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Critics of the concept of a logic of discovery generally hold that discovery involves irrational, aesthetic and metaphoric components which preclude systematic description or reduction to an algorithmizable procedure (e.g. 1, 2). This paper reconsiders certain of the issues involved in this philosophical controversy and discusses the possibilities for computer simulation of inventive scientific thinking.

It has become increasingly clear via philosophical analysis and recent work in artificial intelligence, that traditional forms of logic fall short of providing an adequate description of the thinking underlying scientific discovery (3). For instance, Cohen (4) has shown that: "Newton derives his inverse square law of gravitation by a precise mathematical derivation from, among other things, Kepler's Third Law for planets. . .We can show logically that Newton's system contradicts Kepler's Third Law, while Newton coolly derives one from the other" (5, p. 260). Deductive logic does not seem to be the basis then for Newton's creativity in this instance. Inductive logic seems often to fare no better as an explanation for inventiveness: ". . .most of us cannot conceive that there might be rules that would lead us from laboratory data to theories as complex as quantum theory, general relativity, and the structure of DNA. Our shared archetypes of significant science virtually all involve theoretical entities and processes which are inferentially far removed from the data which they explain" (2, p. 178).

Inductive and deductive logic are incomplete models for a logic of discovery also in that often scientists do not begin with "valid" premises or "sound" data. Yet, they frequently arrive at theories and findings which are deemed highly significant and legitimate. So it was, for example, with Darwin who arrived at the theory of evolution — based on the concept of natural selection — from his monad theory which posited individual primitive life forms that arose spontaneously on a continual basis (6).

An overreliance on traditional logic may account for some of the limitations in contemporary computer simulations of scientific discovery processes (which are quite impressive nonetheless). Thus the Bacon ·1 and ·3 programmes must be given data free of noise to manipulate; lest the programmes' inductive processing be led astray. The ultimate consequence of such an approach is that these programmes can rediscover certain known empirical laws, such as the ideal gas law, but cannot generate new discoveries (7).

What other forms of logic might then be relevant to the problem of scientific discovery? The sort of logic required to account for, for instance, reformulations of problems into useful researchable ones is what Achinstein terms an "evaluative logic" (8). Such a logic would include rules for deciding on the plausibility and importance of research problems and "solutions". A theory might be considered more plausible if it accounts for more data or for puzzling empirical findings. Achinstein uses as an example Bohr's notion that the hydrogen atom consists of a nucleus around which a single electron revolves and sometimes jumps from one stable orbit to another. Achinstein contends that Bohr's hypothesis was considered plausible since it was useful in explaining the spectral lines present when hydrogen is excited by heat or electricity and emits light. Another example is Pauli's "discovery" of the neutrino. The concept of the neutrino was initially reluctantly accepted as plausible — despite the absence of empirical evidence for a "neutrino event" — because it could explain the failure of energy equations to balance before and after beta decay (9).

As the aforementioned examples illustrate, evaluative logic differs in important ways from deductive or inductive logic. It may lead to a concept or model in the absence of direct empirical support as in the case of Pauli's neutrino. In addition, evaluative logic is a flexible system which does not lead inexorably to any particular conclusions(s) as is the case with deductive logic. Thus Bohr's theory may have been a plausible one or the most plausible theory advanced at the time, however, the "logic" of the argument did not inherently preclude other possibilities.

Does this discussion not simply beg the question of how new ideas are generated in the first place, and substitute for that question the issue of theory justification? Gutting (10) holds that a logic of hypothesis generation is intimately linked to an evaluative logic which assesses ideas or models. As Gutting points out, the so-called truism that one can think of almost anything is false. He gives the following example: "Most people. . .even ones with sufficient intelligence and imagination, could not have thought of the hypothesis of electron spin. Only a scientist thinking of the atom in terms of a planetary model could have thought of such a hypothesis. On the other hand, the hypothesis is implicit in the model and so likely to occur to anyone who is seriously concerned with developing this model. So if the question is raised: Why did Goudsmit and Uhlenbeck think of the spin hypothesis? at least a significant part of the answer lies in a conceptual analysis of the nature of Bohr's model of the atom" (10, p. 224-225).

Thus discoveries occur given a particular historical and theoretical context. Such a context or background knowledge is not currently a significant feature of programmes such as the Bacon simulation attempts. It is as if the programme is largely expected to operate in a theoretical vacuum detecting regularities in the data which, as the programme's namesake Francis Bacon held, would "leap out" at the observer (7). However, in providing only "sound" data devoid of anomalies only a low level theoretical bias of a sort is built into the system. It seems that many attempts at simulating scientific discovery are, perhaps unwittingly, designed so as to be consistent with the notion that "science begins in the nothingness of ignorance" (11, p. 12). However, as Gould points out, theories always abound with the result that "science advances primarily by replacement not by addition" (11, p. 12).

Consider for instance Lavoisier's discovery of oxygen. It was his rejection of phlogiston chemical theory which was a prerequisite for development of the notion of combustion as due to a combination effect rather than a dissociation reaction. His contemporary, Priestly, did not reject phlogiston theory in the light of Lavoisier's evidence that combustion led to an increase in the weight of a burned compound and not a decrease as phlogiston theory necessitated. Priestly simply postulated that phlogiston has a "negative weight". This case illustrates Curd's point that: "The factors that justify our inferences to theories in the first place are the same as those that we use to decide which theory to pursue after they have been generated." (12, p. 215).

What is needed then are programmable rules which capture something of the logic of data and problem assessment given a particular theoretical framework. Also, required are higher order sets of rules that reflect on the theoretical assumptions upon which the programme operates. To accomplish this might be akin to equipping the programme with a metacognitive competency. Programmes such as Internist-I (13) come closer than others to operating on data given certain background knowledge e.g. a classification scheme for all possible diseases, and thus are more similar to the scientist who also comes to his research problem with a particular frame of reference. However, the Internist programmes, like the Bacon programmes, cannot make new discoveries e.g. a new disease is not generatable by Internist I or II. Perhaps in part this is because the metacognitive feature (for a lack of a better term) is absent. Fortunately, progress is being made in human research in the understanding of various aspects of metacognitive competencies (e.g. 14, 15, 16). Perhaps, the addition of a metacognitive component in computer simulations of scientific discovery processes will allow for more flexible programmes that make new discoveries, of a sort. Should the latter occur, a logic of discovery would not, as Wartofsky now claims, "dissolve the notion of creativity altogether" (1, p. 8).

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