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Harvey's bloody motion: Creativity in science

Abstract: In this paper, we show how the discovery of the circulation of the blood by William Harvey (1578-1657) sheds new light on traditional models of creativity in science. In particular, the example illustrates where both the enlightenment and the romantic view on creativity go astray. In the first section, we sketch the two views and present a (non-exhaustive) list of problems for both. In the remainder of the paper, we demonstrate how William Harvey's discovery, as a historical case study of creativity in science, gives firmer ground to these objections.

Our argument goes as follows: First, we show that Harvey is a child of his time as his reasoning is influenced by Aristotle, Galen and the school of Padua (section 2). Second, we indicate how analogies play a considerable role in Harvey's reasoning aside from their usual argumentative value (section 3). Third, Harvey's 'quantitative argument' captures an inherent struggle and reveals a new take on experiments (section 4). Fourth, we elaborate on the dimension of touch in Harvey's use of experiments (section 5). Fifth, vivisection as a research method places Harvey for a dilemma (section 6). Sixth, we engage in the discussion of whether Harvey was an Aristotelian or not, not to solve it, but to argue for his particular historical position (section 7). To conclude (section 8), we spell out the effect of this brief analysis for (A) traditional models of creativity in science and (B) Harvey's historical position.

1. Models of creativity in science

When talking about creativity, one traditionally draws the line between a context of discovery[1], which displays an irrational or 'Eureka' moment, and a context of justification, which exhibits a purely rational dynamic. Over the years several critical remarks arose against Hans Reichenbach's distinction (Reichenbach, 1938).

On the one hand, from 1958 onwards with Norwood Russell Hanson's influential 'Patterns of discovery', the distinction came under attack. Many argued that this distinction needed to be refined by introducing an intermediate step. A third context was supposed to cover both the initial theory formation as well as its preliminary evaluation. Richard Tursman speaks of *"the logic of pursuit and/or of preliminary evaluation of hypotheses"* (Tursman, 1987: 13-14). Ernan McMullin speaks of a *"heuristic appraisal"*, which regards the research-potential of a theory (McMullin, 1976). Larry Laudan describes the intermediate step as *"the context of pursuit"* (Laudan, 1977), and Laurie Anne Whitt as *"theory promise"* or *"theory pursuit"* (Whitt, 1992) (Seselja & Kosolosky, 2012: 1-2). On the other hand, especially since the 1930's Karl Popper and several logical positivists (such as Rudolf Carnap and Carl G. Hempel) took over the distinction and insisted that only matters of justification, and not questions of discovery, obtain its place in philosophical discussion (Nickles, 1980: 1-2).

[1] We understand discovery here rather straightforward as *"a process of thought that leads from (at least partially) observational premises to cognitive conclusions, generally in the form of laws or theories"* (Pera, 1987: 177).

The distinction between context of discovery and context of justification translated itself in two models of creativity in science: Enlightenment and Romantic. In the enlightenment (or classical) model the rational discoverer is endowed with exceptional reasoning skills. Information is sufficient to logically deduce or induce a solution. Behind it lies the idea of the autonomous, individual agent who, in principle, accepts nothing on faith and makes decisions only after an independent application of critical reasoning. The romantic model portrays the discoverer as someone who is sensitive to patterned wholes and a lack of overall fit. At crucial moments in time (s)he experiences a brilliant flash of insight (Eureka) distancing oneself in this manner of common people (Nickles, 1994: 277-278). Standard objections against both models are: (1) they are too individualistic, since they discard the difficulty of locating major historical discoveries. *"The bigger the discovery, the more time it typically takes to work out and articulate the conceptual and instrumental breakthroughs in question, an activity that normally involves many members of the community, including critics"* (Nickles, 1994: 279). (2) They endorse a Whiggish view on science by reading recent developments back into the original observations and concepts. They leave out the role of critical discussion by the larger community over a certain period of time (Nickles, 1994: 279-280). (3) They misrepresent what assigning credit for a discovery entails: *"When scientists assign credit for a discovery, they are doing more than stating an historical fact (that person P discovered that D), they are simultaneously legitimating the corresponding claim and technique, which are usually presented as an extension of an older practice, a continuation of an older tradition"* (Nickles, 1994: 279). (4) There is more not less innovation in science than commonly thought (Nickles, 1994: 280). In the remainder of the paper we investigate in detail how Harvey discovered the circulation of the blood and what brought him to this idea in the first place. This case study serves a dual purpose: on the one hand, it illustrates the theoretically conceived shortcomings of both models of creativity from an historical viewpoint, and, on the other hand, zooming in on these objections allows us to pinpoint the historical Harvey [2].

2. Influenced by…

Harvey, being a child of his time, was influenced by important figures[3], such as Aristotle, Galen, Colombo and Fabricius[4]. According to Aristotle (384-322 BC) the problem of the movement of the heart is the central project for a physician (Pagel, 1944: 145). Harvey, in pursuing this project, took Aristotle's view of the heart as the center of the physiological mechanism (Aird, 2011: 119) and was acquainted with the Aristotelian idea of circular motion as the perfect motion, since there is no motion contrary to it (Pagel, 1944: 145). Galen's (131-207/216) medical doctrine influenced Harvey in at least four ways: (1) Galen introduced the distinction between the venal and arterial system. (2) He endorsed Hippocratic dietetic

[2] We focus on Harvey's main works: 'Prelectionis Anatomiae Universalis' (1616) and 'Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus' (1628) and 'De Generatione Animalium' (1651).

[3] Not only people influenced Harvey, but also tangible inventions in engineering. Boyle claims, in his paper, that a prototype of the sluice gate (the Porte Contarine lock), together with the first pound lock constructed on the Thames, provided Harvey with the decisive model for the function of the venous membranes to obstruct reflux of the blood (Boyle, 2008).

[4] Other examples are Andreas Vesalius (1514-64), Michael Servetus (1511-1553), Andrea Casalpino (1519-1603), Salomon Alberti (1540-1600) and Sanctorius (1561-1636).

and humoral theory in medical practice, based on the 'normality interpretation'[5]. Physicians were thus cautious of learning from dissection (= concerns dead bodies that are not representative for the normal state of the living body) and vivisection (= causes a violent disruption of the normal state of the body). (3) Galen stressed that organs have an attractive force or faculty. In the case of the heart the active process, according to Galen, is the diastole (or expansion) *"[…] during which the heart snatches up or sucks in the inflowing blood like a smith's bellow or sponge."* (Aird, 2011: 121) (4) Galen pinpointed the centrifugal flow of the venal blood, or the flow of the blood from the liver and the heart to outer parts of the body. Another major influence on Harvey was the time spent at the School of Padua, where he interacted with Realdo Colombo (1516-59) and Girolamo Fabricius (1537-1619) (Aird, 2011: 123). Colombo was the first person to portray the pulmonary transit of blood from the right ventricle of the heart to the left. He thus had prior insight in the heart, although his writing was rather ambiguous[6]. Colombo had a dual impact on Harvey: (1) He demonstrated that Galen's work was not devoid of mistakes and (2) he used vivisection as a method to trace these mistakes[7]. Fabricius was the one who prior to Harvey discovered the valves in the veins[8]. This section sketched out some ideas and (minor) discoveries originating in Harvey's (immediate) environment, which, as we will show in the following sections, influenced Harvey in devising the circulation of the blood.

3. Analogies at play

The reason we briefly touch upon Harvey's use of analogies is that they play a crucial role in his reasoning, which surpasses their ordinary argumentative value. We present two examples to illustrate this claim:[9]

I. Analogy as a means to extrapolate

Harvey was able to discern the movement and the action of the heart in fish. But, these observations could not automatically lead to the construction of universals or generalization towards the heart of

[5] A body is considered healthy (or normal) if there is a balance of the four humors, i.e. black bile, yellow bile, phlegm and blood. *"Disease was attributed to an imbalance of humors or a shift in the patterns of flow within the body"* (Aird, 2011: 118).

[6] Colombo confused systole, which is now regarded to be the active movement of the heart (or contraction) with a moment of rest. Diastole was understood as the constriction of the heart (Provijn, under review: 6-7).

[7] We get back to this in section 6.

[8] Both Colombo and Fabricius modified Galen's paradigm, so the *"[…] revival of experimental investigation in the 1500s, while opening the door to progress, did not lead to the downfall of Galen's system of physiology. So persuasive was Galen's theory that these new findings were simply integrated as small modifications into the ancient scheme."* (Aird, 2011: 124) Fabricius, for example, replaced Galen's notion of an 'attractive power', which Galen postulated to keep the blood from falling down into the lower parts of limbs, with a more mechanical explanation. Fabricius thought that ostiola or valves function not as one-way valves (as Harvey later on defended), but only as hindrances to the blood's outward flow. Based on this function, Fabricius argued that the purpose of the valves was to slow the blood's flow, preventing it from collecting too rapidly in the body's extremities (McMullen, 1995: 492).

[9] Other examples are (1) the analogy of the glove (Illustrates the possibility of a passive pulse), and (2) the analogy of the pulmonary transit (The transit of blood may have functioned as an analogue that facilitated to conceive of the transit of blood from the left ventricle throughout the body back to the heart, considering the pulmonary transit as the lesser circulation preceding and contributing to the conception of the full circulation) (Provijn, under review: 13-14).

man, since the structure of the hearts differed considerably. Harvey, guided by the supposition that all hearts have the same function and display analogous processes[10], extrapolates his findings from animal vivisections. To justify this extrapolation, Harvey made use of analogies:

> The same thing is also not difficult of demonstration in those animals that have, as it were, no more than a single ventricle to the heart, such as toads, frogs, serpents, and lizards, which have lungs in a certain sense, as they have a voice. […] Their anatomy plainly shows us that the blood is transferred in them from the veins to the arteries in the same manner as in higher animals, viz., by the action of the heart; the way, in fact, is patent, open, manifest; there is no difficulty, no room for doubt about it; for in them the matter stands *precisely as it would* in man were the septum of his heart perforated or removed, or one ventricle made out of two; and this being the case, I imagine that no one will doubt as to the way by which the blood may pass from the veins into the arteries (Harvey, De Motu Cordis, ch.6: 19, own emphasis).

This extrapolation is unique since Harvey extensively vivisected cold-blooded animals and relied on an unseen number of data to draw conclusions on the possible movement and action of the heart in warm-blooded animals and man, which was a dangerous route to pursue at that time (section 2 and 5).

II. The analogy of the muscle

Harvey draws an analogy between the movement of the heart and the contraction of a muscle:

> […] the motion is plainly of the same nature *as that* of the muscles when they contract in the line of their sinews and fibres; for the muscles, when in action, acquire vigor and tenseness, and from soft become hard, prominent, and thickened: and in the same manner the heart (Harvey, De Motu Cordis, ch.2: 10, own emphasis).

This analogy was never drawn by Colombo and was even opposed by Galen. Galen believed that the heart could not be a muscle since all muscles are held to move with a voluntary motion (Aird, 2011). In this manner Harvey opposed tradition, since the analogy allowed him to suppose the contrary claim that the cavities of the heart must become smaller during systole and that blood is trusted out. He could support this further by the observations he made in fish and other cold-blooded animals.

Analogical reasoning thus serves a larger purpose in Harvey's reasoning: Harvey uses analogical reasoning to draw conclusions on the movement of the heart that certainly occurs in cold-blooded animals (i.e. II) and uses extrapolation to draw the same conclusion for warm-blooded animals (i.e. I). So (I) and (II) combined enabled Harvey to describe the proper movement of the heart and how it related to the propulsive action of the heart, more convincingly than Colombo managed to do before.

4. Quantitative argument[11]

[10] Despite there being morphological differences.

[11] The 'quantitative argument' refers to Harvey's argument against Galen that no matter how much blood is injected into the artery if you multiply this amount by the number of beats per hour of a typical heart it becomes clear that more blood than present in the entire body passes through the heart in a single hour (Lennox, 2006: 18-21).

Harvey experienced drawbacks and difficulties in an attempt to match his new findings on the heart (section 3) with the dominant Galenic cardio-vascular system:

> […] what remains to be said upon the quantity and source of the blood which thus passes is of a character so novel and unheard-of that I not only fear injury to myself from the envy of a few, but I tremble lest I have mankind at large from my enemies, […] And sooth to say, (a) when I surveyed my mass of evidence, whether derived from (b) vivisections, and my various reflections on them, or from the study of the ventricles of the heart and the vessels that enter into and issue from them, the symmetry and size of these conduits, - (d) for nature doing nothing in vain, would never have given them so large a relative size without a purpose, - or (c) from observing the arrangement and intimate structure of the valves in particular, and of the other parts of the heart in general, with many things besides,
>
> I frequently and seriously bethought me, and long revolved in my mind, what might be the quantity of blood which was transmitted, in how short a time its passage might be effected, and the like. But not finding it possible that this could be supplied by the juices of the ingested aliment without the veins on the one hand becoming drained, and the arteries on the other getting ruptured through the excessive charge of blood, unless the blood should somehow find its way from the arteries into the veins, and so return to the right side of the heart, […] (De Motu Cordis, ch.8: 25, own emphasis and introduction of (a), (b), (c) and (d)).

The second half of the quote shows how Harvey, in safeguarding his own theses on the forceful systole and the propulsive action of the heart, had to find a solution to this quantitative problem. His solution: the circulation of the blood, which *"[…] implied that blood was not constantly being consumed in the periphery and replenished by ingested nutrients, but rather that blood was conserved."* (Aird, 2011: 119) Strikingly Harvey argued for his solution by using a thought experiment. He explicitly requests his readers to take an educated guess on the amount of blood that is injected into the arteries. No matter what the answer would be, if we calculate the amount of blood that is to pass through the heart each hour, the exuberant number shows Galen's system to be flawed (Lennox, 2006: 18-19)[12]. This thought experiment must have played a major role in the actual discovery process, for at least two reasons: First, when we judge Harvey's testimony above as trustworthy it illustrates to the historian of science how the thought experiment played a central role in discovery. Second, because Harvey requests an input from the reader by endorsing a 'try this for yourself and see what happens'-mentality (Salter & Wolfe, 2009: 117), we are safe to say that Harvey performed it many times himself (De Mey, 2006: 234-235).

This first half of the quote, however, sheds new light on the empiricist toolbox Harvey considered to be available to him. Harvey uses various (a) equal means of searching for possible solutions, such as (b) experiments, (c) observations and (d) philosophical principles (Salter & Wolfe, 2009: 120). Harvey's view prevents us from pinpointing him as a 'standard' empiricist supporting the distinction between experiments as valuable and observations as inferior knowledge. According to Harvey *"both involve the inspection of nature by sensory perception, both involve active intervention and both require repetition to validate and justify the conclusions they suggest"* (Salter & Wolfe, 2009: 119). Salter & Wolfe argue that labeling Harvey as an empiricist thus calls for a new notion of empiricism, namely medical/embodied empiricism, as opposed to the standard proof-and-validation experimentalism of Royal Society

[12] If we conceive of it this way, one could say Harvey's argument is arithmetic without being quantitative since the exact quantities do not matter.

empiricism (Salter & Wolfe, 2009). Further arguments for this kind of empiricism will be given in the next section, as we present the ligature experiment.

5. Experiment by touch

Harvey took notice of the placing of the valves in the veins and, correspondingly, the flow of the blood in the body by performing the following experiment, which came to be known as the ligature experiment:

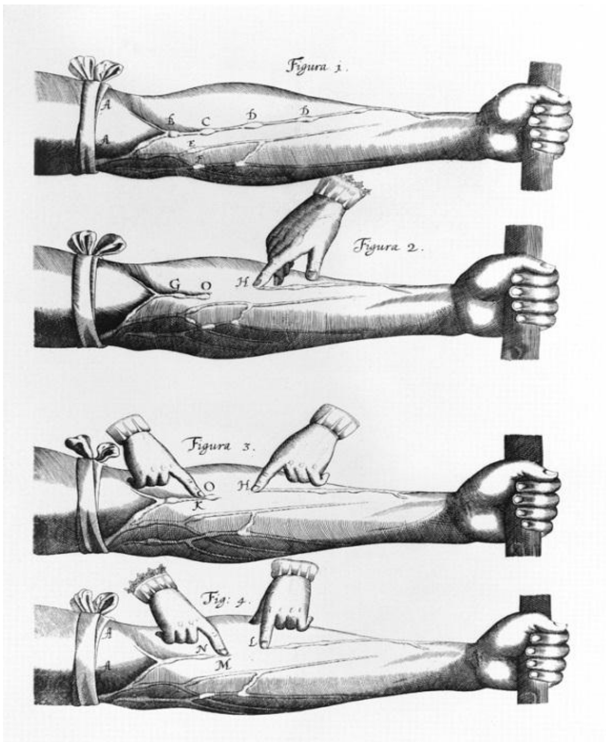

IMAGE Only illustration in William Harvey's De motu cordis, 1628
(Courtesy to the Wellcome Library)

Harvey presents this image (Fig. 1) of an arm prepared for bloodletting, i.e., with a ligature tightly bound around it to make the veins swell – with letters marking the position of the valves. In Fig. 2 a finger presses on valve H. The section of the vein below valve H (nearer to the heart) is shown to be empty of blood until the next valve along, valve O. The blood does not flow back through O to fill the vein. In Fig. 3 one finger presses on valve H, stopping the flow towards valve O, while another tries to push the blood from below valve O towards H; yet this section of the vein remains empty – because the valves are stopping the blood from flowing in this direction. However, (Fig. 4) on the opposite side (section M, between valve L and valve N) the vein can fill. Harvey has thus proven that blood flows around the body in one direction only, from the periphery to the heart.

The credibility of touch as an instrument of perception (in line with Harvey's work ethic of doing it yourself and feeling it yourself, see section 4) is, moreover emphatically illustrated by Harvey's inclusion in De Generatione Animalium (1651) of a nobleman Hugh Montgomery as the subject of Harvey's touch. Harvey recounts his live, beating heart which had been exposed by the injuries from a fall when still a child:

> I immediately saw a vast hole in his chest into which I could easily put my first three fingers and my thumb. At the same time I saw just inside the opening, some fleshy, projecting part which was driven backwards and forwards with an alternating movement, and I touched it very cautiously with my hand […] when I had investigated everything carefully enough, it was evident that the old vast ulcer […] was covered over on the inside with a membrane and guarded all round the edges with a hard skin (Harvey, 1651: 250).

The crucial experiment is, again, the experiment of the ligature – but it succeeded because of touch. Only touch could reveal the actual outward and inward flow of blood and the effect of the venous valves in preventing outward venous flow. Salter & Wolfe's conception of empiricism, as set out in section 4, fits in nicely with Harvey's sense of empiricism, since touch is the crucial characteristic in defining his particular way of experimenting. This kind of empiricism calls for a more 'first person sensitive' perspective, as became evident through Harvey's use of experiments[13].

6. Broadening constraint

Vivisection, as a method of reacting against established theories, served a peculiar role for Harvey. Observing the fast beating of the heart of warm-blooded animals after vivisection did not generate the perspicuous observations needed to draw conclusions on the real active movement of the heart. Harvey was just able to discern the two separate phases, i.e. systole and diastole, but it was impossible to pinpoint one of these as the proper movement. Harvey solved this observation problem by observing cold-blooded animals and dying hearts (section 3 and 4).

From a medical point of view, however, this is both problematic (section 2): (1) The dying heart, plus it being observed during vivisection, could hardly count for the normal situation, and (2) the hearts of cold-blooded animals diverged too much from the ones observed in warm-blooded animals (Provijn, under review: 8). As mentioned in section 4, Harvey tried to bridge this gap through the use of analogies. Vivisection as a method for Harvey could be characterized as, what we call, a 'broadening constraint'. On the one hand, as a natural philosopher it opened up opportunities for him to reject old theories and ground his observations with supplementary power. On the other hand, as a physician it constrained him in using these results and it required supplementary reasoning to convince his fellow physicians, which he found in a thought experiment (section 4), ligature experiment (section 5) and use of analogies (section 3). Understood in this sense, Harvey had the opportunity to be at the interface between being a natural philosopher and being a physician.

7. Conclusion

Our analysis of key factors in Harvey's discovery process sheds light on (A) existing models of creativity in science and (B) Harvey's historical position. Broadly conceived, this paper illustrates how we can understand a historical case in terms of specific characteristics from a philosophy of science perspective, and, vice versa, how a historical case can show us that certain models of scientific discovery and creativity are false, or at least not generalizable.

(A) First, throughout the paper we saw the objections raised against the two models of creativity reemerging:

(1) *Individualistic*: Harvey's ideas were part of a larger community (section 2), governed by critical discussion (section 4 and 5) and a difficulty to pinpoint certain discoveries (e.g. Colombo's part in the discovery of the systole and Fabricius' discovery of the valves in the veins).
(2) *Whiggish*: Since Harvey used the same terminology (e.g. systole, diastole) as his contemporaries, innovation and conceptual change are less straightforward (section 2). His critical interaction

[13] Salter & Wolfe, in understanding empiricism, draw out the following taxonomy: (i) A 'Royal Society', experimentalist empiricism, which may be the context in which an actual 'philosophy of experiment' emerges (i.e. Boyle and Bacon), (ii) A moral/practical empiricism, in which themes such as anti-innatism are in fact not epistemological, that is, not primarily reducible to concerns about the nature of knowledge or of the cognitive states of the knower, but are rather motivated by embedded concerns such as anti-authoritarianism and the desire to articulate a notion of toleration (i.e. Locke and Hume), and (iii) A medically motivated, 'embodied' empiricism (i.e. William Harvey, Pierre Gassendi, Thomas Sydenham) (Salter & Wolfe, 2009).

with Hofmann, Colombo and Fabricius illustrates the presence of critical discussion and assimilation in Harvey's discovery process.

(3) *Assigning credit*: Assigning credit to someone for a discovery entails a legitimation and extension of an older tradition (e.g. Galen, Aristotle, Colombo, Fabricius), combined with new perspectives (e.g. thought experiment, vivisection, role of touch in experiments, analogies).

(4) *More innovation*: Innovation goes in smaller steps (section 2) and experiences restrictions and drawbacks (section 4, 5 and 6), ascribing innovation to more people, since a discoverer is in essence a child of his time.

The example allows us to draw some more general tentative lessons on creativity in science. First, it seems that genuine discoveries are not a product of 'sparks of geniuses' rather than of long, demanding and complex problem-solving processes. Second, the study of creativity should focus on processes and not on products. We have to reconstruct all the elements underlying the process of invention, both historical and formal (i.e. use of analogies) if we aim to address the full extent of the matter. Third, there is nothing magically explanatory about the labels 'enlightenment' and 'romantic', of course both their utility and their potential to mislead should remind us that our ways of describing scientific work, especially innovative research, are tied to larger cultural contexts and are themselves historically conditioned (Nickles, 1994: 308).

(B) Second, we were able to roughly pinpoint the historical Harvey by stressing his interface position in three ways: experimentalist versus Aristotelian (section 2), natural philosopher versus physician (section 6), and embodied empiricist versus experimentalist empiricist (section 4 and 5). Harvey's Aristotelian past, on the one hand, helps him in coming up with possible directions (e.g. heart as central, circular motion), whereas, on the other hand, it also carries constraints (e.g. search for causa finalis). Moreover Harvey was able to combine skills of the natural philosopher and physician in spelling out his circular motion of the blood through, what we would call, an 'experiment/observation grounded thought experiment' (section 6). Last but not least, Harvey is no ordinary empiricist in the sense of Royal Society empiricism, since he places observation and experiment on an equal par (section 4). And so the empirical side of his discovery process consisted mainly of (i) the use of (ligature) experiments and vivisections (section 5 and 6), (ii) the finding of the symmetry and magnitude of the heart ventricles and associated vessels entering and leaving them, (iii) the perceiving of the skillful and careful craftsmanship of the heart valves, fibres and other structural artistry of the heart, (iv) knowing the amount and transmission time of the blood transmitted by the heart, and the fact that the ingested food could not supply this amount without us having the veins (section 4).

It is thus safe to conclude that Harvey represents the struggle between 'the old and the new' and that his intermediary/interface position captures the environment that enabled him to discover the circulation of the blood. This case study, moreover, calls for renewed attention to the study of creativity and discovery in science.

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