state and set of operators (e.g., make "something pretty" with these materials and tools), or an ill-defined initial state and a well-defined final state (e.g., find a vaccine against HIV). But well-definedness depends on the familiarity of the problem-space elements, and this, in turn, depends on an interaction between the problem and the problem solver.

Although scientific problems are much less well-defined than the puzzles commonly studied in the psychology laboratory, they can be characterized in these terms. In both cases, well-definedness and familiarity depend not only on the problem, but also on the knowledge that is available to the scientist. For that reason, much of the training of scientists is aimed at increasing the degree of well-definedness of problems in their domain. The size of a problem space grows exponentially with the number of alternatives at each new step in the problem (e.g., the number of possible paths one must consider at each possible move when planning ahead in chess). Effective problem solving must constrain search to only a few such paths. Strong methods, when available, find solutions with little or no search. For example, in chess, there are many standard openings that allow experts to make their initial moves with little search. Similarly, someone who knows algebra can use simple linear equations to choose between two sets of fixed and variable costs when deciding which car to rent instead of painstakingly considering the implications of driving each car a different distance. But the problem solver must first recognize the fit between the given problem (renting a car) and the strong method (high school algebra).

Weak methods, requiring little knowledge of a problem's structure, do not constrain search as much. One particularly important weak method is analogy, which attempts to map a new problem onto one previously encountered, so that the new problem can be solved by a known procedure. However, the mapping may be quite complex, and it may fail to produce a solution.

Analogy enables the problem solver to shift the search from the given problem space to one in which the search may be more efficient, sometimes making available strong methods that greatly abridge search. Prior knowledge can then be used to plan the next steps of problem solving, replace whole segments of step-by-step search, or even suggest an immediate solution. The recognition mechanism uses this store of knowledge to interpret new situations as instances of previously encountered0.1 Tf [(ate 9.3r

ments or procedures. Breeding experiments go back to Mendel (and experiments for stock breeding go much further back), but the productivity of such experiments depended on mutation rates. Muller, with the simple idea that x-rays could induce higher rates of mutation, substantially raised that productivity.

C EA I I A D BLEM L I G I CIE CE A D BE D

Scientific discovery is a type of problem solving using both weak methods that are applicable in all disciplines and strong methods that are mainly domain-specific. Scientific discovery is based on heuristic search in problem spaces: spaces of instances, of hypotheses, of representations, of strategies, of instruments, and perhaps others. This heuristic search is controlled by general mechanisms such as trial-and-error, hill-climbing, means-ends analysis, analogy, and response to surprise. Recognition processes, evoked by familiar patterns in phenomena, access knowledge and strong methods in memory, linking the weak methods to the domain-specific mechanisms.

All of these constructs and processes are encountered in problem solving wherever it has been studied. A painter is not a scientist; nor is a scientist a lawyer or a cook. But they all use the same weak methods to help solve their respective problems. When their activity is described as search in a problem space, each can understand the rationale of the other's activity, however abstruse and arcane the contions or domain-specific search heuristics, and more reliance has to