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The impact of chess research on cognitive science

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Summary. Although chess research has not been a mainstream activity in cognitive science, it has had a significant impact on this field because of the experimental and theoretical tools it has provided. The two most-cited references in chess research, de Groot (1965) and Chase and Simon (1973 a), have accumulated over 250 citations each (*SSCI* and *SCI* sources summed), with the majority of citations coming a decade or more from their publication dates. Both works are frequently cited in contemporary cognitive-psychology textbooks. Chess playing provides a model task environment for the study of basic cognitive processes, such as perception, memory, and problem solving. It also offers a unique opportunity for the study of individual differences (chess expertise) because of Elo's (1965, 1978) development of a chess-skill rating scale. Chess has also enjoyed a privileged position in Artificial-Intelligence research as a model domain for exploring search and evaluation processes.

Introduction

Chess is a game with a very long history (see Hooper & Whyld, 1984). I am taking an admittedly narrow view of chess research in the interest of brevity, restricting discussion to experimental research that uses chess in one of three roles. The first role is as a subject of inquiry in its own right, usually to look at skill in chess. The second is as a convenient environment for the study of complex cognitive processes such as perception, problem solving, and memory. The third role concerns the use of chess playing as a convenient environment for exploring and developing theories about search mechanisms. Research fitting these qualifications dates from the late 1800s and early 1900s (e.g., Binet, 1893/1966, 1894; Cleveland, 1907), as de Groot (1965) outlined in his classic book. On the other hand, articles and books dealing with non-human chess play and chess programs have a much shorter history (see Berliner, 1978).

I apply three approaches to assess the impact of chess research on cognitive science. The first is to look at the objective measure of citations by scientists working in the sciences and social sciences. The second is to look at citations in textbooks in cognitive psychology. The third is to make a more subjective assessment by reviewing some of the central problems of cognitive psychology and artificial intelligence and evaluating the impact of chess research on them.

Citations

The impact of de Groot (1965) and of Chase and Simon (1973 a)

One way of assessing the scientific impact of a given piece of work is to see how often it is cited in the *Social Sciences Citation Index* and the *Science Citation Index*, two respected sources of such information. The two most cited publications directly concerned with chess are de Groot's (1965) English translation of his earlier Dutch book *Thought and choice in chess*, and Chase and Simon's (1973 a) article in *Cognitive Psychology*, "Perception in chess." The pattern of citations can be seen in Figure 1.

Both works have enjoyed a substantial number of citations, and more significantly, have seen an acceleration in citations a decade or more after their initial publication. De Groot's book, as of 1989, had about 250 citations, and Chase and Simon's article about 350. A "citation classic" accolade is usually awarded when a work has between 100 and 400 citations, depending on the size of the field of inquiry, so these two works can safely be judged to be classic ones. This is a rather remarkable achievement, considering that chess research hardly qualifies as a mainstream activity within cognitive psychology or general psychology. (We examined the number of journal articles published that had a main focus on some aspect of chess,

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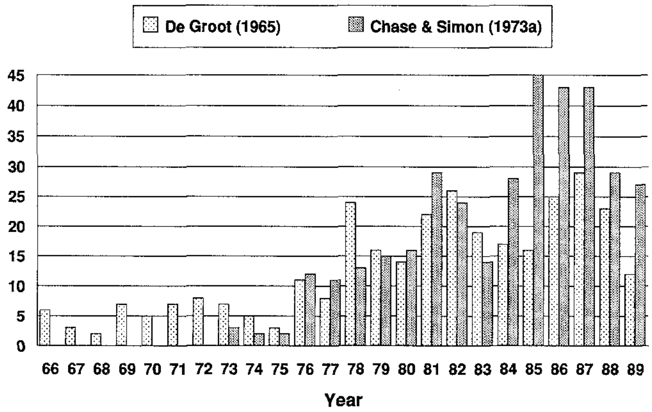

Fig. 1. Yearly citation frequencies (sum of *SSCI* and *SCI*) for de Groot (1965) and Chase & Simon (1973 a).

Table 1. Citations in cognitive-psychology texts.

Textbook	de Groot (1965)	Chase & Simon (1973 a or 1973 b)
Anderson (1990)	yes	yes
Ashcraft (1989)	no	yes
Best (1989)	yes	yes
Bourne et al. (1986)	yes	yes
Ellis & Hunt (1989)	yes	yes
Eysenck (1986)	no	no
Gellatly (1986)	no	yes
Glass & Holyoak (1986)	yes	yes
Greene (1987)	yes	yes
Matlin (1989)	no	no
Reed (1988)	yes	yes
Sanford (1985)	yes	no
Smyth et al. (1987)	yes	yes
Solso (1988)	yes	yes
Proportion cited:	10/14	11/14

via the PsycLIT CD-ROM, between the years 1972 and 1990. The mean was 3.5 (*SD* = 1.5, *Range:* 1–6) journal articles published per year). These two works have obviously attracted the interest of many researchers who do not normally conduct chess research.

Textbooks

Although textbooks have been accused of conveying a delayed image of the field they portray, they are nonetheless important commentators on trends. I sampled all the recent (1985+) English-language cognitive-psychology textbooks that I could find on my shelf, on the shelves of colleagues who teach cognitive psychology, and in our library. I simply counted whether either of these two classics appeared in the texts, with one exception. If either of the Chase and Simon (1973 a, 1973 b) papers was referenced (the *Visual information processing* chapter, "The mind's eye in chess", includes most of the content of the *Cognitive Psychology* article plus additional experiments), I counted this as a hit.

Both works had very high citation rates: 10/14 for de Groot and 11/14 Chase and Simon. In general the citations occurred in sections dealing with such topics as problem solving, memory, and encoding/pattern recognition, as well as expertise. In this more selective niche of social-science research, the textbook area, we have further evidence of the substantial impact of chess research on cognitive psychology. In short, whether a citation count tapping the broad scientific literature is used or one within popular English-language cognitive-psychology textbooks, the same conclusion is reached. These two works have achieved widespread recognition.

Tool development

If you look more closely at why these publications have had such an impact on cognitive science, you find that it is because they have contributed to both methodology and theory. That is, chess research has provided tools that others have found useful. In particular, experimental techniques such as the 5-s-recall task, and think-aloud protocol analysis have been widely adopted by other investigators.

De Groot's original research showed that when chess players were presented with an unfamiliar, but structured, chess position for a few seconds, recall level depended quite strongly on skill level. This finding was replicated and extended by Chase and Simon, who introduced the important control condition of asking for recall of randomly arranged chess pieces. (As Vicente and de Groot, 1990, point out, there have been many misattributions about the introduction of the random control condition). With such positions they were unable to find any skill effects. Many other investigators of skilled performance have used this task and some variants to good effect. For instance, similar findings to those of Chase and Simon have been reported for Bridge players (Charness, 1979), music students (Beal, 1985), electronics technicians (Egan & Schwartz, 1979), and basketball players (Allard, Graham, & Paarsalu, 1980). On the other hand, even failures to show a simple skilled-memory effect have been informative about skilled performance in other domains, such as volleyball (Allard & Starkes, 1980) and medical diagnosis (Patel & Groen, 1986).

De Groot's use of think-aloud protocols has also influenced some researchers to reconsider such techniques for analyzing problem-solving behavior. Think-aloud data were considered quite suspect in North American psychology following the behaviorist revolution. It is unlikely that protocol-analysis techniques would have attracted favorable attention without de Groot's book, and later, Newell and Simon's (1972) book. In particular, the de Groot approach to the analysis of chess search was emulated by Newell and Simon (1972), Wagner and Scurrah (1971), and Charness (1981 b). The legitimacy of protocol analysis as an effective tool for problem-solving research was probably cemented with the publication of Ericsson and Simon's (1984) book.

Probably the most important tool developed for research into expertise in chess is Elo's (1965, 1978) chess-skill rating scale. Elo's interval-level rating scale provides chess researchers with a valid measurement device unrivalled in other areas of expertise research. It is a true gold standard in individual-difference research. In virtually every other area of expertise, determining who are true experts and how far apart they are from other less skilled individuals is a matter of considerable difficulty. Chess as a competitive game has the advantage that paired comparisons can be made to order competitors. Other frequently investigated areas such as physics expertise (e. g., Simon & Simon, 1978) do not permit such fine differentiation.

The theoretical constructs that have arisen from these research projects, however, have probably been even more important than the experimental tasks and task analyses.

Chess research and cognitive psychology

In this section, I would like to offer a more subjective interpretation of the impact of chess research on cognitive psychology. A good starting point is the Simon and Chase (1973) article in which they suggested that chess could act as a model organism for cognitive psychology, a kind of drosophila (fruit fly). This sentiment was also echoed by Newell (1973) as one way to avoid playing a losing game of 20 questions with nature. I also reiterated this idea in a recent chapter (Charness, 1989). The argument is a familiar one. Just as biologists need model organisms to explore genetics, so too do cognitive scientists need model task environments to study adaptive cognitive mechanisms. Chess playing provides a rich task environment that taps many cognitive processes, ranging from perception, to memory, to problem solving. In fact, it was one of the three tasks that Newell and Simon (1972) chose to explore in developing their highly influential information-processing theory of human problem solving. For better or for worse, chess research is appealing in part because it offers a rich, ecologically valid environment in which to do careful laboratory studies of cognition.

Chess research has contributed to the theoretical development of cognitive psychology in three ways: understanding chess playing (narrow task analysis); revealing information about chess skill (individual differences); and helping to trace out the operation of the cognitive system (normative psychology). In the first two senses, chess research reveals a great deal about the psychology of chess playing: how people manage to play chess and what differentiates skillful players from their less skillful counterparts.

One of the important points that chess research has made since its inception is that experts are made, not born. There has been a long tradition of belief (nature over nurture) that those who achieve prominence were gifted, born with certain predisposing traits that enabled them to master their domain in an effortless fashion. Certainly individual-difference psychology in its earliest (English-language) appearance (led by Galton) drew on the Darwinian notions of the survival of the fittest, with fitness being defined in terms of traits that suited some ecological niches better than others. By these tenets, if someone became a chess master it was assumed to be the traits they possessed that enabled them to deal better with that domain than those who did not have such traits. Thus, it was thought initially that chess grandmasters were awesome thinking machines who could plan long sequences of moves that their less able opponents were incapable of considering. De Groot's (1965) work in the 1930s and 1940s, showing that grandmasters did not think more deeply than club players, was a rude shock to those holding this view. Chase and Simon's (1973 a, 1973 b) finding that a master was not even superior to a novice for de Groot's recall task when randomized chess positions were presented challenged the view that grandmasters possessed the trait of superior memory. The finding that even those who had become grandmasters had spent thousands of hours of studying and playing before reaching high performance levels (e. g., Simon & Chase, 1973) swept away the view that mastery is achieved effortlessly. The position that de Groot and Chase and Simon espoused, that knowledge of patterns specific to the domain of chess supported effective search for good moves, led to a major shift in perspective about expertise in cognitive science. It helped to push the field away from the view of intelligence being achievable by general-purpose heuristic-search systems toward the view that expertise demanded extensive domain-specific knowledge coupled with a general-purpose problem-solving system.

It is in shedding light on chess expertise specifically and expertise in general that chess research has undoubtedly had its greatest impact. Certainly chess skill was the major focus of both de Groot's and of Chase and Simon's work. It is also a major focus of Holding's and Saariluoma's recent work (Holding, 1979, 1985, 1988, 1989 a, 1989 b, 1989 c; Holding & Pfau, 1985; Holding & Reynolds, 1982; Saariluoma, 1985, 1989, 1990 a, 1990 b), as well as that of many other recent investigators (e. g., Calderwood, Klein, & Crandall, 1988) too numerous to mention in this brief overview.

Nonetheless, chess research's wider appeal is in the way it manages to address basic questions of psychology and artificial intelligence in a realistic task environment. I shall mention just a few representative cases. The switch in perspective from the Gestalt view that human problem solving can be seen as pattern completion to the information-processing view, best described as serial search in a problem space (with pattern matching as an important component process), owes much to chess research (e. g., de Groot, 1965; Newell & Simon, 1972; Wagner & Scurrah, 1971).

Chess research has also facilitated fruitful investigation of questions in a variety of areas of general psychology. For instance, issues in motivation have been addressed via the question: What motivates people to play chess? Pritchard, Campbell, and Campbell (1977) stressed the superiority of intrinsic to extrinsic motivation. What is the role of intelligence in complex problem solving? Cleveland (1907), looking at a mentally retarded chess player, and Doll and Mayr (1987), using intelligence tests with a large sample of chess players, showed that general intelligence probably accounts for little of the variance in chess performance. What is the nature of talent? Charness (1989) found little evidence of talent (early signs of later high achievement) in a case study. What is the role of emotional arousal in problem solving? Tikhomirov and Vinogradov (1970) showed that low arousal is associated with failure to solve the more difficult chess problems. What parts of the brain mediate complex spatial problem solving? Cranberg and Albert (1989), using data on handedness and the effects of neurological insults such as strokes, found weak evidence to suggest that right-hemisphere involvement may be more important in chess playing than that of the left hemisphere. To what extent do early developmental processes rely on maturation rather than on knowledge accumulation? Chi (1978) showed that skilled children chess players performed better than less-skilled chess-playing adults on chess-memory tasks, with the reverse occurring for digit memory, implicating acquired knowledge as the key ingredient. Horgan and Morgan (1990) showed that the number of games played was related more to rating and rating gains than age. What effect has aging on cognitive processes such as problem solving, memory, perception? Charness (1981 a, 1981 b, 1981 c) showed that problem-solving performance depended on skill, but not on age, whereas memory performance declined with age, but increased with skill for chess tasks; Pfau and Murphy (1988) also showed decline in age-related memory. Elo (1965) replicated and extended Lehman's (1953) classic inverted U-shaped performance function across the lifespan with longitudinal data for chess grandmasters.

More focussed questions have also been addressed about such topics as typicality effects (e.g., Goldin, 1978 b), imagery (Milojkovic, 1982), and pattern-recognition processes (Ellis, 1973; Goldin, 1978 a, 1979; Saariluoma, 1985; Tikhomirov & Poznyanskaya, 1966). A popular goal has been to investigate memory processes such as the effects of orienting tasks (Lane & Robertson, 1979; Goldin, 1978 a), cuing (Watkins, Schwartz, & Lane, 1984), and short-term recall (Charness, 1976, 1981 c; Lories, 1987). The important topic of the development of automaticity under consistent, as against varied, mapping conditions has also been addressed by means of chess-like tasks (e.g., Fisk & Lloyd, 1988). The chess rating scale developed by Elo (1965, 1978) has also inspired mathematical models of scaling for preference data when ties are allowed (Batchelder & Bershad, 1979). In short, a myriad of topics central to general psychology, as well as to cognitive psychology, have found fruitful expression through the chess-task environment.

Chess has also attracted the interest of those whose goal it is to produce computer models that mimic human performance on the psychological level (cognitive simulation). Newell and Simon's (1972) book contains one of the earliest discussions of processing models for many aspects of choosing a move in chess, including their chess-playing program (NSS) and the mating combination program (MATER) developed by Baylor. Simon and Gilmartin (1973) accurately simulated skill-related differences in recall (the de Groot/Chase and Simon chess-position recall task) with their MAPP model. Simon and Barenfeld's (1969) model of eye movements in chess served as one of the component processes in MAPP.

In summary, much of the impact of chess research on cognitive psychology has been through the exploration of chess expertise, as well as through the exploration of basic cognitive processes. I would argue that consideration of both chess skill and general-cognition issues together has led to a useful hybridization of theoretical frameworks. It is this breadth of approach that undoubtedly accounts for the considerable appeal and impact of chess research.

Chess research and artificial intelligence

Ever since the initiation of the field of artificial intelligence (AI), computer scientists have attempted to put together skillful chess programs. (See Berliner (1978) for a concise review.) Chess was seen as a model task environment since it was considered to be a difficult game to play well, yet was amenable to exploration through search and evaluation processes. In fact, many books, when discussing search techniques in adversary problem-solving situations, use chess as a model task (e.g., Clarke, 1989). It is probably fair to say that many of the search-algorithm advances, such as minimax, alpha-beta pruning, nega-scout, B* (Berliner, 1979) originated in the need to find more efficient ways of conducting search through the exponentially branching chess-game tree.

Much of the experimental research on chess in AI has been in the service of establishing the trade-offs between knowledge and search (see Berliner, 1981; Schaeffer, 1986). The way in which this is done in is to run programs with various knowledge sources enabled or disabled to assess the impact on playing ability. The work on the cognitive psychology of chess-playing ability has influenced a number of AI researchers to try to build more knowledge into their programs. It is worth remembering that for humans, search processes are subservient to knowledge processes, whereas for most chess programs, the relationship is reversed. The question of how to balance these two factors is important in both spheres. There have been a number of attempts to embed pattern-recognition knowledge in chess programs. Two of the more successful ones are those of Berliner and Ebeling (1989) and Wilkins (1983). There has also been some success in analyzing endgames, such as king and pawn versus king (e.g., Bramer, 1982). In these cases, programmers have attempted to substitute pattern recognition for search. Pattern recognition, particularly as practiced by machine-vision programs, lags far behind the capabilities of even human infants. Until better human research can provide more helpful models, it is likely that chess programmers will fall back on hardware solutions to their problems.

Notwithstanding the renewed interest in the use of more knowledge, much of the increase in the playing strength of chess programs has come courtesy of the rapid changes in the hardware platform on which chess programs operate. Specialized microchips have enabled consistent increases in depth of search. In recent years, chess programs have reached new heights of excellence, with programs such as *Deep Thought* playing at grandmaster level, courtesy of the ability to examine in excess of 700,000 chess positions every second. *Deep Thought* is now capable of consistently beating all but the top 200 or so humans, the grandmasters. (See Hsu, Anantharaman, Campbell, & Nowatzyk, 1990, for a description of the enormous search capabilities of

Deep Thought.) Nonetheless, the importance of pattern-guided move evaluation is still a lively issue in chess programming, as is witnessed by the impressive strides taken by *Hitech* (Berliner & Ebeling, 1989). If the rate of gain in the playing strength of chess programs is maintained, it is reasonable to predict that within the next few decades a chess program will reign as world champion. Chess will then join other games such as checkers/draughts, Othello, and backgammon, in which artificial intelligence equals or exceeds the best human intelligence. Until that time chess will continue to be one of the most challenging arenas for problem solving by AI programs, and a fertile test-bed for innovations in both hardware and software.

Conclusions

Chess has attracted the interest of psychologists and cognitive scientists for the past century. Cognitive psychologists employ chess in the service of three goals. The first is to understand basic cognitive processes, particularly those that support perception, memory, and problem solving. The second is to understand chess playing as a topic in its own right. The third is to explore individual differences in playing ability: the study of chess expertise. Particularly in the latter case chess research has had an important impact on individual-difference psychology by providing compelling process models. It is perhaps ironic that the modern enterprise of exploring skill differences has depended on the Elo chess-rating scale, a measurement device of unparalleled validity developed by a physicist.

These branches of chess research have also influenced the directions taken by practitioners of machine intelligence. AI, seen as a theoretical branch of cognitive psychology, attempts to build systems that behave intelligently. To behave intelligently, a system needs to be able to solve problems. Successful problem solving demands search and evaluation processes. Chess playing provides a model task environment in which to explore the relationship between these two factors for humans and machines alike.

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