

The contribution of cognitive style, cognitive abilities and expertise to the solving of complex problems

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Abstract

The influence of Need for Cognition, cognitive abilities and expertise on complex problem-solving was examined. A 'Need for Cognition' questionnaire, a cognitive abilities test and five complex problems were presented to a group of experts (Experiment 1) and to a group of novices (Experiment 2). Generally, experts performed better on the complex problems than did novices. Experts low in cognitive ability solved complex problems better than those high in cognitive ability; in addition, experts high on Nfc solved complex problems better than those low on Nfc. Furthermore, experts low on cognitive ability and low on Nfc did best. Within the group of novices, no effect of cognitive ability and Nfc on the complex problems was observed.

Introduction

Problems can be situated on a continuum ranging from well-structured to ill-structured, according to whether the initial states and goal states are well-defined or loosely-defined in the problem statement. Problem-solving has been an important research area since several decades, but rather little research has been conducted on the solving of complex problems, the problems we will focus on. Amongst others, three major variables influence the capacity to solve this kind of problems: cognitive style, cognitive abilities and expertise.

Cognitive style

Cognitive style is described as the individual variation in modes of perceiving, remembering and thinking, or as distinctive ways of apprehending, storing, transforming, and utilizing information (Capitiano & Mason, 2000; Kogan, 1971). One of the most important requirements for an individual to solve complex problems is his motivation to understand and actively structure the relevant variables constituting the problem in meaningful, integrated ways. This kind of intrinsic motivation can be construed as the personality trait 'Need for Cognition' (Nfc).

Cohen, Stotland and Wolfe (1955) defined Nfc as "a need to structure relevant situations in meaningful, integrated ways" (p. 291) and Cacioppo and Petty (1982) as "the tendency for an individual to engage in and enjoy thinking" (p. 116). Both the concept Nfc as well as its influence on information processing has been studied extensively. Over the years, there has been an accumulation of research results indicating a significant relationship between Nfc and various cognitive performance measures. Cohen (1957) reported that individuals with a high Nfc are more likely to organize, elaborate on and evaluate the information they are presented. Furthermore, Cacioppo and

Petty (1982) showed that individuals with a high Nfc consider a larger number of possibilities, generate a higher number of task relevant thoughts and try out more alternative hypotheses during the problem-solving process than individuals with a low Nfc.

To date, the influence of Nfc on the solving of complex problems has only been studied by Nair and Ramnarayan (2000). They found that individuals with a high Nfc (1) were much more likely to solve the problems, (2) considered more informative elements of the problem, and (3) found the problems easier, compared to individuals with a low Nfc."

Cognitive abilities

The capacity to solve complex problems does not only depend on the individual's Nfc, but is also influenced by the cognitive abilities one has at his disposal. Whereas cognitive style bears on the individual differences in the way people process information, cognitive abilities that are related to the diffuse concept 'intelligence', refer to the level of skill by which information is processed (Kogan, 1971).

Gottfredson (1997, p. 13) asked 52 professors, all experts in the field of intelligence, to state their meaning of the concept. Their response was the following: "Intelligence is a very general mental capacity that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas and learn quickly from experience". In his influential triarchic theory of intelligence, Sternberg (1985) and Cianciolo and Sternberg (2004) stressed experience and adaptation to various environmental contexts as highly important.

Despite the lack of consensus in the literature on the questions what intelligence exactly involves and whether there are one or more types of intelligence, it is clear that problem-solving and the ability to learn, make up two crucial components of cognitive ability.

Expertise

Regarding complex problems, consistently superior performing problem solvers are referred to as experts (Ericsson & Lehmann, 1996). It is widely accepted that experts not only have more knowledge at their disposal, but that this knowledge is also better organised. Before they actually apply solving strategies to the stated problem, experts go through an elaborate qualitative analysis of the problem. Novices on the other hand analyze a problem in terms of superficial features, resulting in a

poor problem representation and weak solving strategies (Chi, Glazer, & Rees, 1982). Based on his theory of human abilities, Sternberg (1995) presented a triarchic view of expertise, in which context and experience play a crucial role.

Although expertise is often attributed to the gross amount of experience in a specific domain, Hatano (1982) proposed a distinction between routine expertise, restricted to the domain of expertise, and adaptive expertise, transferable to novel domains and problems. Holyoak (1991, p. 310) characterises the consequences of this difference as follows: "Whereas routine experts are able to solve familiar types of problems quickly and accurate, they have only modest capabilities in dealing with novel types of problems. Adaptive experts, on the other hand, may be able to invent new procedures derived from their expert knowledge".

The aim of this study is to shed light on the influence of cognitive style, cognitive abilities, expertise and the interactions between these variables, on one's ability to solve complex problems. Therefore, we investigate to what extent cognitive style and cognitive capacities contribute to the capacity to solve complex problems, and this within a group of expert problem-solvers (Experiment 1) and within a group of novices (Experiment 2), after which we will compare the performance of both groups. Moreover, in Experiment 1 we will examine whether the experts' knowledge is transferable to problems outside their domain of expertise.

Experiment 1

Barnett and Koslowski (2002) reported that, given their experience with the solving of management-related complex problems, business-consultants are considered as experts. This is why we investigate the role of NfC and cognitive abilities in the process of complex problem-solving within a group of business-consultants.

We hypothesise a positive relation between the NfC and the performance on the complex problems. More exactly, we expect the consultants with a high NfC to achieve a higher quality- and quantity-score on the complex problems, than the consultants with a low NfC. Furthermore, we expect the participants with more cognitive abilities to score better on both types of complex problems than participants with less cognitive abilities. The consultants are given two types of complex problems: three management-related problems, contiguous to their domain of expertise, and two everyday-problems. When they solve both types of complex problems equally well, this bears evidence of the hypothesis that their expertise is transferable to novel domains.

Method

Participants 14 business consultants (8 male, 6 female) with a minimum of 5 years (range 5 -21 years) of professional experience as a management consultant for organizations, took part on a voluntary basis.

Material

Cognitive Style The NfC questionnaire was a Dutch adaptation (Pieters, Verplanken en Modde, 1987) of Cacioppo and Petty's (1982) 34-itemscale, consisting of 15-items. All items measured participants' intrinsic motivation to engage in reasoning and problem solving and had to be judged on five-point scales ranging from A (strongly agree) to E (strongly disagree). Items looked as follows:

- *I really enjoy a task that involves coming up with new solutions to problems.*
- *I tend to set goals that can be accomplished only by expending considerable mental effort.*
- *I take pride in the products of my reasoning.*
- *I don't usually think about problems that others have found to be difficult.*
- ...

Cognitive Ability The test assessing cognitive abilities was a set of 35 well-defined problems, selected from the Dutch intelligence test 'Combined Test for Intellectual adults'. The items were selected in order to assess the capacities needed to solve our selection of complex problems. The test included the following categories: '*diagnostic reading*' (the capacity to extract critical information from a text), '*logical reasoning*' (deductive reasoning with syllogisms), '*digit spans*' (arithmetic), '*word classifications*' (verbal comprehension), '*mathematical problems*' (analytical thinking and numerical skills), '*sorting out words*' (chronological ordering of social situations), '*proverbs*' (associations and verbal comprehension) and '*analogies*' (inductive reasoning with word series).

Complex Problems Five one-page complex problems exceeding domain specific knowledge of the consultants were constructed (for an example of a comparable complex problem, see Barnett & Koslowski (2002). All problems consisted of an equal amount of 15 informative elements. There were *three management-related problems*, about (1) a restaurant loosing clients due to the opening of a new restaurant in the neighborhood, (2) a high-school with a bad reputation needing to suspend specializations and (3) a chemicals factory with unsatisfied employees due to pressure of work and interpersonal conflicts). The *two everyday-problems* dealt with (1) about a young couple having trouble deciding where to live and (2) a boy with an attention deficit hyperactivity disorder causing tension at school and in his family.

Procedure All participants were tested individually and the tests were presented in the same order. They had 5 minutes to complete the NfC questionnaire. Next, they were given the set of 35 well-defined problems, which had to be resolved within 30 minutes. The well-defined problems were presented in a fixed order. It was explicitly mentioned not to write anything down during the problem-solving. After completing the well-defined problems, participants were presented with the five complex problems in randomized order. They had 12 minutes per problem to write down as many elaborated solutions to the problem as possible. All parts of the experiment were presented in Dutch.

Coding For the 35 well-defined problems, a score of one point was attributed to each correct answer. Coding the

complex problems, a quality- as well as a quantity-score was calculated. The quantity-scores were obtained by attributing one point a) to each proposed solution, b) to each element of information used in that solution, c) to each element of information the participant thought that was missing in the problem statement and necessary to solve the problem. The quality-scores were calculated by attributing one to three points, according to their degree of elaboration, to each proposed solution, as well as to each of the elements. To this quality-score, a score ranging from one to five was added, depending on the degree of integration of the global answer. Pilot work showed that the scoring was reliable: The quality- and quantity-scores were determined by two independent raters, with the interrater correlation ranging from .89 to .97.

Results and discussion

We analysed the relation between the NfC scores and the scores on the well-defined problems on the one hand, and the performance on the complex problems on the other hand. For this purpose we conducted two analyses of variance with repeated measures. The dependent variables were the quality-score respectively the quantity-score on the two types of complex problems. The independent variables were the categorical predictors NfC and cognitive abilities, both made up of two levels (1 = low-group, 2 = high-group). This division into a low-group and a high-group was performed by a median split. All variables were tested within-subjects. Finally, we compared the performance on the management-related and the everyday complex problems by means of a t-test, in order to examine the adaptiveness of the consultants' expertise.

The relation between the NfC scores and the experts' quality- and quantity-scores on the complex problems was in the expected direction (the higher the score on NfC the better the performance) but did not meet the .05 significance level. This can be put in perspective as follows: Since our participants chose for a job as a business-consultant, we infer that their search for problem-solving strategies is satisfactory. Moreover, we contacted a large group of consultants with the request to participate in this study, and only 14 individuals took part entirely free of charge. So we are dealing with a select group of participants having a maximal NfC. In addition, the consultants filling in the NfC items used a reference-group (their colleagues) with a higher NfC than average. Therefore, in a second experiment we will select a 'low group' and a 'high group' on this variable.

The global score on the variable cognitive abilities affected the quality- and quantity-scores on the complex problems in the expected direction, although not significant. Concerning the cognitive abilities, we are also dealing with a select, homogenous group: individuals with one or more university diplomas. Within the general population, the range of cognitive abilities is larger, thus a positive relation between their cognitive abilities and the performance on solving complex problems is to be expected. The difference between convergent thinking, as measured by the well-defined problems, and divergent thinking, which is needed to solve complex problems,

might be another explanation. We come back to that in the general discussion.

Both types of complex problems were solved equally well. There was no significant difference between the scores on the management-related and the everyday-problems, neither concerning the quality-scores, nor concerning the quantity-scores. Even within the low-group and the high-group of both NfC and cognitive abilities, no significant difference between the two types of complex problems was found. This bears evidence of the hypothesis that the participating consultants are no routine experts but adaptive experts.

Experiment 2

It is possible that the relation between the scores on NfC and cognitive abilities on the one hand, and the scores on the complex problems on the other hand, is masked by the expertise the consultants have at their disposal, cancelling out the smaller effects of NfC and cognitive abilities. In order to examine this supposition, the same hypotheses are tested within a group of novices in problem-solving: undergraduate students.

Method

Participants A total of 145 first year psychology students filled in the NfC questionnaire. The 30% students with the highest score and the 30% with the lowest score were asked to take part in the continuation of the experiment. 21 individuals from the low-group and 26 from the high-group accepted.

Material The same material as described in Experiment 1 was used.

Procedure and coding The procedure and coding were identical to those described in Experiment 1. The participants were pre-tested for NfC. They first solved the well-defined problems, next the ill-defined problems.

Results and discussion

Within this group of novices we analyzed, similar to Experiment 1, the relation between NfC and cognitive abilities on the one hand, and the performance on the complex problems on the other hand. We conducted the same two analyses of variance with repeated measures, with respectively the quality-scores and the quantity-scores on the two types of complex problems as dependent variables. The independent variables were the categorical predictors NfC, and cognitive abilities, both made up of a low-group and a high-group-level. This division into a low-group and a high-group was executed according to a median split. All variables were tested within-subjects. For this group of participants we also compared their performance on the management-related and the everyday complex problems by means of a t-test.

We found a pattern of results similar to the one observed within the group of consultants. The influence of the NfC scores on the quality- and quantity-scores for both types of complex problems, did not meet significance, but was in the right direction. The same goes for the relation between

the score on the variable cognitive abilities and the quality- and quantity-scores on the complex problems. We come back to possible explanations in the general discussion

Students solved the management-related and the everyday-problems equally well, and this adds for both the quality- and the quantity-scores. Within the low- and high-group of both NfC and cognitive abilities, no significant difference between the two types of complex problems occurred.

Experts versus novices

In order to draw a straight comparison between the novices and the experts regarding their scores on the NfC questionnaire, on the well-defined problems and on both categories of complex problems, we will conduct the same analyses on the pooled. The hypotheses are as follows: Given their professional activities, we expect the consultants to have a higher NfC than the average student. Regarding the students from the high-group for NfC, we expect their score to approximate to the score of the consultants. Concerning the well-defined problems, we do not expect the performance of the students and consultants to be widely divergent. All participants have a university-level and have therefore already proven to have disposal of the needed cognitive abilities. In the view of their expertise and experience with problem-solving, we expect the consultants to perform better on the complex problems than the students. When they are only better at solving the management-related problems, we can infer that the consultants are routine experts, but when they also achieve a higher score on the everyday-problems, this constitutes evidence for the adaptiveness of their expertise. Finally, we examine once more the relation between NfC and cognitive abilities on the one hand and the performance on the complex problems on the other hand. We hypothesise the participants with a high NfC to obtain a higher score on the complex problems than the participants with a low NfC, and we expect the participants with high cognitive abilities to score better on the complex problems in comparison to those with low cognitive abilities.

Results

The consultants generally scored higher on NfC than the students ($60.0 > 49.04$, $t(59) = -3.95$, $p < .01$), both groups having a comparable range ($9.25 \approx 8.57$). The consultants and the students did not differ regarding their cognitive abilities ($22.14 \approx 22.36$), nor did the range ($4.14 \approx 4.17$). The consultants had only a marginally significant higher NfC score than the students from the high-group, $56.5 \approx 60$, $t(38) = -1.754$, $p = .09$, and achieved virtually the same score on the well-defined problems than the students, $22.4 \approx 22.1$, $t(59) = .172$, $p = .864$.

We wanted to examine the relation between the participant's status (novice or expert), their score on the variables NfC and cognitive abilities on the one hand and their score on the complex problems on the other hand. For this purpose, we conducted two analyses of variance with repeated measures: the first for the quality-scores on the management-related and everyday complex problems, and

the second for the quantity-scores. Categorical independent variables were expert status, NfC and cognitive abilities.

The analysis of variance with the quality-score on the complex problems as a dependent variable yielded a main-effect of expert status. The consultants' score on the complex problems was significantly higher than the students' score, $20.9 > 13.9$, $F(1, 53) = 61.22$, $MSE = 1020.20$, $p < .01$. This goes for both the management-related problems, $21.3 > 14$, $F(1, 53) = 62.686$, $MSE = 547.927$, $p < .01$, and for the everyday-problems $20.5 > 13.8$, $F(1, 53) = 40.892$, $MSE = 473.627$, $p < .01$. The interaction NfC x cognitive abilities was also significant, $F(1, 53) = 4.147$, $MSE = 69.11$, $p < .05$. Both effects were involved in a significant three-way interaction expert status x NfC x cognitive abilities (see Figure 1), $F(1, 53) = 9.337$, $MSE = 155.59$, $p < .01$. Within the group of novices, there was neither a significant relation between the NfC and the quality-score, nor between the cognitive abilities and the quality-score. Within the group of consultants, we observed another pattern of results: Regarding the low-group on cognitive abilities, the consultants from the low-group on NfC obtained a higher quality-score than the consultants from the high-group on NfC. This difference was significant, both for the management-related problems, $25.1 > 19.6$, $F(1, 53) = 5.19$, $MSE = 45.375$, $p < .05$, and for the everyday-problems, $25.7 > 18.1$, $F(1, 53) = 7.63$, $MSE = 86.26$, $p < .01$. Regarding the high-group on cognitive abilities, the consultants with a high NfC achieved a higher score on the complex problems than did those with a low NfC. This effect was marginally significant for the management-related problems, $22.2 > 18.3$, $F(1, 53) = 3.51$, $MSE = 30.681$, $p = .067$. The difference in quality-score between the two NfC-groups was not significant concerning the everyday-problems.

The analysis of variance with the quantity-score on the complex problems as a dependent variable yielded a pattern of results similar to the analysis with the quality-scores as a dependent variable: There was a main-effect of expert status, with the experts achieving a significant higher quantity-score on the complex problems than the novices, $12.9 > 9$, $F(1, 53) = 38.135$, $MSE = 314.63$, $p < .01$. The interaction was significant for the management-related problems, $13 > 9.3$, $F(1, 53) = 38.43$, $MSE = 144.207$, $p < .01$, as well as for the everyday-problems, $12.9 > 8.8$, $F(1, 53) = 24.967$, $MSE = 170.992$, $p < .01$. The interaction NfC x cognitive abilities was also significant, $F(1, 53) = 5.078$, $MSE = 41.9$, $p < .05$. Similar to the previous analysis of variance, these effects were involved in the significant higher order interaction expert status x NfC x cognitive abilities, $F(1, 53) = 8.203$, $MSE = 67.68$, $p < .01$.

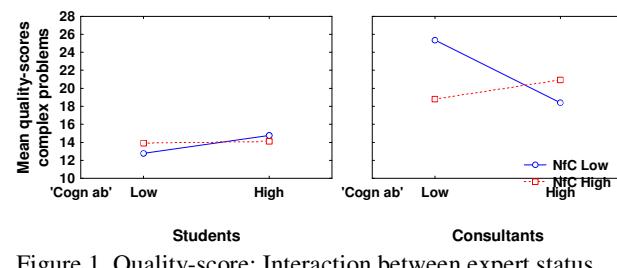


Figure 1. Quality-score: Interaction between expert status, NfC and cognitive abilities.

Within the group of novices, no significant relation between NfC and the score on the complex problems was observed, neither was there a significant relation between cognitive abilities' and the performance on the complex problems. Regarding the consultants, results similar to the quality-scores were observed. Within the low-group on 'Cognitive abilities, the experts from the low-group on NfC achieved a higher quantity-score than the experts from the high-group on NfC. This contrast was significant, both for the management-related problems, $14.3 > 11$, $F(1, 53) = 4.29$, $MSE = 16.116$, $p < .05$, and for the everyday-problems, $15.9 > 10.3$, $F(1, 53) = 7.03$, $MSE = 48.167$, $p < .05$. Within the high-group on cognitive abilities, there was a significant difference in quantity-score between the two groups on NfC regarding the management-related problems: The consultants from the high-group on NfC achieved a higher score than the ones within the low-group, $14.8 > 11.8$, $F(1, 53) = 4.93$, $MSE = 18.503$, $p < .05$. This difference was not significant regarding the everyday-problems.

Discussion

The first result catching the eye is the superiority of the consultants compared to the students regarding both the quality- and quantity-scores on the complex problems. This shows that the expert status is an important factor in the solving of (complex) problems, over and above intelligence and intrinsic motivation.

The experts perform better than the novices, both on the management-related problems, contiguous with their domain of expertise, and the everyday-problems, not related to their domain-specific knowledge. This bears evidence of the adaptive nature of the consultants' expertise.

We infer the following from the significant expert status \times NfC \times cognitive abilities interaction (see Figure 1): Regarding the students, there was no significant relation between NfC, and cognitive abilities on the one hand and their performance on the complex problems on the other hand. Similar results were already discussed in Experiment 2. Regarding the consultants, we observe other quality- and quantity-scores on the complex problems. Concerning the low-group on cognitive abilities, consultants from the low-group on NfC perform, against all expectations, better on the complex problems than the consultants from the high-group on NfC. The experts within the high-group on cognitive abilities did perform as hypothesised on the complex problems: the consultants with a high NfC score better than those with a low NfC. In our opinion, this pattern of results can be explained as follows: The consultants having disposal of high cognitive abilities, make good use of these skills, but especially when they are motivated (having a high NfC). The consultants with low cognitive abilities, who in addition are not motivated, are exactly the ones who will use resources facilitating the problem-solving process. This are external resources such as pen and paper compensating their lack of cognitive abilities. Experts having disposal of more cognitive abilities make less use of these external resources since they trust in their own abilities. That is why they sometimes perform

less well in comparison to situations in which they would make use of these resources. We will come back to this tentative explanation in the general discussion.

General Discussion

In the conducted experiments, we investigated to what extent cognitive style, operationalised as NfC, and cognitive capacities, assessed by means of well-defined problems, contribute to the capacity to solve complex problems. This was examined within a group of consultants (experts) and within a group of students (novices). We hypothesised the participants with a high NfC-score to perform better on complex problems. Moreover, we expected those with much cognitive abilities to achieve a higher score on the complex problems.

Neither in Experiment 1, nor in Experiment 2 the hypothesised relation between NfC and the score on the complex problems was found. A possible explanation for this is in terms of motivation: Cacioppo et al. (1996) describe NfC as a more or less stable, intrinsic motivation. The test situation however, and the instructions accompanying the complex problems to write down as many as possible elaborated solutions within a span of 12 minute, make up a source of extrinsic motivation. The influence of adding extrinsic motivation to already existing intrinsic motivation has been investigated extensively (for a review, see Deci, Koestner & Ryan, 1999). The general conclusion is that intrinsic and extrinsic motivation are not necessarily additive, but that the addition of extrinsic motivation can undermine and replace existing intrinsic motivation. Applied to our experiments, it is not inconceivable that we do not find a significant influence of NfC, because this intrinsic motivation was cancelled out by the extrinsic directions and limitations characteristic to the test situation and the instructions.

In both conducted experiments, no significant relation was found between the participants' cognitive abilities (their score on the well-defined problems), and their score on the complex problems. Next to restriction of range, another explanation is worth considering: Well-defined problems require convergent thinking or the application of particular rules in well-defined situations to find the one correct solution. In order to solve the complex problems presented to the participants, not only convergent but also divergent thinking is necessary, since the given information has to be processed in a creative manner to obtain various elaboration solutions. In the psychological literature, divergent thinking and creativity are often put on the same level. Creativity can be defined as the capacity to come up with new and applicable solutions to a problem (Lubart, 1994). This property is required to achieve a high score on the complex problems in our experiments, but is not necessary to solve the well-defined problems.

When we take a look at the results from the analyses on the pooled dataset, the most striking finding is that the consultants perform better on the complex problems than the students although their performance on well-defined problems is at level with the students. This bears evidence of the fact that experience with complex problems plays an important role in the performance to do so. Considering the

global results, we also revealed a remarkable interaction between expert status, NfC and cognitive abilities. Within the students there is no relation between NfC and cognitive abilities on the one hand, and the score on the complex problems on the other hand. Possible explanations were described above. Within the group of consultants however, we observe a surprising pattern of results. The consultants with a low score for both NfC and cognitive abilities perform better on the complex problems than those with a high NfC. The consultants with much cognitive abilities perform equally well on the complex problems, but only when they have a high NfC. The consultants with little cognitive abilities and a low intrinsic motivation, choose the line of the least resistance and solve the complex problems by means of external resources as pen and paper. The consultants with more cognitive abilities make less use of these written elaborations, since they know from experience they have enough cognitive abilities to perform a large amount of mental operations without the help of external resources. When they are intrinsically motivated, they achieve a high performance; otherwise they easily overestimate their competence and perform worse. Since we scored the written elaboration coding the answers, the compensatory use of external resources may lead to a higher performance-level.

Finally, our experts solved the everyday-problems equally well compared to the management-related problems. Moreover, comparing the score of the students and the consultants, we observe that the consultants perform considerably better than the students and this on both types of complex problems. From this we can conclude that our consultants are adaptive experts since they are capable to transfer their domain specific knowledge to novel problems.

A concluding practical advice to the consultancy firms: Keep your most intelligent consultants motivated and stress the others to rely on external resources.

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