THEORY OF STRUCTURED INTELLIGENCE
Results on Innovation-based and Experience-based Behaviour

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Abstract: An agreed-upon general theory of intelligence would enable significant scientific progress in all disciplines doing research on intelligence. Such a theory, namely the theory of structured intelligence is tested by relating it to other theories in the field and by empirically testing it. The results demonstrate (1) that the theory of structured intelligence uses a similar concept of intelligence as do other theories but offers greater scientific insights in the how intelligent behaviour emerges and (2) that its distinction between innovation- and experience-based solutions can be found in the behaviour of the study's participants. This yields the opportunity to (1) allow technically testing intelligence in an easier and less time-consuming ways as do traditional intelligence tests, and (2) allow technology classifying the intelligence of its user and using adaptive interfaces reducing the possibility of serious handling errors.

1 INTRODUCTION

Many different theories of intelligence have been developed in the varying disciplines (for a summary see Badreddin & Jipp, 2006). So far, these approaches have been isolated not sufficiently taking into account results from other disciplines. An opposite example is the theory of structured intelligence developed by Badreddin and Jipp (2006). The authors make use of research results in neurophysiology, psychology and system theory and present the theory itself and discuss ways of technical implementation. The theory defines intelligence as the ability to solve problems using limited space and time resources. The concepts of Innovation, Experience, Fusion, and Learning are distinguished to explain problem solving behavior. *Innovation* reflects the capability to come up with totally new, unpredictable solutions to the current problem. *Experience* refers to using past, known, and successful solutions for the current problem. If a problem is faced, two solutions are worked out, one based on innovation ("new solution"), the other based on experience ("past solution"). These two solutions are fused by appropriate algorithms and the final solution will be applied to the current problem. This derived solution is saved, so that it is available the next time the same or a similar problem is faced. Hence, any combination of new and well-known solutions to a problem can be developed. Fig. 1 gives an overview over the described structure.

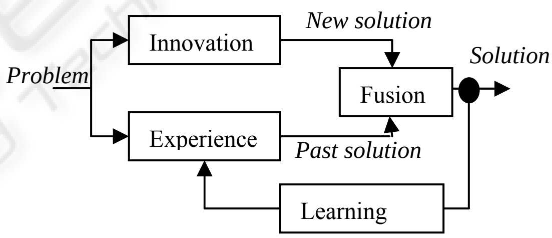

Figure 1: Theory of structured intelligence (see Badreddin & Jipp, 2006).

2 PROBLEM STATEMENT

The, by Badreddin and Jipp (2006) developed theory of structured intelligence needs further testing to see whether it (1) allows the realization of a qualitatively different concept of artificial intelligence, (2) allows easier testing of human intelligence, (3) enables technology to test their user's intelligence and adapt interfaces according to the level and structure of intelligence to avoid possible errors, which is especially of importance in safety-critical systems.

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3 SOLUTION APPROACH

To test the theory at hand, a way similar to what is known as construct validation has been taken (Campbell & Fiske, 1959): First, the concept of intelligence as described in Section 1 will be set into relation with other existing theories (see Section 2.1). To empirically test the defined relations and related hypotheses, a study has been conducted in a second step, which results are presented in Section 2.2.

3.1 Theoretical Foundations

In order to perform the construct validation, the theory of structured intelligence must be put in theoretical relation with another theory which has proven empirical adequacy. The theory used here is the theory of skill acquisition, which was developed by Ackerman (1988) and is based on research performed by Fitts (1964), Anderson (1982), Fleishman (1972), as well as Schneider and Shiffrin (1977). Ackerman (1988) distinguishes three phases of skill acquisition:

- The first phase is characterized by a relatively strong demand on the cognitive-attentional system, so that performance is slow and error prone. Ackerman (1988) explains this phase as the one in which potential ways for executing the current task are worked out and (mentally) tested. Attention is focused on thoroughly understanding the task's constraints in question. With consistent practice, performance gets faster (see Schneider & Shiffrin, 1977) and attentional demands are reduced (see Fisk & Schneider, 1983).
- During the second phase, the applied and successful ways of executing the task in question are strengthened and fine-tuned. More efficient ways of solving the task in question are found.
- Finally, performance is fast and accurate. The task is automated and can be completed without much attention.

Performance in each of these three phases is determined by abilities, namely by general intelligence, perceptual speed ability, and psychomotor abilities. *General intelligence* was defined by Ackerman (1989) in accordance to Humphreys (1979), as the ability to acquire, store, retrieve, combine, compare, and use information in new contexts. *Perceptual speed* refers to the ability to complete very easy cognitive tasks. The core cognitive activity is to generate very simple potential solutions to effectively solve tasks as quickly as possible. The key is the speed with which symbols can be consistently encoded and compared (Ackerman, 1989). Last, *psychomotor abilities* represent individual differences in the speed of motor responses to problems without information processing demands.

Ackerman (1988) proposes that general intelligence determines initial performance on a task with new information processing demands, i.e. the first phase of skill acquisition. The influence of general intelligence diminishes, when potential ways for the solution have been formulated (for empirical support, see e.g., Ackerman, 1988). The learner proceeds to the second phase of the skill acquisition process, when an adequate cognitive representation of the task has been built. Then, performance depends more on psychosensoric abilities. It is required to fine-tune and compile the determined solutions, which equals the definition of the abilities underlying psychosensoric abilities. Sequences of cognitive and motor processes get integrated, ways of solution adapted for successful task performance. With further practice the impact of psychosensoric abilities on performance decreases and psychomotor abilities play a more important role. In this third phase of the skill acquisition process, the skill has been automated, so that performance is only limited by psychomotor speed and accuracy (Ackerman, 1988).

Fig. 2 summarizes the described relationship between skill acquisition and ability-performance correlations.

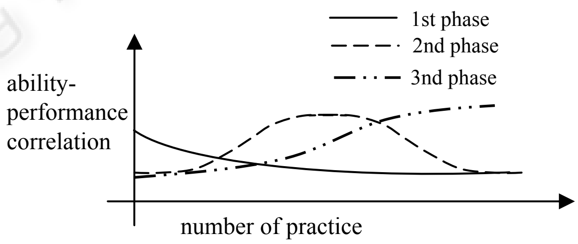

Figure 2: Theory of Skill Acquisition (adapted from Ackerman, 1989).

Taken into account the above described theory of structured intelligence it is to be assumed that in the first phase of skill acquisition, in which the learner is confronted the first time with a new problem, innovation processes affect the derived solution. In contrast, the solution to a well-known problem will be chosen based on the memory traces of the already successfully applied solution alternatives. Hence, in this case, behaviour is experience-based.

3.2 Conducted Study and Relevant Research Results

3.2.1 Research Questions and Hypotheses

The, in the previous section described theory of skill acquisition has been tested by various researchers (see e.g., Jipp, Pott, Wagner, Badreddin, & Wittmann, 2004) and proved its empirical adequacy in various settings and circumstances. The relationship to the theory of structured intelligence has been established theoretically in Section 2.1 and will be tested empirically. Therefore, the following research questions and hypotheses are of interest:

- It is hypothesized that the degree of consistency with which given tasks are tackled decreases with the familiarity of the task. This is the case as formerly applied successful solutions will be used to solve the problem at hand. Variation does only occur when the former solution has not lead to a satisfying result.
- It is hypothesized that the transition from innovation-related processes to experience-based solutions is determined by intelligence factors as measured with traditional measurement scales for intelligence factors. This is based on Ackerman's theory (1989) combining skill acquisition processes with factors of individual differences, i.e., general intelligence, perceptual ability and motor skills. The last is not considered in this paper due to the focus on structured intelligence.

3.2.2 Description of the Sample and Course of the Study

To be able to answer these research questions, a study has been conducted at the vocational school of the *Protestant Foundation Volmarstein* (Evangelische Stiftung Volmarstein, Germany). Data from 13 students (6 male, 7 female students) was at hand for the present analyses. The students were wheelchair-users and have been disabled for more than 12-15 years. Their average age was 22.5 years (SD = 1.6 years). The disabilities of the participants were spasticity, spina bifida, dysmelia or incomplete paralysis.

The study was conducted within two sessions. The first session lasted between one and two hours depending on the speed with which the participants performed the designated tasks (see also Jipp, Bartolein, & Badreddin, 2007). The tasks the participants conducted referred to leading a little garden market. More specifically, the participants had to prepare products potential customers requested. These customer wishes were sorted in two categories: sowing seeds (either sunflower or ramson seeds) and setting in seedlings (either flowering or foliage plants). The following actions were required in order to sow the seeds:

- The pots had to be placed in a seed box.
- The pots had to be filled with loosened soil.
- A hole had to be made into the soil.
- One seed had to be put in each hole.
- If the seeds were light seeds (as indicated on the customer wish), the holes had to be covered with wet pieces of newspaper.
- If the seeds were dark seeds (as indicated on the customer wish), the holes had to be covered with a 0.5 cm level of soil.
- The pots had to be watered. The water had to be prepared so that it had a temperature of 25°C and a, in the instructions specified acid value.

For setting in the seedlings, the following actions had to be performed by the participants:

- The required pots had to be filled half with soil, which had to be loosened before.
- The seedlings had to be put into the pot.
- The correct fertilizer had to be chosen (as indicated on the instructions, which were handed out to the participant).
- The pot had to be filled with layers of soil and fertilizer until the roots of the seedlings were covered.
- The seedling had to be watered with appropriate water (25°C and an acid value of 5-6).

In order to acquire the task of leading the market garden, four customer requirements had to be executed: the first required the participants to sow sunflower seeds, the second to set in flowering seedlings, the third to set in foliage plants and the last one to sow ramson seeds. The two categories of tasks have been defined based on only minor differences in order to allow the participants to acquire the skill in question. Further customer wishes could not be executed by the participants due to problems related to maintaining attention for such a long time frame. The actions of the participants were filmed with a standard web camera.

In the second session of the study, the participants performed tasks of the Berlin Intelligence Structure Test (BIS, Jäger, Süß & Beauducel, 1997). These tasks were based on the Berlin Intelligence Structure Model (Jäger, 1982), which is a hierarchical model of intelligence. General intelligence, at the top, is composed of two facets, which are categories for factors at the next lower level (Guttman, 1954). Jäger (1982) distinguished the facet *operations* and *contents*. The last subsumes three content abilities (i.e., numerical abilities, verbal abilities, and numerical abilities), which refer to how a person cognitively deals with the different types of contents. The facet operation subsumes what is cognitively done with the given contents. Four operations are distinguished: *Reasoning* is the ability to solve complex problems (Jäger, Süß, and Beauducel, 1997). *Memory* asks the participants to memorize pieces of information and retrieve them from short-term memory or recognize them after a short time period. *Creativity* refers to the ability to produce a variety of differing ideas controlled by a given item. Last, *perceptual speed* is the ability to work as fast as possible on simple tasks, requiring no or only little information processing demands. The BIS tests all these factors of intelligence. However, the original test has been shortened. Test items were deleted which required the participants to write a lot, as – due to the given time constraints for working on the test items – especially participants with spacticity would have been disadvantaged. The conducted test comprised the tasks as indicated in Table 1 and took the participants about two hours to complete.

Table 1: The, from the BIS chosen and in this study applied test items and their sorting in the factors of intelligence according to the Berlin Intelligence Structure Model.

General Intell-igence	*Figural abilities*	*Verbal abilities*	*Numerical abilities*
Perce-ptual speed	- Erasing letters - Old English - Number Symbol Test	- Part-Whole - Classi-fying words - Incomplete records	- X-Greater - Calcul-ating characters
Memory	- Test of orientation - Company's symbols - Remem-bering routes	- Mean-ingful text - Remem-bering words - Language of fantasy	- Pairs of numbers - Two-digit numbers
Reason-ing	- Analogies - Charkow - Bongard - Winding	- Word analogies - Fact opinion - Comparing conclusions	- Reading tables - Arithmetic thinking - Arrays of letters

3.2.3 Data Analyses and Results

The following variables were derived:

- general intelligence, perceptual speed, reasoning, memory, figural abilities, verbal abilities, numerical abilities, figural perceptual speed, verbal perceptual speed, numerical perceptual speed, figural reasoning, verbal reasoning, numerical reasoning, figural memory, verbal memory, numerical memory were derived based on the reduced set of test items applied from the BIS
- number of strategic changes in the participants' behavior for each of the four customer wishes
- index for the continuity of the order of actions while performing each of the four customer wishes

In order to derive the numerical values for the intelligence factors, the test items were analyzed as indicated in the BIS's handbook (Jäger, Süß, and Beauducel, 1997).

Altogether eight variables have been used to operationalize the degree of the innovation in the observable behavior (i.e. in this case the gardening tasks): the first is the number of strategic changes in the behavior of the participants for each of the customer wishes. For this purpose, the videos have been transliterated: A list of possible actions has been identified and the order of actions conducted has been analyzed. Each participant used a typical order of how to perform the task in question. The number of changes to this typical order has been counted as indicating the number of strategic changes in the behavior.

To derive the four indices for the continuity of the order of actions while performing the customer wishes, the number of grouped actions was counted. A participant conducting all required actions for one pot received a very low index of continuity (i.e. 1); whereas a participant executing one action for all pots received a high level of continuity (i.e., 10). Participants with a medium-sized index changed their strategy within the task. In order to be able to distinguish the participants who did not change their strategy and did change their strategy, a dichotomization was performed – the medium-sized numbers received the final index number 0, the high- and low-sized numbers received the final index number 1.

In order to test the hypotheses, repeated measurement analyses have been performed with each of the intelligent variables derived (list see above) as independent variables and either the number of strategic changes for all four customer wishes or the index of continuity for all four customer wishes as dependent variables. The significant results are given in Table 2. More specifically, the tested variables, the value of the used test statistic with the number of degrees of freedom, the probability that the expected effect did not occur due to chance and the size of the detected effect using a classification presented by Cohen (1992) are given.

Table 2: Results of the repeated measurement analyses.

Tested variables	Value of the used test statistics	Prob-ability	Effect size
1) Learning factor of the number of strategic changes	$F(3,36) = 5.80$	$p = 0.00$	$f^2 = 0.49$[1]
2) a) Learning factor of the number of strategic changes b) Two way interaction between the learning factor and the verbal perceptual speed factor	$F(3, 30) = 4.09$ $F(3, 30) = 2.75$	$p = 0.02$ $p = 0.06$	$f^2 = 0.41$[1] $f^2 = 0.28$[2]
3) a) Learning factor of the number of strategic changes b) Two way interaction between the learning factor and the verbal memory factor	$F(3, 30) = 4.20$ $F(3, 30) = 3.31$	$p = 0.01$ $p = 0.03$	$f^2 = 0.42$[1] $f^2 = 0.33$[2]
4) a) Learning factor of the index of continuity b) Two way interaction between the learning factor and the numerical memory factor	$F(3, 30) = 4.34$ $F(3, 30) = 4.66$	$p = 0.01$ $p = 0.01$	$f^2 = 0.43$[1] $f^2 = 0.47$[1]

*significant with $\alpha < 0.01$
[1] = large effect, [2] = medium-sized effect

As Table 2 indicates, the first analysis testing the learning factor of the number of strategic changes over the performed tasks is significant. A large effect has been found: The number of strategic changes shrinks with the number of customer wishes performed.

The second analysis tested the learning factor and the two way interaction effect between the learning factor and the verbal perceptual speed factor. Figure 3 shows this interaction. The participants with greater verbal perceptual speed abilities demonstrate more continuity regarding the strategic changes. The graph showing the course of the number of strategic changes while performing the four customer wishes for the participants with less verbal perceptual speed abilities demonstrates (1) that the general level of the number of strategic changes is greater compared to the number of strategic changes executed by the participants with higher verbal perceptual speed abilities and (2) that the variance of change is bigger.

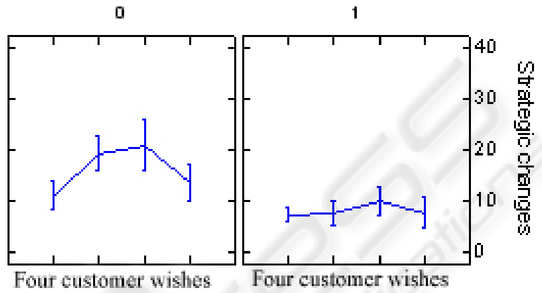

Figure 3: Line graph with standard error bars of the relationship between the strategic changes for the four customer wishes and the verbal perceptual speed of the participants (Graph 0 shows the less intelligent participants, Graph 1 the more intelligent participants).

The third significant analysis tested the learning factor and the two way interaction effect between the learning factor and the verbal memory factor. Figure 4 shows the direction of the effect. The two graphs comparing the course of the number of the strategic changes while performing the four customer wishes for the two groups of participants with high and low scores on the verbal memory factor closely resemble the graphs displayed before (see Fig. 3). Again, the less able participants demonstrate (1) a greater number of strategic changes and (2) a bigger change in the course of the skill acquisition/learning process.

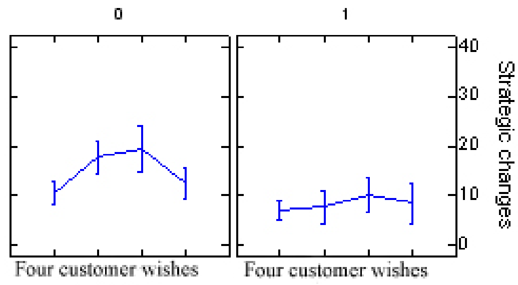

Figure 4: Line graph with standard error bars of the relationship between the strategic changes performed for four customer wishes and the verbal memory factor of the participants (Graph 0 shows the less intelligent participants, Graph 1 the more intelligent participants).

The fourth analyses tested (1) the learning factor of the index of continuity and (2) the two way interaction between the learning factor and the numerical memory factor. The results were significant as well. Hence, the index of continuity changes with the number of practice trials performed and this change depends on the level of numerical memory abilities of the participants.

4 CONCLUSIONS AND TECHNICAL IMPACT

Summarizing, relevant research results regarding the theory of structured intelligence are presented (Badreddin & Jipp, 2006). More specifically, the study confirmed the hypotheses: First, the degree of consistency in the behaviour of the participants gets greater with the task's familiarity. This transition shows the learning effect, i.e. the transition from innovation-based to experience-based, i.e., well known solutions. Second, a relationship between this transition and traditional measures of intelligence has been found. Significant predictors were intelligent factors such as the verbal perceptual speed factor. However, compared to traditional research on intelligence, the theory of structured intelligence goes one step further: it provides an explanation of how intelligent behaviour emerges and not only a classification of intelligent behavior. Drawbacks of the study refer to the small number of participants, which has reduced the power of the study, so that some possibly existing effects might not have been detected. Further, the creativity items had to be deleted from the intelligence test as they required the participants to draw solutions, which would disadvantage some of the participants due to their disability. Hence, future research should investigate the relationship between traditional creativity tests with innovation-based behaviour.

The study's main contribution is twofold: First, the theory of structured intelligence demonstrates links to traditional measurements of intelligence, but also gives an explanation of how intelligent behaviour emerges and provides the opportunity to measure intelligence in easier and less time-consuming ways and. It allows intelligence to be judged on (1) by using activity detection and (2) by observing the participants' actions when being aware of the familiarity of the task. The degree of consistency gives valuable information on intelligence. This has not only the potential to revolutionize intelligence diagnostics but also intelligent interface design: if an intelligent machine were capable of judging on its user's intelligence, the interface can be adapted to the user and different levels of support given. This might have a big impact on safety-critical applications with the user is in the loop of controlling e.g., nuclear power plants. Second, the theory of intelligence gives the artificial intelligence research a new direction, as not only experience is relevant, but also innovation-driven behaviour, which can be modelled as chaotic behaviour (see also Badreddin & Jipp, 2006).

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