Acquiring Expertise: Determinants of Exceptional Performance

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Introduction

This chapter focuses on the respective roles of cognitive ability and domain-specific knowledge in predicting exceptional performance. Since the beginning of this century, educational researchers and psychologists have tried to locate the sources of outstanding (academic) behavior and performance. At least two different ways of tackling this problem can be distinguished.

The earlier research paradigm explored the impact of giftedness on exceptional performance. According to this scientific approach, general intellectual abilities assessed in early childhood or adolescence strongly influence later academic or professional performance. As noted by Ericsson and Smith (1991), this approach is guided by the basic belief that behavior is predominantly influenced by inherited qualities. The paradigm seems particularly attractive because of its implicit assumption that only a few general, basic abilities are sufficient to predict and explain a large variety of specific performances. The longitudinal study of gifted children carried out by Terman and his colleagues (to be described below) is representative of this line of research (cf. Terman, 1925, 1954; Oden, 1968).

A second, more recent scientific approach differs from the giftedness paradigm in that exceptional performance is assumed to be primarily acquired. Accordingly, specific educational experiences and intensive as well as extensive domain-specific training and practice determine the acquisition of skill in particular domains. General abilities play a minor role in this explanatory approach (cf. Anderson, 1990; Ericsson & Crutcher, 1990). Since the late sixties, the study of expertise has attracted many researchers interested in human information processing. In particular, research on chess expertise has enriched our knowledge about the acquisition of domain-specific skills and the preconditions for outstanding performance in this domain.

Given the popularity of the expertise approach in current cognitive psychology, the merits of research on the impact of early intellectual ability on later academic performance seem dubious. Proponents of the expertise approach (e.g., Ericsson & Crutcher, 1990) claim that individual differences in intellectual ability do not account for much of the variance in exceptional performance. Difficulties with evaluating this view are related to theoretical problems, that is, problems with defining and operationalizing intelligence and cognitive ability. Recent reviews on this issue emphasize the fact that research on intelligence has abandoned traditional lines, focusing on cognitive task analysis, processing strategies and features of context (see Ceci, 1990; Gruber & Mandl, 1992).

Although there seems to be broad agreement in the contemporary literature on exceptional performance that the old concept of basic intellectual ability has lost its importance and should be replaced by the concept of acquired skill, the relationship between cognitive ability and the acquisition of expertise has not been sufficiently considered in most of these studies. It is the major purpose of this chapter to explore this relation in more detail. In a first section, developmental research on giftedness and its impact on later performance is briefly reviewed. Next, an overview of research dealing with expertise in adulthood is provided. After a summary of the most important findings, theoretical assumptions and models concerning the process of acquiring expertise derived from this research with adults will be discussed in more detail. In the next section, developmental research on knowledge acquisition based on research with children will be reviewed. Here, the basic goal is to assess the generalizability of findings from work with adult experts to child samples and to broaden the perspective by adding data from prospective studies on the development of expertise to the predominantly retrospective inferences of acquisition processes derived from studies with adults. In the final section, theoretical models are introduced that describe possible relationships between aptitude and the acquisition of expertise.

Prospective and Retrospective Approaches Explaining Giftedness and Exceptional Performance

Prospective Studies

As noted above, the well-known Terman Gifted Children Study can be conceived of as the most impressive attempt to explore the predictive power of high intellectual ability for subsequent academic performance and success in later life. In this study, about 1500 young Californian children with an IQ of 135 and above were recruited in the early twenties of this century and followed up until recently. Although the theoretical focus of the study changed over the years, the body of data seems suited to evaluate the relevance of high aptitude for academic and professional performance. At first glance, the findings seem to support Terman's expectations: On average, the gifted children performed very well in school and were rather successful in later life. However, a closer look at the findings revealed that the expected collection of "eggheads" and outstanding personalities was not found (cf. Sears, 1984). As noted by Howe (1982), the data collected by Terman and his colleagues provided little information that would have helped one to predict which of the children under study would be most successful in later life. Thus the conclusion to be drawn from this study is that educational achievement and success in life cannot be sufficiently predicted by indicators of high intellectual ability measured at an early point in time.

Further research indicated that the quality of the IQ predictor does not change much when aptitude is assessed considerably later, that is, during the college years (cf. Samson, Grane, Weinstein, & Walberg, 1984). In this study, an average correlation of about .15 was found between college students' aptitude and their professional productivity assessed several years later, indicating that the subsamples representing "schoolhouse giftedness" and "production giftedness" do not have much in common (cf. Siegler & Kotovsky, 1986). Obviously, information about intellectual ability alone does not allow for reliable predictions of later academic and professional success.

Retrospective Studies

Another line of research focused on subjects with reliably superior performances, with the goal to reconstruct their cognitive and noncognitive abilities. Most of that research was similarly motivated by the belief that exceptionally high levels of performance should reflect some basic cognitive ability like general intelligence, atttention, or memory (e.g. Cox, 1926). Some researchers studied other stable individual characteristics, such as aspects of personality and motivation (Roe, 1952, 1953). In short, the results of these retrospective studies seem to confirm the outcomes of the prospective studies in that individual differences in intellectual abilities did not show up as the crucial determinant of outstanding professional careers. For example, Roe's analysis of the careers of outstanding scientists showed that noncognitive factors like endurance, concentration power and committment to work turned out to be more important for professional success than the individuals' cognitive abilities, despite the fact that the latter were generally above average.

More recently, Roe's findings were confirmed in an interview study with excelling scientists, sportsmen and artists organized by Bloom (1985). The data obtained from these subjects and their parents did not support the view that outstanding basic abilities were solely responsible for success in later life. Instead, the study provided strong evidence that no matter what the initial gifts or basic abilities of the individuals, extreme levels of capabilities in their fields of expertise were not attained unless there was a long and intensive process of encouragement, education and training. Bloom concluded from these findings that his research has raised serious questions about earlier views of special gifts and innate aptitudes as necessary prerequisites of talent development (1985, p. 3).

Taken together, prospective and retrospective studies focusing on the impact of intelligence and other stable cognitive factors on academic and professional success have been largely unsuccessful in identifying strong and replicable relations (see Ericsson & Smith, 1991, for more evidence on this issue). Instead, most of these studies have shown that noncognitive factors like motivation, concentration and endurance as well as parental and school support systems seem responsible for exceptional performances in later life.

Evidence From the Expertise Approach

Studies With Adult Experts and Novices

Undoubtedly, the pioneering work on chess conducted by de Groot (1946, 1978) and Chase and Simon (1973) has stimulated numerous studies on the nature of expertise. For most cognitive psychologists, an approach based on acquired characteristics seems much more suited to account for outstanding and superior performance than research on giftedness relying on stable inherited characteristics. The game of chess appears particularly attractive for researchers interested in the preconditions of outstanding performance because it is rather easy to produce and observe outstanding performance under standardized conditions. One advantage of this game over others is that it is possible to measure a subject's chess-playing ability from the results of matches against different opponents in different tournaments (cf. the index developed by Elo, 1978). Another, related advantage is that groups of chess players differing reliably in chess skill can be easily selected. As chess skill can be measured with remarkable precision, the domain of chess seems ideal for the study of acquired skill. Models of chess skill have strongly influenced investigations of expertise in other domains like physics, medical sciences, music and sports. The most important findings concerning cognitive and noncognitive characteristics of expertise in chess and these other domains will be discussed below. Before doing so, however, general theoretical and methodological problems with the expertise approach will be briefly summarized.

Problems With the Expertise Approach

Despite its obvious advantages, the expertise approach still suffers from several problems. One of the problems is that the term "expertise" has a number of popular definitions, which all are somewhat vague (cf. Gruber, 1991; Salthouse, 1991). Although the broadly accepted definition that expertise refers to extreme or exceptional performance implies that the evaluation of expertise should represent some measure of actual competence, rather than a possible correlate of competence such as amount of experience, the categorization of a subject as an expert is still relatively arbitrary given that researchers disagree with regard to the particular level of competence that qualifies one as an expert. Although attempts to specify subcategories of expertise like layperson, novice, intermediate, subexpert and expert (cf. Patel & Groen, 1991) seem to represent an improvement, this classification does not solve the problem because the boundaries between categories remain unknown. In many empirical studies, the definition problem becomes obvious when the median of the distribution of a competence measure is taken as the critical boundary for expert–novice distinctions.

As noted by Ericsson and Smith (1991), another critical issue in the expertise approach is how to identify standardized tasks that will allow the real-life outstanding performance to be reproduced in the laboratory. As our knowledge of complex domains of expertise like writing, physics, or medical reasoning is incomplete, it seems impossible to specify a population of tasks to capture such expertise. The problem is also apparent in the domain of chess. For example, de Groot (1978) designed the task of selecting the best move for a number of different chess positions in order to simulate "real-world" problem solving behavior. Although the task seems valid at first glance, its problems relate to the fact that it is very difficult—if not impossible—to evaluate the quality of chess moves for an arbitrary chess position (cf. Ericsson & Smith, 1991). Given the vast number of possible sequences of moves and the fact that chess players employ a wide variety of chess-playing styles, it seems impossible to identify a single "best" move. Despite these obvious problems, however, it should be noted that de Groot was able to localize a few differences in cognitive processes between the grand masters and the other class experts in his study by analyzing think-aloud protocols from his best-next-move task. Although the ecological validity of the task remains uncertain, it at least can be used to illustrate differences in thinking processes of more or less eminent chess players.

The same validity problem also holds for the various memory tasks repeatedly used in studies of expertise. Undoubtedly, performance on such tasks (i.e., recall or recognition) is much easier to evaluate than, for example, a protocol of thinking processes obtained for the next-best-move task. It is questionable, however, whether those aspects of memory assessed in the laboratory really capture the crucial features of expertise in real-life situations. The reader should keep in mind that despite the popularity of the expertise approach, these problems have not been solved yet.

Performance Differences Between Experts and Novices

In the classic studies by de Groot (1946, 1978) and Chase and Simon (1973), exceptional performance in the domain of chess was linked with exceptional memory for information related to that domain. In order to capture skill differences in chess, de Groot used a task that assessed memory for briefly presented chess positions. He found that when chess masters were shown a chess position consisting of 20–30 pieces for a very brief duration (e.g., 5 seconds), they were able to remember the position far better than less experienced chess experts. Chess masters were able to recall the positions of all pieces virtually perfectly, whereas the positions recalled by the less experienced chess experts ranged from 50–70%.

Chase and Simon (1973) followed up de Groot's finding that there were major memory differences in regard to recall of briefly shown game positions. They added an important control, showing expert and novice players also random arrangements of pieces. As the experts' advantage in recall with structured positions disappeared when random positions were reconstructed, it could not be attributed to superior visual short-term memory on the part of the experts.

In order to understand the chess master's recall superiority for meaningful chess positions, Chase and Simon attempted to uncover the structure of his chess knowledge. They showed that the recall advantage depended on the master's ability to recognize familiar patterns or "chunks". That is, the master was able to recall pieces more effectively than the novice because groups of pieces, rather than single pieces, formed his chunks. According to this finding, quantitative differences in the memory performance of experts and novices can be largely explained by *qualitative differences* in memory behavior.

Research on expert–novice differences in the use of complex knowledge in other domains like electronics or architecture has also revealed the importance of higher-order chunk structures for superior performance (cf. Chi, Glaser, & Rees, 1981). Although the notion of chunking as a major determinant of expert–novice performance differences seems broadly accepted in the literature, findings from more recent studies have seriously questioned the assumption that chunking affects experts' short-term memory. Carefully designed studies of superior memory performance for chess positions have shown that experts store information about chess positions in long-term memory, not solely in short-term memory as Chase and Simon (1973) originally proposed (see for a review Charness, 1991). These findings do not cast doubts on the basic assumption that there are qualitative differences in memory behavior of experts and novices. However, they indicate that Chase and Simon's (1973) original theoretical assumptions need to be replaced by more sophisticated views of skilled memory like those by Chase and Ericsson (1982; see also Ericsson & Staszewski, 1989), stressing the importance of domain-specific, easily activated retrieval structures in recall performance.

Qualitative differences in the problem-solving and memory behavior of experts and novices have also been reported in studies dealing with other domains like physics and medical diagnosis and reasoning (see Anzai, 1991; Chi, Glaser, & Rees, 1981; Patel & Groen, 1986, 1991). Evidence on such differences has been based on tasks different from those used in the domain of chess.

Basic differences in problem representations between physics experts and novices were suggested in an experiment by Chi, Feltovich, & Glaser (1981). Chi et al. were able to show that experts and novices in physics differ in their categorization of physics problems: Whereas experts classified the problems with respect to underlying principles, novices tended to use superficial meanings of words and diagrams for the purpose of classification. Expert–novice differences in the domain of physics can also been seen in procedural knowledge for problem solving. For example, Simon and Simon (1978) found blatant qualitative differences in experts' and novices' solution processes. That is, experts solved problems in a "forward" way from the given data to the goal, whereas novices tried to solve problems in a "backward" way, starting from the goal (e.g., an equation containing the unknown of the problem) in search for appropriate data to satisfy each subgoal. Although this finding seems counterintuitive at first glance given that the novices appear to use the more sophisticated strategy, there are at least two explanations accounting for the experts' problem solving behavior. The first is that experts know that they can achieve the goal simply by direct calculations of the unknowns from the given. Another interpretation is that experts do not require complex planning for simple tasks. Evidence for this explanation stems from research showing that experts change to very sophisticated means-end analyses when the physics problems become more difficult (Larkin, McDermott, Simon, & Simon, 1980). In summary, the studies on expert–novice differences in the domain of physics thus show that the superior performance of experts on a variety of problem solving tasks is mainly due to the experts' well-organized declarative and procedural knowledge. As a consequence, performance differences between experts and novices can be explained by qualitatively different strategies.

Further empirical evidence concerning qualitative differences in the way experts and novices recall and comprehend domain-related information stems from studies on medical expertise (cf. Lesgold, 1984; Patel & Groen, 1986, 1991). The work by Patel and colleagues seems related to the research on expertise in physics outlined above in that one focus of expert–novice comparisons was on reasoning strategies. Patel and colleagues used a basic experimental procedure where subjects were presented with a written description of a clinical case and were asked to study the text for a specific period of time, after which it was removed. The dependent measures used in the various experiments on medical expertise were free recall, diagnosis and diagnostic explanation. Diagnostic explanation was included to identify the direction of the reasoning strategy (forward or backward method). Here, subjects were requested to explain the pathophysiology (causal patterns) underlying the clinical case.

Based on their fine-grained classification of expertise (i.e., laypersons, beginners, novices, intermediates, subexperts and experts), Patel and colleagues analyzed differences among the subgroups concerning recall, diagnosis and reasoning strategy. When experts and subexperts were compared on these measures, no recall differences were found. Below that level of expertise, substantial recall differences could be demonstrated (i.e., for the novice and intermediate subgroups). On the other hand, diagnostic accuracy was considerably higher in the experts, as compared to the subexperts (for confirming evidence, see also Lesgold, Glaser, Rubinson, Klopfer, Feltovich, & Wang, 1988). In addition, forward reasoning was closely related to diagnostic accuracy. Patel and colleagues inferred from their results that diagnostic accuracy is monotonically related to expertise, whereas recall performance is nonmonotonically related to expertise. Reasoning strategies, on the other hand, should be considered an all-or-none phenomenon that may be related to the two extremes of the expert–novice continuum.

Taken together, research on expertise in different domains like chess, bridge, music, has shown that experts display superior memory performance for stimuli from their domain of expertise when adaptations of Chase and Simon's (1973) original procedure have been used (for a review, see Ericsson & Smith, 1991). Other studies using the expert–novice paradigm have shown superior recall of domain-related information as a function of the subject's amount of knowledge of the domain. Examples include the domains of baseball and soccer (e.g., Voss, Vesonder, & Spilich, 1980; Morris, Tweedy, & Gruneberg, 1985). Most of these studies have found evidence supporting a monotonic relation between recall of domain-related information and domain-specific knowledge. They have also supported the view that the main differences among experts and novices in a wide range of domains concern the speed of access to relevant knowledge as well as the sophistication of knowledge-based strategies.

THE ROLE OF BASIC ABILITIES

What do the studies on expertise tell us about the *impact of basic abilities* on exceptional performance? The empirical evidence for such an influence is rather scarce.

In the case of exceptional chess performance, superior spatial ability often was assumed to be important (Chase & Simon, 1973; Holding, 1985). However, a recent study by Doll and Mayr (1987) does not confirm this view. Doll and Mayr compared about thirty of the best chess players in Germany with those of about ninety normal subjects of similar ages, using an IQ test with seven subscales. As a main result, Doll and Mayr (1987) found no evidence that chess players were selectively better on spatial tasks. In general, the relation of IQ to outstanding performance seems rather weak in several domains (for a review, see Ericsson & Crutcher, 1990).

Although general abilities do not seem to make a major difference, the results of several studies suggest that *special abilities* like speed of information processing or basic memory abilities could be a source of individual differences. Regarding reaction times, for instance, it has been repeatedly shown that experts are faster and more accurate than less experienced subjects. A closer examination of these studies, however, does not confirm the view that experts outperform novices with regard to information processing speed. For instance, it was shown that experts' superior speed in their domain of expertise does not transfer to other tests of speed, like simple reaction times, or to general tests of perception (cf. Starkes, 1987).

Similarly, the exceptional memory performance shown by many experts for materials from their domain does not generalize to materials outside their domain, as demonstrated by Chase and Simon (1973). Studies focusing on exceptional memory performance have described in detail how subjects with initially normal memory skill acquired exceptional memory skill through extensive practice (cf. Chase & Ericsson, 1982; Staszewski, 1988, 1990). In these studies, subjects were provided with several hundred hours of practice on the classic digit-span task. After 50–100 hours of practice, subjects were able to increase their digit spans from about 7 to over 20 digits. Subjects going through a very extensive training program were even able to attain digit spans of over 100.

How was it possible to acquire this skill? The explanation is that these subjects were experienced long-distance runners with a rich knowledge base for running times. They were able to use their knowledge for recoding and interpreting incoming digit sequences as specific running times. The fact that exceptional memory performance can be successfully trained was further demonstrated in a recent study by Kliegl, Smith and Baltes (1986). Kliegl et al. trained young and old adults to memorize digits using phonemic recoding of digits into concrete words, which were stored in long-term memory using the ancient "method of loci". It could be shown that with extensive training, speed of memorization dramatically increased, approaching a rate of 1 digit per second.

Accordingly, exceptional memory performance demonstrated by many experts cannot be attributed to inherited basic abilities but has to be conceived of as an acquired competency, that is, as an outcome of extensive practice and training in the domain of expertise. This competency was labeled "skilled memory" by Chase and Ericsson (1982) who identified three basic principles in the acquisition process. First, information is meaningfully encoded in terms of knowledge structures in semantic memory. Second, retrieval cues are constructed during the encoding process, which are explicitly associated with the encoded information and can be easily retrieved from long-term memory. Third, encoding and retrieval processes can be considerably accelerated by extensive practice. As a consequence of long training, the speed of these encoding and retrieval processes are assumed to approach those observed in short-term memory.

All in all, research dealing with the relevance of biological dispositions, innate talent and basic abilities for exceptional performance has been rather unsuccessful in establishing such relationships. The best evidence for the importance of inherited characteristics comes from the domain of sports, for example, the domains of basketball or gymnastics, where anatomical characteristics such as height obviously make a difference. For a few abilities, such as perfect pitch in music, tapping speed in the case of typists and specific abilities revealed by children and idiots savants, innate "talent" may be a plausible explanation. However, recent research on expert performance has convincingly shown that exceptional performance in many fields is primarily due to a vast body of acquired knowledge and experience as well as to acquired skills (Ericsson, Krampe, & Tesch-Römer, in press).

What follows from this is that practice plays a crucial role in the acquisition of expertise. Across a wide range of tasks, improvements in performance seem closely related to the amount of practice. Reviews of skill acquisition indicate that the relationship between performance and practice is monotonic (Anderson, 1982; Newell & Rosenbloom, 1981) and that a power function provides a very good fit for a variety of tasks and skills.

However, taking the amount of practice as the only important predictor of performance probably oversimplifies the problem. Our everyday experiences show that not all people practicing and working extensively in a specific domain end up as eminent experts in that area. Similarly, observations from laboratory experiments have indicated that providing motivated subjects with repeated exposure to a task does not ensure that they will attain the highest levels of performance on that task (Chase & Ericsson, 1981). In particular, inadequate strategies often account for suboptimal performance. The available evidence indicates that subjects can either discover or deduce superior strategies for performing tasks, or learn them through instruction. For instance, the training study by Kliegl, Smith, and Baltes (1989) showed that subjects were able to improve rapidly and attain exceptional levels of performance only after being instructed to use adequate strategies. Thus the *amount* of practice may be a necessary but not sufficient condition for expert-level performance. Obviously, the *intensity* and *quality* of practice are at least equally important in order to reach ambitious goals. Recent theoretical models dealing with the acquisition of expertise have tried to take these different aspects of practice into account.

Theoretical Models Describing the Acquisition of Expertise

MODELS OF SKILL ACQUISITION

There have been several models of skill acquisition in the literature. The classic model developed by Fitts and Posner (1967) proposed three different acquisition stages: The "cognitive stage" can be characterized by an effort to understand the task demands and to distinguish between important and unimportant aspects of the task. The focus is on the acquisition of declarative knowledge about the task. The "associative stage" involves making the cognitive processes more efficient to allow rapid retrieval, thus transforming declarative knowledge into procedural forms. During the third and final phase, labeled the "autonomous stage", performance is automatic and conscious cognition and control is minimal. See Anderson (1982) for a similar theoretical model.

Although these models of skill acquisition have been attractive for many researchers in the field, stimulating much important research, it remains unclear whether the learning mechanisms and developmental stages they propose do generalize from adult learners to children. We know from numerous reports on the careers of chess experts, eminent musicians, or world-class tennis players that these individuals have started their careers at a very early point in life, that is, between 6 and 10 years of age (e.g., Bloom, 1985). We also know from several sources that the time between experts' first experiences with their domain of interest and attaining international-level performance is about 10 years (Chase & Simon, 1973; Krogius, 1976; Sosniak, 1985). As pointed out by Ericsson and Crutcher (1990), this 10-year rule is supported by data from a wide range of domains, including sports, music, chess and science.

Given that the attainment of exceptional performance in real life usually takes place in childhood and adolescence, it seems important to identify the learning mechanisms, rules of practice and support systems that enable this rapid development. Recent research conducted by Anders Ericsson and his colleagues (Ericsson, 1990; Ericsson & Crutcher, 1990; Ericsson, Tesch-Römer, & Krampe, 1990; Ericsson et al., in press) has led the authors to propose a theoretical framework for the acquisition of expert-level performance. The attractiveness of this model stems from the fact that hypotheses about the developmental history and practice intensity of expert-level performers have been systematically evaluated against empirical evidence on exceptional performances in various domains.

A THEORETICAL FRAMEWORK FOR ACQUISITION OF EXPERT-LEVEL PERFORMANCE: THE ROLE OF DELIBERATE PRACTICE

The model presented by Ericsson and colleagues differs from the skill acquisition models presented above in that it explicitly considers developmental issues within a life-span perspective. Whereas skill acquisition has, for the most part, been studied with college students, most information relevant for Ericsson's theoretical framework stems from observations and retrospective reports dealing with performances in childhood and adolescence.

Ericsson and colleagues adopt and extend the basic characteristics of a framework first developed by Bloom (1985b). Accordingly, the preparation period for reaching exceptional performance can be conceived of as a sequence of states, each representing rather stable characteristics for a specific time period in the individual's life. The first stage corresponds to the playful introduction to the domain, the second to the start of systematic practice supervised by a coach or a teacher and the third and most crucial stage to attaining exceptional levels of performance (cf. Ericsson et al., 1990).

This model suggests that the type and intensity of training may differ as a function of developmental stage. Whereas it is most important to keep children motivated and interested in the domain during the first stage, methods of instruction and the quality of teachers become more relevant with increasing levels of performance. An early start as well as parental interest and support seem particularly important for the earlier stages. With increasing skill, factors like availability of excellent instruction, quality of practice equipment and access to practice facilities become most relevant. As noted by Bloom (1985b), performers at an international level have almost always been instructed by master teachers who themselves had once achieved that level.

Ericsson et al. (1990) provide multiple evidence from the domains of chess, sports and music that is in accord with the core assumptions of this model and that shows surprising parallels in developmental patterns observed across these domains. For example, the available data indicate that the average starting age for exceptional performers is uniformly young across the three domains (about 7 years of age), with the best performers on average having the youngest starting ages. Similarly, the retrospective estimates consistently showed that the amount of practice increases as a function of age and expertise, regardless of domain. It appears that systematic practice is most often initiated by parents, who very actively support and reward the acquisition of practice habits. Increases in the weekly amount of practice occur throughout adolescence and reaches its peak around the age of 20. In most studies, the reported amount of practice was often highly correlated with levels of performance and comparable amounts of practice were reported for subjects of the same performance level across domains. The empirical evidence collected and discussed by Ericsson et al. (1990) not only supports Bloom's original assumptions but also extends the findings by Bloom (1985b) and his collaborators, in so far as performers at levels below international level were shown to engage in less practice.

One apparent problem with this account is that it focused on the *extent* of practice, although individual differences in the *intensity* of practice were also observed. In a more recent review paper, Ericsson et al. (in press) take care of this problem in that they focus on the role of *deliberate* practice. This term refers to practice activities that aim at maximizing improvement. Deliberate practice is conceived of as a highly structured activity which requires effort and is not inherently enjoyable. According to Ericsson and Krampe, individuals are motivated to engage in deliberate practice only because practice improves performance, not because of monetary reward.

Ericsson and colleagues point to several methodological problems involved in demonstrating the fact that performance changes as a consequence of deliberate practice. During the first decade of preparation necessary for attaining exceptional performance, many aspects of training and evaluation change. It is important to note here that one reason for the difficulty to predict adult performance from early performance is that the criteria used to evaluate performance change with increasing level of performance. For example, whereas beginners in the domain of music are mainly judged on their technical skills, expert adult performers are predominantly judged on their interpretation and their ability to express emotions through music (Sloboda, 1991). Similar considerations may explain why mathematical prodigies can be unsuccessful as adult mathematicians.

According to the theoretical framework established by Ericsson and colleagues, other constraints inherent in the attainment of exceptional performance concern resources, effort and motivation. In many cases, it has been shown that parental support is a major variable and that extraordinary commitments by parents may be necessary to cope with the demands (cf. Bloom, 1985b). Further, as deliberate practice requires effort, fatigue is a frequent result. The success of deliberate practice seems to depend on a careful balance of intensive practice and recovery. Disregard of the effort constraint on deliberate practice may result in maladaptation, injury and even failure. Finally, as deliberate practice is not inherently enjoyable, the motivational constraint has to be given special attention. The loss of the goal to improve can have different causes. Problems with external support may be as relevant as problems due to a temporary stagnation of performance despite continued practice. These problems seem particularly related to the initial stages of the preparation period and may loose their importance when individuals get more involved in a domain. As noted by Ericsson et al. (in press), at this point the motivation to practice becomes closely connected to the goal of becoming an expert performer and integrated in the daily routine.

The framework presented by Ericsson et al. (in press) differs from earlier views in that deliberate practice is the important factor mediating the observed relation between experience, full-time engagement and exceptional performance. Accordingly, extended experience or practice (the 10-year rule) is necessary but not sufficient for attaining the highest levels of performance in a domain.

In an attempt to test the validity of this framework, Ericsson et al. (in press, Study 1) compared three groups of elite, adult violinists regarding their current and past levels of deliberate practice. The group labeled "the best violinists" were rated by music professors as having the potential for careers as international soloists. The music professors also nominated a second group of "good violinists" with less potential but still very promising perspectives. A third group of students with comparably lower admission standards were called "the music teachers" because teaching was the most likely future profession for this group.

It was predicted that the highest improvement of performance and indirectly the highest attained performance, should be associated with the largest weekly amounts of deliberate practice. The assumption was that even among individuals with more than 10 years of practice, performance should be closely related to the amount of deliberate practice.

The analysis of interview data concerning the amount and distribution of deliberate practice confirmed this assumption. The best violinists estimated more practice hours per week than the good violinists during early adolescence and more than the music teachers during their entire developmental period. Regarding the diary data which included the practice hours for a full week, clear differences between the music teachers and the two best groups, but no differences between the two best groups were found. Also in accord with the expectations, the top violinists rated sleep as highly relevant for improvement of violin performance. As a matter of fact, the two best groups of violinists with the highest levels of deliberate practice were found to nap more in the afternoon than did the group of music teachers. All in all, the results of this study are in line with the predictions derived from the theoretical framework developed by Ericsson and colleagues.

In their discussion of results, Ericsson et al. (in press) emphasize the fact that individual differences in expert performances should not be attributed to individual differences in natural, innate abilities. Instead, they argue that expertise has to be conceived of as the result of extensive and intensive practice activities and that individual differences in ultimate performance can be accounted for by differential amounts of past and current levels of practice. The claim is that once individuals have started deliberate practice, it is virtually impossible to distinguish the role of natural, innate ability from that of acquired skill in their current level of performance. According to Ericsson and colleagues, it is not the innate talent but rather the *perception* of talent that motivates parents to invest time and money to support deliberate practice. Needless to say, perceptions of talent should not be equated with objective indicators of innate ability.

Although Ericsson et al.'s theoretical framework for the acquisition of expert-level performance seems impressive and well-suited to account for much of the empirical evidence on the causes of exceptional performance, one possible problem with the empirical evidence described above is that it mostly consists of cross-sectional studies predominantly dealing with retrospective estimates of past behavior and interview data obtained from adults. In our view, prospective studies carried out with child experts and novices may add substantially to our knowledge about the origins and determinants of exceptional performance, particularly as far as the role of domain knowledge and basic abilities is concerned. As a consequence, the empirical evidence on determinants of exceptional performance based on cross-sectional as well as longitudinal developmental studies with child experts and novices will be summarized next.

Studies With Child Experts and Novices

Most developmental studies using the expert–novice paradigm focused on the impact of domain-specific knowledge on memory. In the field of memory development, numerous studies conducted during the past two decades have demonstrated the importance of the knowledge base for various aspects of memory performance (for reviews see Chi & Ceci, 1987; Schneider & Pressley, 1989). According to many developmental researchers, the knowledge base seems to be one of the crucial sources of memory development in childhood and adolescence, probably outweighing other relevant factors like capacity, strategies, or metamemory (cf. Bjorklund, 1990; Siegler, 1991). Although the number of developmental studies based on the expert–novice paradigm is still small, as compared to the number of studies on expertise with adults, their findings have attracted much attention in the developmental literature. In the next section, developmental studies focusing on the role of knowledge will be presented first, followed by those studies that explored the importance of basic ability in addition to that of the knowledge base.

Developmental Studies Exploring the Impact of Domain Knowledge on Performance

From a developmental perspective, the major advantage of the expert–novice paradigm is that knowledge and chronological age are not necessarily confounded. It is not only possible to recruit adult chess novices but also to find young chess experts for experimental studies. The classic developmental study was conducted by Chi (1978) who recruited experienced and inexperienced chess players and gave them Chase and Simon's chess board reconstruction task (see above). The most interesting aspect of this research was that subjects' knowledge correlated negatively with age; the children were the experts and the adults were the novices. As a main result, Chi found that the children's short-term memory for chess positions was superior to that of the adults. On the other hand, the typical adult superiority in short-term memory capacity could be demonstrated for the memory span control task, dealing with a domain (i.e., digits) that adults were more familiar with. Chi concluded from her results that short-term memory capacity was not inherently a function of the subjects' age, but rather of their knowledge. The most impressive finding was that the impact of the knowledge base on recall resulted in a reversal of the typical age effect.

From a methodological point of view, both the small sample size of Chi's study and the fact that only two of the four possible groups (i.e., child and adult experts and novices) were included called for a replication and extension of Chi's work. Two subsequent developmental studies on chess expertise (Roth, 1983; Opwis, Gold, Gruber, & Schneider, 1990) found supportive evidence. Roth (1983) did not assess memory performance but tested child and adult experts and novices on a chess board comparison task. The magnitude of the knowledge effect was sufficient to eliminate any significant differences between child and adult experts. Further, the knowledge effect accounted for between-age group differences in that child experts outperformed adult novices. Thus Roth's findings for the area of perceptual speed seem to validate Chi's results obtained for short-term memory processes.

In the study by Opwis et al. (1990), groups of child and adult chess experts and novices were compared on various chess board and control board reconstruction tasks which included both replications and extensions of Chi's original work. The major extension concerned a procedure that aimed at identifying possible sources of the experts' superior memory performance. Opwis et al. believed that several aspects like the experts' greater familiarity with the constellation of chess pieces on the board (i.e., meaning of constellations) and their greater familiarity with the characteristics of the chess board (i.e., geometrical pattern, form and color of chess pieces) all contribute to superior performance. They expected all these factors to be effective in the meaningful chess board reconstruction task. The effects of expertise on performance should be considerably smaller (but still significant) in the random board reconstruction task because only familiarity with the basic charactistics of the chess board was assumed to be greater for the experts, as compared to the novices. Finally, no performance differences between experts and novices were expected for a control task that required the reconstruction of wooden pieces on a board that had little in common with a chess board.

The results of the study basically confirmed these assumptions. Similar to the findings by Roth (1983), no performance differences between adult and child experts were found. Expert–novice differences on the chess board reconstruction task were most pronounced for the meaningful chess positions and considerably smaller but still significant for the random board positions. In accord with their hypothesis, Opwis et al. found that experts and novices did not differ in immediate reconstruction of items on the control board. Opwis et al. concluded from this finding that experts' performance on the chess board reconstruction tasks is facilitated by the two context factors described above. Probably due to these factors, experts are able to process information faster and in larger semantic units.

Although the results were inconsistent with those by Chi (1978) and also Chase and Simon (1973) in that no pronounced expert–novice differences in chunking were observed based on inter-response latency measures, the analysis of videotapes suggested qualitative differences in the reconstruction strategies used by the expert and novice groups. While most experts seemed to start with the reconstruction of specific meaningful units, the novices focused on aspects like color of pieces or specific positions on the board. From a developmental perspective, it seems particularly interesting that no qualitative differences in the strategies of the child and adult experts were detected.

Taken together, the findings from the developmental studies on chess expertise corroborate those obtained from studies dealing with expert/novice differences in adults in that performance differences can be attributed to qualitative differences in strategic processing. Due to their rich knowledge base, child experts seem to process information in a way very similar to that of adult experts. Although most developmental studies did not focus on the interplay of knowledge components (i.e., declarative and procedural knowledge) in the determination of performance, a recent developmental study on expertise in tennis (McPherson & Thomas, 1989) provides information on this point. McPherson and Thomas compared expert and novice tennis players (10–11 and 12–13-years-old) on tennis performance and tennis knowledge. Declarative knowledge about tennis was related to the development of procedural knowledge, that is, the quality of decisions and selection of actions made within the context of a game. Regardless of age, both knowledge components discriminated between experts and novices and were significantly related to tennis skill.

The developmental studies on expertise discussed above all have demonstrated the fast developmen of domain-specific knowledge in child experts and its close relationship to performance in the domain of interest. However, they do not inform about the relative importance of ability because this variable was not included in the design. As a matter of fact, only a small number of developmental studies considered the impact of basic ability intelligence on performance in addition to that of domain knowledge. These studies will be summarized next.

Developmental Studies Exploring the Impact of Aptitude and Knowledge on Performance

A series of developmental studies investigated the importance of domain knowledge and general ability for processing of text information related to the domain of expertise. They can be conceived of as replications and extensions of studies on text processing carried out with adults. As already mentioned above, Jim Voss and his colleagues (Spilich, Vesonder, Chiesi, & Voos, 1979; Voss et al., 1980) had used this paradigm in their studies on expertise in baseball. Voss and colleagues assessed subjects' declarative knowledge about baseball in order to form groups of baseball experts and novices. Next, a passage dealing with a baseball game was presented, which had to be recalled some time later. Not surprisingly, the baseball experts recalled more information than the novices. The more interesting finding was that the quality of experts' and novices' recall protocols differed considerably. Whereas the baseball novices recalled as much unimportant as important information, the experts mostly recalled important information.

A group of researchers at the Max Planck Institute for Psychological Research in Munich adopted this paradigm for developmental studies with soccer experts (see Körkel & Schneider, 1992; Schneider, Körkel, & Weinert, 1989, 1990). More than 500 third, fifth and seventh graders participated in this project. According to their performance on a questionnaire tapping knowledge about soccer rules and important soccer events, these children were categorized as either experts or novices with respect to soccer. The students at each grade level were asked to recall a story about soccer. In addition, information about metacognitive knowledge (i.e., knowledge about text processing) and subjects' intellectual ability was obtained. A second assessment using the same instruments followed about a year later.

The analysis of free recall data yielded significant effects of grade and expertise for each measurement point. While seventh graders recalled more text units than both third and fifth graders, experts outperformed novices at each grade level. The findings also confirmed Chi's (1978) result in that a reversal of developmental trends was demonstrated: third grade experts recalled more text information than seventh grade novices.

The measures of intelligence and metacognitive knowledge were included to explore the impact of these variables relative to domain knowledge. With regard to metacognition, the expectation was that in both the expert and novice groups, subjects with high metacognitive knowledge on text processing should outperform those with low metacognitive knowledge. The results clearly confirmed this prediction, indicating that the combination of rich domain knowledge and metacognitive knowledge lead to optimal performance on the recall task.

The results concerning the impact of general ability were different. The experts and novices were classified into high-ability and low-ability subjects on the basis of their performance in the intelligence tests. Thus, four groups resulted at each grade level: high- and low-ability soccer experts and high- and low-ability soccer novices. When the longitudinal recall and comprehension data were analyzed using grade, expertise and general abilities as independent factors, only effects of expertise and grade were found. Most strikingly, neither a single effect was found for general ability, nor were there any significant interactions. Schneider et al. concluded from these findings that rich domain-specific knowledge can sometimes compensate for overall lack of general cognitive abilities.

As supporting evidence for this has been provided in a number of recent studies with children and adults (e.g., Ceci & Liker, 1986; Recht & Leslie, 1988; Walker, 1987), it appears that individual differences in general ability do not make a difference when the task is to process new information in a highly articulated domain. Please note that this is also the conclusion Ericsson and colleagues have drawn from their research on adult expertise. Thus research on exceptional performance in adults and developmental studies on text processing in child experts and novices lead to similar insights, as far as the role of basic abilities is concerned.

One problem with the developmental studies on the roles of domain knowledge and general ability in affecting text processing is that they have been based on a small number of tasks and paradigms. The question remains whether their main finding concerning the role of general ability can be generalized across different tasks and domains. A recent study by Schneider and Bjorklund (1992) shed some doubts on this assumption. Schneider and Bjorklund adopted the basic design used by Schneider et al. (1989). However, instead of assessing text processing, they tested second and fourth grade soccer experts' and novices' performance on a sort–recall task dealing with soccer words.

In accord with their expectations, Schneider and Bjorklund found significant effects of expertise on recall, thus confirming the results of the previous studies. However, soccer expertise did not modify a significant effect of IQ level, with high-IQ children recalling more than low-IQ children for all contrasts. The results thus demonstrate that domain knowledge played an important role in children's memory, but could not fully eliminate the effects of IQ on sort–recall tasks using domain-related materials. That is, although rich domain knowledge seemed to compensate for low aptitude, in that low-aptitude experts performed at the level of high-aptitude novices, its effects were not strong enough to eliminate performance differences between high- and low-aptitude soccer experts.

Schneider and Bjorklund (1992) concluded from their work that the findings from developmental studies dealing with text processing did not generalize to the sort–recall paradigm, at least as far as the aspect of general ability was concerned. One difference between the text recall task used in the previous studies and Schneider and Bjorklund's sort–recall task concerned the role of strategies and memory capacity. Whereas neither strategies nor capacity seem particularly important in the case of gist recall (text recall), they are certainly more relevant when verbatim recall is required, as is true for sort–recall. It appears, then, that being an expert does not eliminate the effects attributable to individual differences in intelligence when deliberate strategies play a role in task performance.

One problem with most developmental studies using the expert–novice paradigm concerns the extent of expertise. For example, no official chess ratings were available in most developmental studies on chess expertise, making it difficult to judge the competence of child experts as compared to that of adult experts. Also, most developmental studies on text processing experienced problems with defining expertise. Taking the median of the distribution of scores in domain-specific knowledge tests as the critical boundary for expert–novice distinctions not only creates the possibility of misclassifications but can also imply that the average level of expertise is rather low.

This problem was not an issue in two recent developmental studies on the impact of domain knowledge and aptitude on domain-specific performance (Horgan & Morgan, 1990; Schneider, Bös, & Rieder, 1993), which thus will be considered next. Both studies included samples of true child experts, that is, young promising subjects with already extraordinary competencies in their domain of interest. In Horgan and Morgan's study, official ratings were available for all child chess experts ($N = 113$). The elite subsample consisted of the twenty best players of this sample. Most of the young elite players had skill ratings of 1300 and more (the mean for all U.S. tournament players of all ages is 1500 and the standard deviation is 200). The Schneider et al. study consisted of a reanalysis of data on the development of a group of 109 tennis talents collected about 10 years ago. At the beginning of the study, the children's age ranged from 10 to 14 years of age. As we know today, the careers of most of these tennis talents were very successful. Most players are still listed in the national rankings and more than 10% of the sample have made it to the top 100 in the world, with a few players even belonging to the best ten players in the world.

Furthermore, the two studies seem theoretically interesting because they were longitudinal in nature. In their correlational study, Horgan and Morgan (1990) examined children's chess records for one academic year. The reanalysis of tennis talent data by Schneider et al. (1992) was based on a 5-year longitudinal study, including repeated measurements of basic motor abilities, skill-related tests, psychological tests concerning achievement motivation and concentration skills and interview data focusing on parental support and amount of practice.

What does the chess study by Horgan and Morgan tell us about the roles of IQ and experience in developing chess skill? The elite subsample was given two tasks that tapped general abilities and one test of domain-specific skill. The Raven's Matrices test was used as a measure of intelligence because it was considered a measure of logical abilities as well as spatial abilities. The authors felt that the type of reasoning required was similar to chess reasoning. In addition, a Piagetian task measuring combinatory logic in formal reasoning was used. Finally, the Knight's Tour, that is, a chess-specific test that is believed to be closely related to chess skill was provided.

As one main result of the longitudinal study based on the total sample, it was shown that improvement in chess skill was significantly correlated with experience. Using age and pretest ratings as covariates, Horgan and Morgan could demonstrate a close relationship between experience in terms of games played and posttest chess rating. In sum, the more improved players played more and won more.

Additional stepwise regression analyses carried out for the elite subsample showed that pretest chess skill accounted for about 65% of the variance in post-test chess skill. When the Raven's test was added as a predictor, the amount of variance explained in the dependent variable increased to 77%. Another 10% of the variance were accounted for by the addition of numbers of games played. Horgan and Morgan concluded from this finding that both experience and nonverbal intelligence significantly contribute to improvements in chess skill. As the Piagetian task showed no significant correlation with chess skill in the young elite players, it appears that the type of reasoning assessed in general ability tests makes an important difference in this regard.

One of the goals of the study by Schneider et al. (1993) was to test Ericsson and Crutcher's (1990) assumption that the basic findings concerning expertise in chess can be generalized to other domains, including sports. In particular, the reanalysis of tennis talent data aimed at estimating the relative impacts of basic motor ability and tennis-specific skills on performance in tennis, as indicated by national rankings. Indicators of motor ability included assessments of sprint ability, whereas measures like string-frame bouncing tests and target hitting tests were used to tap tennis-specific skills. In addition, variables like parental support, estimated intensity of practice, achievement motivation and concentration skill were considered in the analyses.

Results of causal modeling procedures showed that tennis-specific skills explained most of the variance in the tennis rankings obtained for the last year of the longitudinal study (1982). Similarly, intensity of practice and parental support during the early stages of the children's tennis career significantly predicted the tennis rankings. The impact of basic motor ability on tennis performance was comparably small but reliable. That is, when the basic ability construct was omitted from the model, it no longer fitted the data. The same pattern of results emerged when tennis rankings obtained 7 years later were used as the dependent variable. Rankings obtained in 1982 and in 1989 correlated with $r = .70$, which indicates high stability of individual differences in tennis skill during adolescence and early adulthood.

Taken together, the findings by Horgan and Morgan (1990) and Schneider et al. (1993) basically confirm the theoretical framework developed by Ericsson and colleagues. They all highlight the importance of deliberate practice in developing domain-specific expertise in children. The results provided by Schneider et al. additionally prove the significance of parental support systems for skill development. However, both studies do not support the assumption that individual differences in basic ability can be completely neglected when it comes to predicting the development of expertise. In the case of chess expertise, intelligence as measured by the Raven's test accounted for a small but significant amount of variance explained in the dependent variable, that is, improvement in chess skill within a year. Similarly, the study by Schneider et al. showed that the relative impact of basic ability on performance was small but reliable. This finding seems particularly impressive given that the basic abilities found for the two elite samples in chess and tennis were clearly above average and that the range of scores was small due to the homogeneity of the samples. The results of these studies thus seem to indicate that experience, while extremely important, cannot completely substitute talent. As emphasized by Horgan and Morgan, no amount of experience will make an ordinary player into a grandmaster. Thus the message is that one should come up with models of skill acquisition that account for possible influences of individual differences in cognitive abilities. Theoretical models including the basic ability component will be discussed in the final section of this chapter.

Conclusion

In this chapter, it has been shown that exceptional performance usually is based on an extremely rich knowledge base, acquired through a very long lasting process of motivated learning. In order to reach this point, cognitive personality characteristics like high intellectual ability seem less important than noncognitive factors like endurance, dedication, concentration and motivation. The most important accomplishment of the skilled memory theory was to highlight and demonstrate the relevance of acquired skills in explaining exceptional performance. The findings by Ericsson and colleagues even suggest that individual differences in basic abilities can be ignored in view of the overwhelming effects of expertise on performance. However, one problem with most of the studies on adult expertise was that individual differences in basic abilities were not explicitly measured. Given the evidence from developmental studies on expertise which took those abilities into account, one is inclined to believe that the impact of innate, basic abilities should not be completely ignored in theoretical models dealing with the acquisition of expertise. But as even the developmental studies do not show substantial influences of high ability or talent, one can easily accept that the original approach of prospective research in giftedness outlined above does not pay off in the long run. In most theoretical models relating giftedness to exceptional performance, the impact of early basic abilities on performance later in life has been largely overestimated.

On the other hand, it does not seem to require much effort to change developmental models derived from giftedness research into models compatible with the expertise approach. For example, Renzulli's (1986) three-ring model of giftedness includes several components highly important for the acquisition of expertise. According to Renzulli's model, aptitude, creativity and a motivation plus context component determine giftedness or talent. If one replaces talent by exceptional performance and also gives a low weight to the aptitude and creativity factors, as compared to the motivation and context factor, one only needs to add a big knowledge component in order to be in line with core assumptions of the expertise approach.

Another modification of the theoretical framework of expert performance was suggested by Schneider (1988, 1992). Schneider emphasized the fact that most studies in adult expertise dealt with subjects of at least average intelligence (e.g., physics professors, chess players). He voted for a "threshold" model of exceptional performance that can be described as follows: If the ability parameter of a subject is close to or beyond a critical or "threshold" value of ability (typically assumed to be slightly above average), then individual differences in noncognitive variables like commitment, endurance, concentration, or motivation decide about peak performance. In this case, it does not matter at all whether the subject is gifted or only of normal intelligence. Although this model appears intuitively plausible, one of its problems lies in the definition of critical or "threshold" scores for different domains (cf. Weinert, 1992). The boundaries may be well above average for domains/tasks where complex problem solving activities and strategy utilization are necessary components and may be clearly below average for less complex domains or tasks that mainly rely on automatical processes (e.g., pattern recognition processes or text processing).

Another model concerning the acquisition of expertise and including ability components was developed by Ackerman (1987). Following the theoretical assumptions of Fitts and Posner (1967), Ackerman assumes that three stages of skill acquisition can be distinguished: a first cognitive stage deals with the acquisition of declarative knowledge. This is followed by an associative stage, where elements of declarative knowledge are composed into larger units and procedural knowledge is gradually acquired and improved. Although the final, automatic stage of skill acquisition does not differ from the second as far as qualitative aspects of information processing are concerned, its unique features may be seen in increased, optimal speed of processing as well as fine-tuned and automatized problem solving activities.

According to Ackerman (1987, 1988), different aptitudes are necessary to master the three stages described above. Regarding the first cognitive stage, individual differences in general intellectual ability seem to be most important. That is, the higher the general intelligence of an individual, the faster declarative knowledge about a specific domain should be acquired. During the second, associative stage, indicators of perceptual speed appear to be particularly important for combining elements of declarative knowledge and initializing the procedural knowledge component. Finally, individual differences in psychomotor abilities seem most relevant for mastering the stage of automatization.

This model suggests that the impact of individual differences in basic intellectual abilities on the process of skill acquisition diminishes as a function of time. Supporting evidence for this assumption can be derived from experiments conducted by Ackerman (1988, dealing with a variety of cognitive tasks. Although these findings confirm Ackerman's core assumption concerning the changing role of basic intellectual abilities during the process of skill acquisition, it still remains unclear whether the role of perceptual speed and psychomotor ability components can be generalized across a wide variety of domains.

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