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Opinion: *Discovery in the Everyday Practice of Science: Abduction and the Logic of Unintended Experiments*

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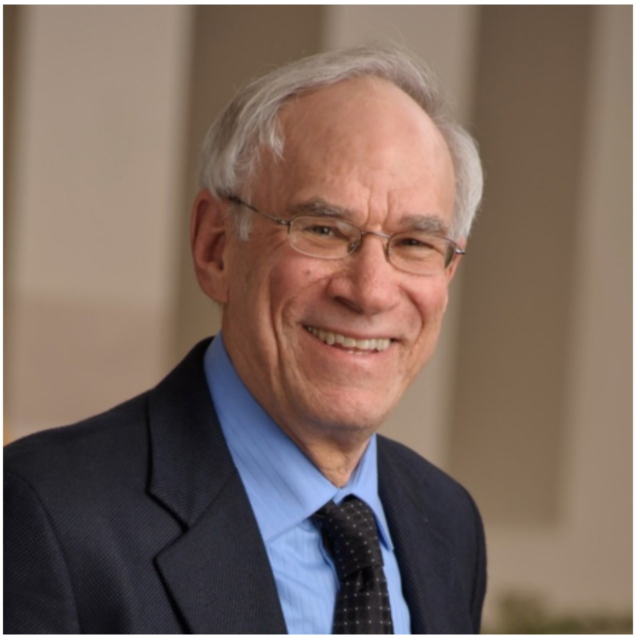
Introduction

Generating new ideas – innovation and novelty – is central to what those of us practicing science hope to accomplish. We call it research, but what we really aim for is new-search – discovering new things about the world and how it works. Contrary to the idealised view of science practice typically portrayed in science education, it is important for students to understand that the path to discovery tends to be an adventure, highly ambiguous and convoluted. When scientists write their research papers, they recast these adventures into stories that follow a linear path from hypothesis to discovery and, as a result, hide the real-world complexity of practice. The plot of every good science paper is the scientific method (Grinnell 2009).

Surprisingly, some of the most important experiments leading to discoveries are unintended. The American philosopher and logician Charles Peirce, inventor of pragmatism, gave the name "abduction" to what he described as the only logical operation that introduces any new idea. Peirce's logic of abduction,



> The surprising fact, C, is observed.
> But if A were true, then C would be a matter of course.
> Hence, there is reason to suspect that A is true. (CP 5.189, EP 2:231, 1903)

corresponds exactly to what I think of as the logic of unintended experiments.

The Conventional View of Abduction and Sherlock Holmes

One longstanding view in philosophy equates abduction with the idea of inference to the best explanation (IBE) (Harman 1965, Lipton 2003). Not all philosophers agree. Some argue that in his later writing Peirce meant to emphasise abduction as generating rather than testing explanatory hypotheses, whereas IBE is more concerned with evaluating hypotheses that have already been generated (Minnameier 2004, Campos 2011, Mcauliffe 2015). Others suggest that abduction is neither generating nor evaluating, but rather selecting which hypotheses should be evaluated, i.e., which are pursuit worthy (Laudan 1978, McKaughan 2008). And yet another point of view is that Peirce meant all of the above, i.e., abduction as insight and inference combined (Anderson 1986).

Sherlock Holmes' reasoning is often mentioned as representative of abductive thinking (Fann 1970, Eco and Sebeok 1983). Here is an example from the story "Silver Blaze" (Doyle 1905):

> Colonel Ross still wore an expression which showed the poor opinion which he had formed of my companion's [Holmes] ability, but I [Watson] saw by the inspector's face that his attention had been keenly aroused.
> Inspector: Is there any point to which you would wish to draw my attention?
> Holmes: To the curious incident of the dog in the night-time.
> Inspector: The dog did nothing in the night-time.
> Holmes: That was the curious incident.

Rewritten in the format of Peirce's logical scheme of abduction, the story becomes:

> The surprising fact C (the dog did nothing in the night-time) is observed.
> But if A (the dog was familiar with the killer) were true, then C would be a matter of course.
> Hence, there is reason to suspect that A (the dog was familiar with the killer) is true.

In the Sherlock Holmes story, the hypothesis – the dog was familiar with the killer – fits all three ways of understanding abduction – (i) a new hypothesis; (ii) a new hypothesis worth pursuing; and (iii) a likely explanation for what had happened (IBE). It is of particular importance for the discussion in this paper that in all three cases the surprising fact and corresponding abductive reasoning occurs within a particular context. Holmes was consulted to figure out who stole the race horse and committed the murder. He begins with a problem at hand, and he solves just that problem.

Lewis Thomas and the Case of the Floppy-Eared Rabbits

The following example from the history of science illustrates a different way to understand abduction. In April 1956, biomedical scientist Lewis Thomas published a report in the Journal of Experimental Medicine entitled "Reversible collapse of rabbit ears after intravenous papain, and prevention of recovery by cortisone" (Thomas 1956). The article begins:

> For reasons not relevant to the present discussion rabbits were injected intravenously with a solution of crude papain, and the following reactions occurred with unfailing regularity: Within 4 hours after injection, both ears were observed to be curled over at their tips. After 18 hours they had lost all of their normal rigidity and were collapsed limply at either side of the head, rather like the ears of spaniels. After 3 or 4 days, the ears became straightened and erect again.

The published paper included figure to illustrate the rabbit ears before and after papain treatment. The paper goes on to report additional experiments that showed that ear collapse was associated with a change in ear cartilage matrix; that similar changes occurred in all the other cartilage tissues of the rabbit's body; and that when the ears returned to normal shape, the cartilage matrix also had returned to its original characteristics.

When asked how the research had come about that led to this work, Thomas commented that five years earlier,

> I was trying to explore the notion that the cardiac and blood vessel lesions in certain hypersensitivity states may be due to release of proteolytic enzymes. It's an attractive idea on which there's little evidence… [Injecting several different enzymes including papain into rabbits intravenously was intended to test the hypothesis.] [W]hat papain did was always produce these bizarre cosmetic changes. It was one of the most uniform reactions I'd ever seen in biology. It always happened. And it looked as if something important must have happened to cause this reaction. (Barber and Rox 1958)

As in the case Silver Blaze, the case of the floppy-eared rabbits can be rewritten according to the logic of abduction.

> The surprising fact C (i.v. papain injection caused rabbit ear flop) is observed.
> But if A (rabbit ear rigidity depends on a papain-sensitive mechanism) were true, then C would be a matter of course.
> Hence, there is reason to suspect that A (rabbit ear rigidity depends on a papain-sensitive mechanism) is true.

The abductive format is the same as in the Sherlock Holmes case but incorporates an important added feature. Unlike Holmes and the mystery of Silver Blaze, the surprising fact of the ear flop was irrelevant to the question at hand, viz., the role of i.v. proteolytic enzymes in cardiac and blood vessel lesions in hypersensitivity states. Instead, the surprising fact suggested a new problem – the mechanism underlying rabbit ear rigidity – a question that Thomas had not thought about before observing the surprising experimental results. His findings about rabbit ear flop contributed to the emergence of a new problem and research field – proteinases and destruction of cartilage matrix – a potential mechanism of osteoarthritis.

Peirce described the connecting link between perception and abduction as a gestalt switch. The gestalt switch in Lewis Thomas's experience can be understood as follows: Thomas began with an intended hypothesis to test – do i.v. enzymes cause cardiac and blood vessel lesions such as occur in hypertension? Since the observation didn't advance understanding of blood vessel lesions in any obvious way, Thomas could have simply moved on to experiments that focused on other possible puzzle pieces (e.g., other enzymes or other potential causes of damage). The abductive moment – gestalt switch – came about when Thomas reframed the unexpected observation in the context of a different question – does the mechanism of rabbit ear rigidity depend on an i.v. papain sensitive mechanism? If one were interested in the latter question, then injecting i.v. papain would have been a very good experiment to carry out. The surprising rabbit ear flop observation would no longer be surprising in the context of the second research puzzle. Thomas had carried out an unintended experiment.

As I will discuss later, for Lewis Thomas (or any researcher) to follow up the results of an unintended experiment is a potentially risky choice. Peirce embraced the value of accepting this risk when he contrasted hypotheses that offered security (likely correctness) with those that offer uberty (fruitful potential). As the Editors of EP 2 put it, "Deductive reasoning provides the most security, but little uberty, while abduction provides much uberty but almost no security" (EP 2:463, 1913).

In "On the Logic of Drawing History from Ancient Documents," Peirce describes abduction as leading to discovery of entirely new research problems. The scientific impulse will always be in the position of striving to reconcile the new to the old. "Thus it is," he writes,

> that all knowledge begins by the discovery that there has been an erroneous expectation of which we had before hardly been conscious. Each branch of science begins with a new phenomenon which violates a sort of negative subconscious expectation, like the frog's legs of Signora Galvani. (CP 7.188, EP 2:88, 1901)

Abduction in the Larger Scheme of Research

In his dialogue Meno, Plato has the title character ask: "How will you look for it, Socrates, when you do not know at all what it is?"(§80d) Discovery at the edge of knowledge means looking for something without being exactly sure what it looks like and guessing what might be the answer (Tschaepe 2013).

Conducting an experiment to test a hypothesis begins with an investigator's explicit and implicit assumptions. Explicit assumptions concern the experimental question to be tested and the imagined likely results to be obtained. Implicit assumptions concern the adequacy of the experimental design and methodology selected to accomplish the research.Since the answer is not known in advance, every experiment tests both explicit and implicit assumptions.

Because of the ambiguity of experimental design, failure to get the expected results might be the result of a wrong hypothesis or inadequate experimental design. Max Delbrück, a winner of the 1969 Nobel Prize in Physiology or Medicine and one of the founders of modern molecular genetics, called this ambiguity the principle of limited sloppiness – sloppiness in the sense that our knowledge about any system under investigation is always muddy – never completely clear Hayes, 1982 #42. As a result, during our experiments, we sometimes test unintended questions as well as those explicitly intended.

Experiments typically fit into one of three categories: heuristic, demonstrative, and failed Fleck, 1979 #35. Heuristic experiments offer researchers new insights into the problem under investigation. Demonstrative experiments clarify heuristic findings into a form suitable for making discovery claims public, what philosophers typically call the logic of justification. Failed experiments, perhaps the most common, are those that yield results that are inconclusive or uninterpretable, which may occur for many reasons including technical errors, mistaken assumptions about methods, and poor study design. As a result, in research publications, ten research notebooks frequently can be represented by ten figures.

Surprising observations, at least initially, typically are assumed to be failed experiments.

Are you sure the dog did nothing in the nighttime?
Are you sure something else didn't happen to the rabbits besides papain injection?
Are you sure the culture dishes weren't dirty?

Even once observed and confirmed, surprising observations sometimes will be ignored as technical problems to be overcome. Experienced researchers know – Don't give up a good hypothesis just because the data do not fit.

Surprising facts that become moments of abduction are often labeled instances of serendipity in science. Sir Peter Medawar, who in 1960 won a Nobel Prize in Physiology or Medicine for his work on transplantation immunology, liked to point out that there is a big difference between finding a winning lottery ticket and buying one. The researcher who buys a lot of tickets puts himself in the winning way – creates opportunities for discovery to occur (Medawar 1984). Serendipity is all about opportunity. Abduction goes further and requires noticing and making the gestalt switch.

Understanding the impact of unintended experiments is important not only to following the history of science, but also to promoting the likelihood of a researcher's success in the laboratory or field. Becoming self-aware and open to noticing the unexpected will facilitate discovery. Nothing noticed – novelty lost!

Why "Surprise" Matters

Most philosophers don't take seriously the "surprise" in Peirce's abduction scheme. Why do I say that? When Gilbert Harman (1965) writes that IBE corresponds to approximately what others have called "abduction," he uses examples in which surprise doesn't figure. Peirce, on the other hand, takes surprise very seriously. Jaime Nubiola (2005) counted 127 appearances of the word "surprise" in the Collected Papers and suggested calling abduction the logic of surprise.

Surprise is critical to the sense of abduction that I am describing for two reasons. The first reason is that the surprising fact must be sufficiently surprising to attract a researcher's attention. Results that fall outside a researcher's expectations will often go unnoticed. Things haven't changed since Claude Bernard, one of the founders of modern biomedical research, wrote 150 years ago that,

> [m]en who have excessive faith in their theories or ideas are not only ill prepared for making discoveries; they also make very poor observations. Of necessity, they observe with a preconceived idea, and when they devise an experiment, they can see, in its results, only a confirmation of their theory. In this way they distort observations and often neglect very important facts because they do not further their aim. (Bernard 1957)

Most of us are not like Sherlock Holmes. His ability to notice everything is what makes him so appealing. The rest of us, like Watson, tend to overlook the unexpected or sometimes the absence of the expected.

The second reason that surprise is critical to the sense of abduction that I am describing is that the surprising fact must be sufficiently intriguing to overcome the resistance of a researcher to considering focusing on a new problem for investigation. When one decides to study a research problem, they take for granted important assumptions: that there is a question unanswered; that the question will be worthwhile answering; and that the infrastructure, personnel, and financial resources necessary to succeed are available. Time, energy and money are limiting resources in laboratory life. Starting something new is risky. Investing in one project almost always means that something else will not be accomplished. Failure could slow down or even end one's career in science. The surprising fact and new research problem that it brings to mind must be sufficiently surprising to abduct the researcher's mind away from the initial problem at hand to pursue studies on a new project.

Final Comment

In conclusion, I am suggesting that incorporating the idea of abduction and unintended experiments into science education represents an important means to introduce science students to the adventure of science. That is, to understand that for a research scientist doing experimental work, abduction sometimes describes the logic of a surprising observation that becomes reconfigured as an unintended experiment about an entirely new research problem. The consequences can be transformative, leading to a new research trajectory. Looking back on one's life in science, researchers often will be able to understand their experiences as histories of abductive moments gained or (in retrospect) lost.

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