the individual researcher and their team in relation to a field of inquiry, and then its role in ensuring the wider epistemic community are persuaded of the reliability and significance of one's results. My methods included short bouts of laboratory observation, observation at team meetings, and many hours of interview with the

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Process, eds. Michelfelder Diane p., Natasha McCarthy and David Goldberg. Dordrecht: Springer. Philosophy of Engineering and Technology, vol 15.

[4] Wimsatt, William C. 2007. *Re-Engineering Philosophy for Limited Beings: Piecewise Approximations to Reality*. Cambridge, MA: Harvard University Press, pp. 154-157.

[5] Bucciarelli, Louis L. 2003. *Engineering Philosophy*. Delft: Delft University Press.

[6] Wylie is currently preparing an article on disaster stories for publication, a version of the vicarious learning work is published as Wylie, Caitlin Donahue and Michael E. Gorman. 2018. Learning in Laboratories: How Undergraduates Participate in Engineering Research. American Society for Engineering Education. Paper ID #22448.

[7] Feedback given by Alok Srivastiva to my initial working paper was exceptionally helpful for seeing these connections.

two principal postdoctoral researchers on the dandelion project. The wording of any quotation from interviews, team meetings, or lab visits was a verbatim note taken at the time of discussion.

2. Plots and askability

Research questions may come and go, but some are more compelling, useful, and revealing than others. In this section I demonstrate that we can understand the making of a good question in the same way as literary theorists argue one can make a good or 'tellable' narrative. While any given research question may well be disposable depending on how research actually unfolds, even provisionally held questions play an active role in the daily management and conduct of research. My materials come from a research project in which engineers and applied mathematicians with expertise in fluid dynamics, and biologists with expertise in plant form and function, collaborated to investigate the flight of dandelion seeds. The project's overall question was 'how do dandelion seeds fly?' But on its own this question was too thin to organise work and build an epistemic position. The questions and answers produced by narrative, through the finding and bringing together of different plots, were more numerous and fine grained, and as we shall see, were also essential for making room for new knowledge. After all, the question 'how do dandelion seeds fly?' can always be answered with 'the wind blows them', and any further elaboration of the process, i.e. any claim to new knowledge, would land on infertile ground. The difference here pointed to can be better understood through discussion of tellability.

Though scholars in literary studies and narratology have developed a number of different accounts of tellability, I will rely exclusively on that of Marie-Laure Ryan.[8] Tellability is central to making one narrative dynamic, intriguing, exciting, and capable of building tension, surprise, and so on, while another narrative would fail to hold our interest for long, or we might not see the point in its being told at all. The difference, according to Ryan, "is that tellability is at least partly a matter of conceptual and logical complexity, and that the complexity of a situation, or a

[8] Ryan, Marie-Laure. 1986. Embedded narratives and tellability. *Style* 20:319-340.

sequence of events, depends on an underlying system", her underlying system being 'embedded narratives'.[9] We can understand the embedding of a narrative by first reducing a narrative to a collection of plots, each of which is made up of a series of events or anticipated events, interrupted by new physical states and/or mental acts. Ryan argues that we can therefore understand interesting and tellable narratives as those that have multiple interlinking and proliferating plot lines. "It also accounts for the meaning of the expression "the plot thickens" by representing "thick" plots as a densely connected graph with an extensive parallelism of competing plans, while "thin" plots appear as linear strings dominated by the weakly integrated nodes of accidental happenings."[10] Most of Ryan's scheme is invested in how people manifest and bring about real (if imagined) worlds, and so it translates very readily to settings beyond the literary.

The collection of plots that I am about to explain and bring together were actually compiled by one of the central postdoctoral researchers in the first couple of months of the project. They completed this exercise before any experiment had been organised or begun. It was they who, in collaboration with the Principal Investigators, pulled together a wide range of examples of previously completed work, many from otherwise unrelated disciplinary perspectives, in order to motivate and better define the questions for this new dandelion project. Sometimes this involved seeing analogies between earlier work and the new case, but more often it came directly from finding what research had already been done on the dandelion seed, laying all these unconnected findings out, and deciding from the overall picture what it suggested they ask next. My contribution is to interpret this activity as one of epistemic positioning by narrative means, the collection of these starting points as equivalent to the collecting of a range of different plots. The potential for plots to intersect, or invite intersection, is the narrative function I am here translating from the literary context into the work of science and engineering. This section therefore charts the making of an epistemic viewpoint that was new in certain respects and from which askable questions

[9] Ryan, pp.319-320.
[10] Ryan, p.322.

could be generated, just as a collection of plots makes for a tellable narrative, one that hooks an audience and begins to stimulate anticipations of what might be coming down the road.[11]

The following 7 starting points were compiled by one of the two central postdoctoral researchers and collated into an internal project report, which I was then given a copy of. First, some earlier biologists had focussed on a different though similar kind of plant seed, those of *Tragopogon dubius*, finding that the moment of 'abscission', when the body of the seed leaves the head of the plant, occurred more often in the presence of a strong updraft rather than during high winds approaching from the side.[12] This, the authors argued, was evidence of an evolutionary strategy aimed at maximising the length of dispersal range. Second, and beginning with a paper from 1919, a number of different mathematicians had made simplifying assumptions about the shape of each individual filament on the dandelion pappus (pappus being the name for the parachute of filaments at the top of each seed, see Figure 1 for reference), in particular assuming they conformed closely to a cylinder, extrapolating from there what the drag force must be for the whole pappus, using drag to explain the speed of descent.[13] Third, ecologists had completed work with computer simulations, also modelling with simplified assumptions about the drag laws operating on the individual seed, varying the wind angles in their simulations, and likewise finding that updrafts mattered most for distance.[14] Fourth, plant morphologists interested in biomechanics had investigated the structure and material composition of the individual seed, and its

[11] Zach Pirtle here suggested the language of 'path dependence', which I think helps explain important parts of what I mean to convey, but risks restricting the extent to which we might expect questions and research programmes to change quite dramatically. I do however think the suggestion a helpful one, to show how narrative provides momentum, so I include it here.

[12] Greene, David F. and Mauricio Quesada. 2011. The differential effect of updrafts, downdrafts and horizontal winds on the seed abscission of *Tragopogon dubius*. *Functional Ecology* 25 (3):468-472.

[13] Greene, D., and Edward A. Johnson. 1990. The aerodynamics of plumed seeds. *Functional Ecology* 4:117-125. Small, James. 1919. The origin and development of the Compositae. *New Phytologist* 18(5-6):129-156.

[14] Tackenberg, O., P. Poschlod, and S. Kahmen. 2003. Dandelion Seed Dispersal: The Horizontal Wind Speed Does Not Matter for Long-Distance Dispersal-it is Updraft! *Plant Biology* 5(5):451-454.

behaviour in the air.[15] Aspects of this approach would be replicated for the new dandelion project, including gathering their own data from a scanning electron microscope, and pursuing photography of the seed 'in flight'. Fifth, applied mathematicians using computational fluid dynamics had focussed on the whole pappus (this time of *Tragopogon pratensis*) as the thing to be simulated, rather than focussing on individual filaments and multiplying up their effects.[16] In their terms this meant the pappus could be treated as a more or less porous disk, of which computer simulations could then predict the aerodynamic behaviour. They had concluded that the parachute of filaments maximises the drag force and helps maintain stability by being both solid *and* permeable, where others had only thought solidity significant. Some of their iterations of the simulation showed the presence of vortices, which they included as video submissions available for download with their publication.

These first 5 starting points all concerned work either on dandelion seeds themselves, or species with flight methods that were very closely aligned to the dandelion's. By contrast the final two starting points came from outside the dandelion and its method of flight, but were nevertheless drawn in as part of positioning activity. Sixth, fluid engineering completed by materials scientists had studied the behaviour of flexible fibres in various different rates of flow.[17] Thinking of the individual dandelion filaments as flexible fibres meant the results of these simulations could be taken to speak to and describe their flow behaviours. The seventh and last was probably one of the most important influences on the design of the dandelion project, work that had been done on a different seed, that of the maple, completed by David Lentink's lab in the mid-2000s, in which he had

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[15] Sudo, Seiichi, Nao Matsui, Koji Tsuyuki, and Tetsuya Yano. 2008. Morphological design of dandelion. *Proceedings of the XIth International Congress and Exposition*. Society for Experimental Mechanics.

[16] Casseau, Vincent, Guido De Croon, Dario Izzo, and Camilla Pandolfi. 2015. Morphologic and Aerodynamic Considerations Regarding the Plumed Seeds of *Tragopogon pratensis* and Their Implications for Seed Dispersal. *PloS one* 10(5):e0125040.

[17] Cox, R. G. 1970. The motion of long slender bodies in a viscous fluid Part 1. General theory. *Journal of Fluid mechanics* 44(04):791-810. Zhu, Luoding. 2007. Viscous flow past a flexible fibre tethered at its centre point: vortex shedding. *Journal of Fluid Mechanics* 587:217-234.

shown that maple seeds shed vortices as they span.[18] Lentink had used flow visualisation to great effect, a method that we will come to in section 3.1.

To reiterate, these seven starting points do not cover all of what these researchers knew before they started. These starting points also demonstrate things that could have been guessed about the project, for instance that the project would have a selectivity towards the fluid dynamic questions around the seed because the engineers and applied mathematicians on the project were experts in fluid dynamics. But this collecting together also achieved something analytically non-obvious: it built a larger narrative, composed of multiple plots, from which sharper questions could be formulated. Likewise, it provided a range of different potential experimental research paths forward, looking for good examples to follow, or gaps in earlier approaches that could be improved on. The core of the new epistemic position that emerged was "To date, there have been no studies done to examine the flow structure around the dandelion in the presence of...updrafts."[19] Grinding away at literatures and building a new platform for one's own project out of them is not just part of the ephemeral stuff of research life, but is a concrete epistemic activity that positions the engineer and their team in a particular relation to nature's potential, and its potential for investigation. We can better recognise the epistemic aspect of this work by rendering it in the terms of narrative tellability.

In the dandelion case, an epistemic position gets embedded thanks to the bringing together of a set of plots, plots which provoke more or less askable questions. The question 'How do flow structures work in the presence of updrafts?' is very askable, while 'How do dandelion seeds fly?' is not. This is because the former requires us to know a range of quite specific methods and analytical techniques beyond the average person's expertise, thereby inviting thick answers, where the latter stays in the vernacular and picks out no particular epistemology, accordingly its answers are comparatively thinner. As Ryan explains, in a tellable narrative one

[18] Lentink, David, W.B. Dickson, J.L Van Leeuwen, and M.H. Dickinson. 2009. Leading-edge vortices elevate lift of autorotating plant seeds. *Science* 324 (5933):1438-1440.
[19] Literature review: *Taraxacum officinale*. Weekly project meeting 16/2/2016.

needs to build plenty of room for inferential reasoning.[20] In the present case we have to be allowed to infer that 'flow structures' might matter, that looking at seeds 'in the presence of updrafts' might matter: there is little to infer from the question of how dandelion seeds fly, unless the reader has never seen a dandelion seed fly. This observation is more than a passing thought. At the start of the dandelion project these researchers faced the possibility that they might, eventually, have to admit that there was nothing particularly interesting about the flight of the dandelion seed if it turned out that its aerodynamics could be explained solely by drag. The postdoc leading design of the flow visualisation experiments, discussed in section 3, was well aware that they might find nothing outside of drag, at which point the project might have to slightly change focus, i.e. rearrange the plots to produce a different narrative. If that occurred the postdoc thought it most likely they would have to switch to explaining only the stability of the seed's fall, or in my terms, increase the value of a stability narrative over a flight narrative.[21] The hope however was to avoid this outcome and instead find interesting vortex behaviour in the flow. What that vortex behaviour might be could not be guessed ahead of time, nor its potential causes, which could have been to do with the properties of each filament, the body of the seed, the stem, the arrangement of all these parts in relation to one another, and so on. The potential rewards for pursuing a flight narrative were greater, more numerous, and more exciting than those of a stability narrative, and research was ordered accordingly.

To translate and summarise, the dandelion project began by taking many disparate and only partially connected starting points, which we can now understand as plots: the plot of abscission in updrafts, the plot of drag laws, the plot of weather simulations, the plot of plant structure, the plot of the porous disk, the plot of the flexible fibre, and the plot of the vortex shedding maple seed. These plots are the ingredients for an embedded epistemic position. Pooled together these could produce a range of overall narratives, with all plots (or a select few) in play and in tension. So arranged it became possible to point out potential holes,

[20] Ryan, p.322.
[21] Note taken during laboratory visit 4/12/2016.

such as where there was a fluid dynamics gap, and where existing assumptions might be challenged, such as the pre-existing emphasis on drag. Different narratives could be weighed against each other, the most attractive (on whatever grounds) being prioritised, but always provisionally, so that the project could change and adapt to emerging results or other circumstances that might make a different arrangement of plots, or a different overall narrative, more significant. This overall set of starting points and the inferences they allow us to make produces an embedded epistemic position. The essential elements of the particular new position that the dandelion project drew on became that: 1) no empirical effort had yet been made to measure the flow around the seed during the experience of an updraft; and 2) earlier investigators had assumed that drag provided a sufficient explanation for flight. Arriving at this new epistemic position involved both reading past works and placing them into an intelligible historical tension with one another (not a temporal sequence in this case, as Ryan otherwise expects, but through something more like a collage), and also projections regarding action in the future: i.e. an intention to look at or do things not yet looked at or done, to bring into connection things not yet connected or intersected.[22] In the following section I address how narrative functions in a different mode of epistemic positioning, that between the new evidences produced by the dandelion project and the wider community of experts assessing their reliability and significance.

3. Interpretation and synoptic judgement

Having demonstrated the importance of narrative for the epistemic positioning of an individual and their team in relation to a field of inquiry, this section takes us to a different context of positioning, that between a project's results and the wider community of experts. Working at a larger scale, the historian and philosopher Robert Meunier is currently building an account of 'research narratives', as recorded in sources such as journal articles, and which communities of scientists

[22] There are similarities here with Mieke Boon's 'interpretive frameworks'. Boon, Mieke. 2009. Understanding in the Engineering Sciences. In *Scientific Understanding: Philosophical Perspectives*, eds. De Regt, Henk W., Sabina Leonelli and Kai Eigner. Pittsburgh: University of Pittsburgh Press, p.261.

use for functions such as concept formation.[23] I here concentrate on only one set of evidential outputs and their entry into the communal space, to keep my argument to its essentials, but the particular activity I am describing might also be understood as contributing to the larger sphere of narrative work that Meunier addresses, and was certainly informed by his analysis. The making of an interesting, well-informed, and plausible question would be for nothing if that question and the experimental designs intended to help answer it are insufficiently persuasive, reliable, or even interesting enough to prompt agreement that new knowledge has been produced. Narrative is key to understanding how new knowledge claims are set up and offered to wider communities, which I demonstrate through particular attention to the evidence produced by flow visualisation experiments and the kinds of judgement or interpretation that they invite. Where I previously used a narrative concept developed in literary theory (tellability), I here make use of a narrative concept developed in the philosophy of history, Louis Mink's notion of 'synoptic judgement'. The latter has been drawn upon recently by a range of philosophers and historians of science dedicated to improving and expanding our understanding of narrative in science.[24] I do not need to argue that my case exemplifies synoptic judgement at work, merely that parts of the reasoning apparent in the dandelion case share interesting features with synoptic judgement. To put the same point slightly differently, judging synoptically has a range of features that matter for epistemic positioning at the communal level, parts of which become easier to identify thanks to my narrower case.

When assessing research completed by others, the expert audience is invited to recognise and somewhat adopt the epistemic position of the original researchers,

[23] Meunier, Robert. Manuscript in draft. The emergence of a new research field in interwar biology: Genetic mosaics and the narrative space of gene action in physiological genetics.

[24] Beatty, John. 2017. Narrative possibility and narrative explanation. *Studies in History and Philosophy of Science* 62:31-41. Hurwitz, Brian. 2017. Narrative constructs in modern clinical case reporting. *Studies in History and Philosophy of Science* 62:65-73. Morgan, Mary S. 2017. Narrative ordering and explanation. *Studies in History and Philosophy of Science* 62:86-97. Norton Wise, M. 2017. On the narrative form of simulations. *Studies in History and Philosophy of Science* 62:74-85. Roth, Paul, A. 2017. Essentially narrative explanations. *Studies in History and Philosophy of Science* 62:42-50.

to take a look around, and decide for themselves if they agree with the conclusions drawn, disagree with certain elements, and so on. To some extent the capacity to provisionally adopt the epistemic position of another will be possible thanks to their having shared similar experiences.[25] But narrative, either as something that goes beyond shared experience (or as something part of it), is key to explaining why some kinds of evidence are better at provoking dissemination and inspiring assent to new knowledge than others. This is because narrative increases opportunities for synoptic judgement, and synoptic judgement is a very effective way to gain assent to new knowledge. The following sub-section explains the particular experimental setup of interest, and the kinds of evidence it produced. These are then analysed through the lens of synoptic judgement.

3.1 Flow visualisation

A core set of experiments pursued by the dandelion team owed a lot to the work mentioned earlier as plot number 7, work completed by the Lentink lab on the maple seed, which had been a particularly widely celebrated case in biological engineering. Learning from this research, and building on the design of the maple seed experiment, adapting it to make it more suitable for the dandelion case, was a core feature of the dandelion project, one which produced some of its most compelling results.

Flow visualisation is a technique used widely by scientists and engineers intent on understanding flow (of air, fluid, etc.) around an object, and any flow behaviours caused by the material properties of that object. The aim is to gain visual evidence of the airflow in order to study its patterns and stabilities. The way this is done, is to fix the object of interest within the field of view of a camera. They then start forcing a controlled stream of air around it, in the dandelion case this was from beneath an individual seed, because as we saw earlier, they had already decided updrafts were more fundamental than horizontal winds. Once they have all that in place, they then fill the air around the object with fine particles of smoke, using

[25] Leonelli, Sabina. 2009. Understanding in biology: The impure nature of biological knowledge. In *Scientific Understanding: Philosophical Perspectives*, eds. De Regt, Henk W., Sabina Leonelli and Kai Eigner. Pittsburgh: University of Pittsburgh Press, p. 199.

a standard smoke machine, making sure the air around the object is well saturated. They then fire a laser at particular areas of space around the object that they want to illuminate, taking in a range of different planes, in order to build up a more complete picture of the flow around the object and to find the most revealing angles. The camera will then take photographs of the smoke particles illuminated by the laser, and they can look for patterns in the smoke in the photos. A photograph of an early iteration of this experimental setup made for the purposes of prototyping is available as Figure 2, while a photograph of the final experimental setup used is available in the *Nature* paper reporting their results.[26] Interventions here include affixing the seed to a solid support so that it will not fly away and out of your camera focus at higher rates of flow, and filling the air with very fine smoke, avoiding larger particles that are likely to produce their own behaviours.

In the weeks leading to the initial design of this experiment one of the lead postdocs spoke of "trying to imagine what it is like to be one of the pappus".[27] During a team meeting, one of the PIs recommended that the experiment did not need to worry about the tips of each of the individual filaments interacting with each other because they are, in terms of the aerodynamics, too far apart "the physics don't see each other".[28] In an early preliminary experiment, a lead postdoc tried balancing one seed on top of another, using the prototype updraft apparatus to pass a flow of air around them, and noticed that the top one wobbled a lot more than a single seed left on its own. This, they explained to me, meant "Either [the top one is] amplifying the physical movement of [the] bottom seed or there is a wake being created by the one at the bottom".[29] They further imagined life at seed level in other ways, by "flying over the dandelion"[30] as another postdoc referred to it when explaining the computer visualisations resulting from sending seeds to be

[26] Cathal Cummins, Madeleine Seale, Daniele Certini, Enrico Mastropaolo, Ignazio Maria Viola, and Naomi Nakayama. 2018. A separated vortex ring underlies the flight of the dandelion. *Nature* 562:414-418.
[27] Note taken during laboratory visit 4/12/2016.
[28] Note taken during team meeting 1/3/2016.
[29] Note taken during laboratory visit 8/6/2016.
[30] Note taken during team meeting 5/4/2016.

analysed by computed tomography. The latter also added further encouragement to a change in their mathematics, turning each filament into a truncated cone rather than leaving them as cylinders. In time, with more collaboration and more reading, the idea to treat the whole parachute of the pappus as a porous disk also began to emerge so that, as one of the lead postdocs explained "We want to distinguish between whether it is behaving like independent filaments or like a disk".[31] Such were the origins of 'plot 5' referred to earlier, which actually only emerged some months into the project, though still before the flow visualisation experiments were attempted. We have here an example of the way new plots can be drawn into the narrative when they are found to be useful. Finally, in another team meeting, after the group watched a video of a seed parachute folding up on contact with water, one of the PIs became particularly excited by this possibility: "for us what we want is a similar video for all the aerodynamic properties working on the [individual] seed. A second video showing how different conditions change the trajectories. This is how you motivate doing the mathematics model."[32] Imagining a range of future videos was a way of thinking about the seed aerodynamics and future expert audiences all at once.

3.2 Narrative helping others to see

The photographs and videos produced by the flow visualisation experiment have been central to the successes of the dandelion project. An example is included here as Figure 3, further examples can be found in their *Nature* paper, and another won an annual photography competition organised by the UK Fluids Network, a national special interest group of researchers in fluid dynamics. The photographic results showed that there was indeed an interesting vortex phenomena being created by the seed, which for a brief period of time was referred to as a 'halo vortex'. This name was lost prior to publication, in exchange for something that conveyed more information about the phenomena (we could conceive of the halo name as too 'thin'), though as you can see, halo vortex pays tribute to the immediately interesting features. "We found a stable air bubble (a vortex ring)

[31] Note taken during laboratory visit 4/10/2016.
[32] Note taken during team meeting 1/3/2016.

that is detached from the body, yet steadily remains a fixed distance downstream of the pappus...Bluff bodies (such as circular disks) may generate vortex rings in their wake, but these are either attached to the body or shed from it and advected downstream. The vortex ring in the wake of the pappus is neither attached nor advected downstream, and we therefore called this vortex a separated vortex ring (SVR)."[33] Though some might disagree on final interpretation, there is little arguing with the evidence of a vortex being produced, remaining stable, and its being detached, as recorded in these videos and photographs. Indeed these images alone are enough to command attention, motivating an appreciation of the broader and deeper claims that the dandelion team want to make about the flow behaviours seen here and their presence in nature. Without all of the work that went into their initial epistemic positioning, these images could risk being interpreted too thinly. Convincing a wider community of experts of their significances requires a different kind of epistemic positioning, one in which narrative again plays a key role.

These visualisations are persuasive thanks to narrative in ways similar to arguments made by Norton Wise in the context of chemistry.[34] For Norton Wise, different methods for visualising research and research outputs are essential for making complex phenomena legible. As he writes "visualization is the only effective means for following a [complex] process". We have already seen that the engineers and scientists in my case placed a great deal of emphasis on being able to *see*, by various different means, what was or might be happening, emphasising the need to make movies of the phenomena where possible. Norton Wise goes on to argue that the ways in which visualisations convince us of new knowledge is largely thanks to their narrative features, drawing on the work of philosopher Louis Mink concerning the making of historical narratives, and what Mink terms synoptic judgement. Mink was interested in explaining what is happening when a historian draws together a range of different influences and causes to produce a historical narrative, to make coherence out of that complexity. As Mink wrote in

[33] Cummins et al. 2018, p. 414.
[34] Norton Wise, 2017.

1966 “the distinctive characteristic of historical understanding consists in ‘seeing things together’ in a total and synoptic judgement which cannot be replaced by any analytic technique”.[35] Norton Wise goes beyond Mink by demonstrating the presence of this kind of analytical approach in the sciences. Complex phenomena are made manageable thanks to some abstracting assumptions and the making of videos and images that we can watch and interpret for ourselves, based on past experiences and understandings. Elements of this form of understanding and ‘seeing together’ – both in the sense of seeing parts of the phenomena al together and also seeing with other people – are present in the dandelion case.

On seeing photographs such as Figure 3, and the set of photographs that it comes from, we are given a visual guide into something that is otherwise overwhelmingly complex. It is not as though this picture is detailing how or why the smoke particles make this arrangement, or trying to provide the mathematical or structural insights into their production. Much of the article publishing these results is indeed arguing for particular answers to these questions, but those potential answers are given credence and made worthy of our attention by the stark flow visualisation results. The community of researchers see the point that the flow visualisation results are making because the photograph delivers it to us, whatever that ‘it’ might be, all at once. A shared epistemic position concerning the presence of the SVR is made possible by slowing the phenomena down, to a snapshot, and by magnifying it to a scale we can more easily see.

The videos go on to create an opportunity for shared epistemic positioning all of their own. The first shows a freely floating seed passing through the plane of illumination, out of focus, then in focus, then out again, allowing us to see the vortex in cross section. In comparison with the photographs it is less easy to see the shape of the flow, and we lose the stability of the photograph, but in return we gain dynamism. We see how much the presence of the swirling vortex is directly dependent on the presence or absence of the seed, rather than some feature of the

[35] Mink, Louis (1987). *Historical understanding*. Edited by Brian Fay, I. O. Golob, & R. T. Vann. Ithaca and London: Cornell University Press, as quoted in Norton Wise, 2017.

apparatus, and that the vortex does not seem to disturb the seed. Everything looks *right*. This video also primes us for the later ones, in which the seed is fixed to a solid support so that higher and higher rates of flow can be used without it disappearing off into the air. They provide a translational sequence of events demonstrating how alike the vortex is both when the seed is free *and* when it is fixed, further developing our general sense of the phenomena and how it works, and the extent to which the experimenters are providing a reliable account of the phenomena. When it comes to their argument that the explanation for the phenomena is due to the overall head of the pappus acting as a more or less porous disk, they include further video evidence, but this time of silicon disks of their own fabrication, designed to emulate the pappus structure. The collection of videos and photographs produce their own narratives but also a sequence: first they show the new phenomena; then they decompose it into the parts that are believed to matter most; then they demonstrate the presence of detached vortices that do not shed but which are now due to the silicon disks. The argument of their paper, and their results, can be grasped at once thanks to these visualisations, which facilitate a shared epistemic positioning. This process continues in the publication. For instance, it is explained that they used the same ten seeds for both the free flying and the fixed flow visualisation experiments.[36] The reader is asked to step inside the experimental process from start to finish, see how correspondences were made, where trust can reside, how the phenomena behaves, and so on. In the interdisciplinary setting of a biological engineering project such evidence is all the more valuable, allowing different kinds of experts to appreciate the arguments being made without needing to understand every element in full.

4. Conclusion

This chapter has drawn upon analyses from literary studies and the philosophy of history in order to explore new terrain in the philosophy of engineering concerning question formation and the interpretation of evidence. The concepts of tellability and synoptic judgement, as developed for literary and historical analysis of narrative, have been applied to a case intersecting biology and engineering and

[36] Cummins et al. 2018, p. 419.

brought together as contributing to the larger function of epistemic positioning. I have by no means exhausted the number of ways in which, and times when, epistemic positioning is achieved in engineering and the sciences (with or without narrative), and the question of how narrative contributes to a whole host of other epistemic functions (outside of positioning), has barely begun. Both of these paths invite further attention.

A focus on narrative in epistemic positioning has also achieved a number of other goods that are worth reflecting on. First, attending to narrative's role in epistemic positioning allows us to deal with interdisciplinary contexts quite naturally, because the ability to draw in numerous and potentially unconnected plots is precisely the activity that we search for. Second, epistemic positioning seen through the lens of narrative is clearly an active process that responds to changes in circumstances and results as they emerge over time. We therefore avoid frameworks that treat research questions as something more static.[37] Third, narrative has been a useful way to get at practices as they relate to theory and evidence, rather than treating these individual elements in isolation. As the philosophy of science edges ever-closer to a phenomenology of experimentation, as can be glimpsed in a recent edited collection on *Scientific Understanding*, narrative can potentially play an important integrative role.[38]

If narrative is readily recognised as an important part of the epistemic work in different areas of engineering and technology, then now is a good time for philosophers of engineering to begin exploring and explaining these functions more explicitly. Likewise, historians and philosophers of science invested in narrative can and should draw upon examples taken from technology and engineering. Remembering and articulating the importance of such integration is a generic point, but one still in need of stating.

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[37] My thanks to Mary S. Morgan for suggesting this additional benefit.
[38] De Regt, Henk W., Sabina Leonelli and Kai Eigner eds. *Scientific Understanding: Philosophical Perspectives*, eds. Pittsburgh: University of Pittsburgh Press.

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Figure 1: Simple schematic of the dandelion seed. A real dandelion pappus contains hundreds of filaments.

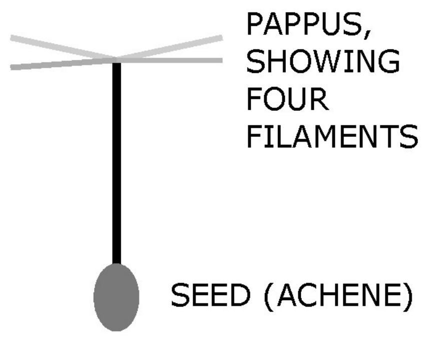
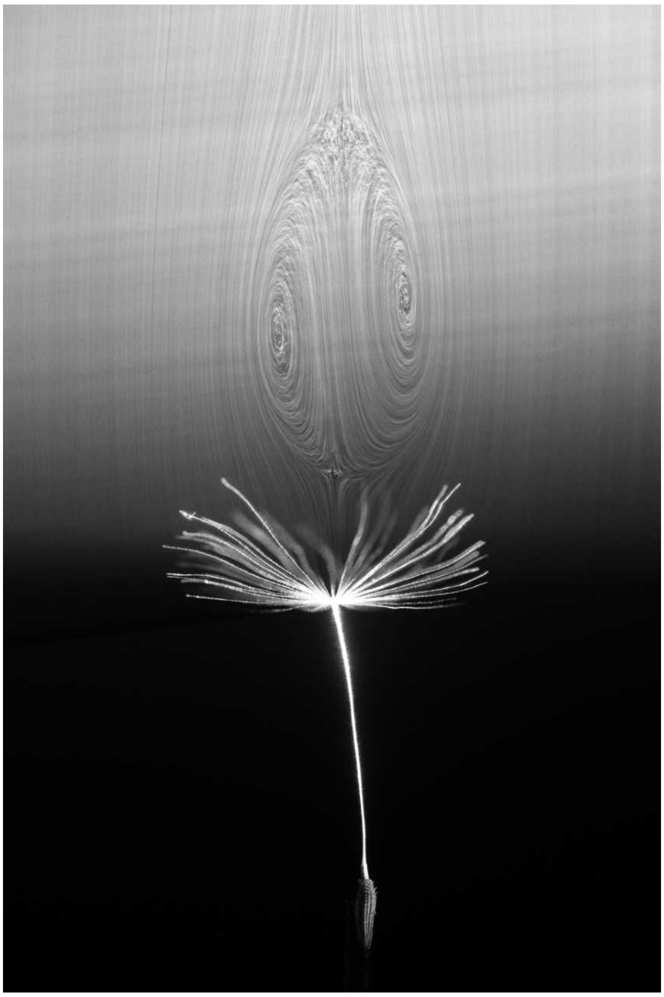


Figure 2: Very early iteration of the apparatus needed for the flow visualisation experiments. This was a prototype setup used to test generally important features, such as ability to control airflow rate, ease of focussing on the seed with camera equipment, and the different kinds of gauze or other flow stabilising materials that might be needed.

Figure 3: Illustrative example of one of the many flow visualisation photographs taken showing the presence of an 'SVR'. Photograph kindly provided by, and credit to, Cathal Cummins, Madeleine Seale, Enrico Mastropaolo, Ignazio Maria Viola, and Naomi Nakayama.



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