The Impact of Problem Space on Reasoning: Solving versus Creating Matrices

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Abstract

Creative reasoning in ill-defined problem spaces operates differently from classical reasoning in well-defined spaces. To systematically compare the two in an identical knowledge domain, we applied a classical intelligence test: the Standard Progressive Matrices (SPM), in combination with two tests of creativity: the Test for Creative Thinking - Drawing Production (TCT-DP) and the newly developed Creative Reasoning Task (CRT), in which participants are asked to create an SPM-like item, to two age groups (N_1 = 511, 4-12y old; N_2 = 205, 6-10y old). For SPM and CRT the knowledge domain consists of relationships amongst geometrical components in 3 x 3 matrices. We developed a typology for scoring the number and complexity of the relationships used in these matrices. For the SPM, we scored frequencies of relationships solved and for CRT those created, and interpreted the scores in terms of differences and similarities between classical and creative reasoning in cognitive development.

Keywords: Cognitive development; intelligence; reasoning; creativity; creative cognition; creative reasoning.

Classical and Creative Reasoning

In creativity, both convergent and divergent thinking are needed, in order to arrive at a quality formulation (Jaarsveld & van Leeuwen, 2005). Creative processes often consist of iteratively generating, testing, and selecting intermediate productions, ultimately leading to an integral result. We interpreted this process in terms of the integration of convergent and divergent operations characteristic of *creative reasoning* (Jaarsveld et al., 2010). Here we will consider the integration of convergent and divergent operations against the alternative possibility that both are used as independent, quasi-additive resources.

Convergent operations are typically associated with classical reasoning. A consequence is that classical and creative reasoning share processing components. Therefore, if convergent and divergent operations constitute independent resources, test results between classical and creative reasoning will be correlated. Longstanding investigations of intelligence and creativity test scores suggested only a moderate relationship (Wallach & Kogan, 1965; Kim, 2005; Silvia, 2008). The strength of the relation, however, may be a matter of differences between the knowledge domains of both tests that are unrelated to the differences between reasoning types per se. To illustrate this issue, here we compared a classical intelligence test, the Standard Progressive Matrices (SPM; Raven, 1938/1998), with two creativity tests, one of which, the Creative Reasoning Task (CRT; Jaarsveld et al., 2010; Jaarsveld, Lachmann, & van Leeuwen, 2012), shares the domain of knowledge with the SPM and the other, the Test for Creative Thinking - Drawing Production (TCT-DP; Urban & Jellen, 1995) does not (Jaarsveld et al., 2010; 2012).

Knowledge Domain

In general, classical and creative reasoning tests tend to operate in different knowledge domains. For instance, the SPM, which is considered to measure convergent thinking, operates in the domain of relations among geometrical components contained in a matrix (Figure 1). By contrast, the TCT-DP, which is considered to measure divergent production, operates in the domain of figural associations. Smilansky (1984) introduced a paradigm which we named the Single Knowledge Domain Paradigm. Smilansky asked participants first to solve the SPM and next to create an SPM-like item in a task which we named the Creative Reasoning Task (CRT). Hence, between SPM and CRT cognition operates on the same knowledge domain (Figure 1). Solving a classical reasoning task does not always mean the problem is understood: often a correct solution is accompanied by an incorrect line of verbal reasoning or is obtained without any conceptual understanding (Chi & VanLehn, 1991; Karmiloff-Smith, 1992; Pine & Messer, 1999). Such distortions are less likely with ill-defined problems.

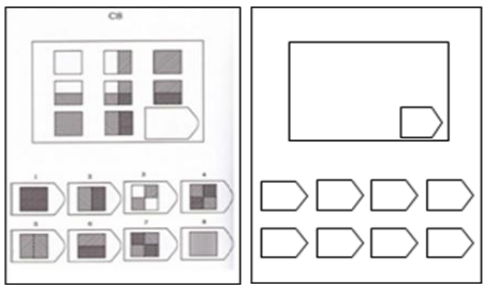

Figure 1: An item of the solving test (SPM) and the empty response form of the Creative Reasoning Task (CRT).

Problem Space

In the literature, classical and creative reasoning are both understood as processes operating in abstract problem spaces (Hayes & Flowers, 1986; Simon, 1973; Kulkarni & Simon, 1988; Runco, 2007). A problem space contains all possible states that are accessible from the initial state through iterative application of transition rules, including the ones that bring the problem solver from the initial state to the final solution. Problem spaces in classical reasoning are well-defined; like in a game of chess, no reinterpretation of rules is possible. Problem spaces in creative reasoning are ill-defined, and may allow re-interpretation of rules during the problem solving process. For instance, in rearranging your room you uncover implicit requirements that introduce a set of new transformations and/or eliminate existing ones (Barsalou, 1992) or, when conflicting constraints arise, you introduce new trade-offs (Yamamoto, Nakakoji, & Takada, 2000).

In our first study we compared reasoning performances in well and ill defined problem spaces, those of the SPM and CRT, respectively (Jaarsveld et al., 2010). For analyzing the performance on both tasks, we developed a scoring method based on a typology of the number and complexity of the relationships in evidence in the 3 x 3 matrices that feature in these tests. In a second study (Jaarsveld et al., 2012) we developed for the CRT two sub-scores: *Relations*, which reflects convergent production in ill defined problem spaces, and *Components and Specifications*, which reflects divergent production. We compared across grade levels, firstly, the CRT sub-scores of Relations with scores of the SPM and the CRT sub-scores of Components and Specifications with scores on the TCT-DP. Secondly, we analyzed the complexity in matrices solved in the SPM with created in the CRT. This analysis would allow us to observe whether more advanced pupils have a higher developed ability to process complex information (Halford, 1993).

Method

Participants Children of the first study were from Nursery and Elementary Schools ranging from four to twelve years old (N_1 = 511), 52% girls Mean age per grade in years: Younger Nursery school children (M = 4.64, N = 33), Older Nursery school children (M = 5.68, N = 31), Elementary school Grade 1 (M = 6.73, N = 41), Grade 2 (M = 7.79, N = 42), Grade 3 (M = 8.81, N = 59), Grade 4 (M = 9.80, N = 132), Grade 5 (M = 10.87, N = 91), Grade 6 (M = 11.91, N = 82). In the second study we only had children from Elementary School ranging from six to ten years old (N_2 = 205), 50% girls. Mean age per grade in years: Grade 1 (M = 7.06, N = 51), Grade 2 (M = 8.16, N = 43), Grade 3 (M = 9.07, N = 51), Grade 4 (M = 10.05, N = 60). Age limits within grades for both studies were not absolute, but the average age increased with 1 year per grade.

Material The SPM is contained in a booklet, which displays one incomplete matrix per page, together with a multiple choice of completion alternatives. Participants had to infer relations between given components and choose the completing figure from among the alternatives given below the matrix (Figure 1). A separate answering sheet is offered, on which individuals mark the number of the alternative they consider to be the proper completion. The CRT asks participants to create an SPM-like item. The instruction was to make the item as difficult as you possibly can such that it will be a hard puzzle for others to solve. On an empty form reflecting the format of the SPM items (Figure 1) participants had to create components and relations, and to draw the completing figure in one of the cells in the lower part of the response form. The TCT-DP asks participants to complete a drawing on a form containing five simple components within a frame and a sixth one outside the frame. The instruction conveyed that one could do nothing wrong and draw as one liked.

Design and procedure Children first performed the solving test (50 minutes). Nursery School children and those up to Grade 3 performed the Coloured Progressive Matrices test (CPM; Raven, 1956/1976) which is designed to assess the cognitive abilities of young children. Older children performed on the SPM. Consecutively, in both studies all were asked to create a matrix in the CRT (15 minutes). Finally, the children of the 2nd Study performed the Test of Creative Thinking (10 min). Nursery school children performed the tasks individually; group testing was applied for the classes of the Elementary School.

Analysis The scores of the CPM and SPM equaled the number of items solved correctly. Scores of the CPM were converted to SPM scores according to the scale provided by Raven, Raven, and Court (1998), in order to enable direct comparisons between grade levels. The score of the TCT-DP was a summation of grade points (range 0-6) for each of the 14 sub-scores: *Continuation*, *Completion*, *Connections Made with a Line*, *Connections Made to Produce a Theme*, *Figure-based Boundary Transgression*, *Figure-independent Boundary Transgression*, *Perspective*, *Humor and Affectivity*, *Unconventionality-a*: any manipulation of the material; *Unconventionality-b*: any surrealistic, fictitious and/or abstract elements or drawings; *Unconventionality-c*: any usage of symbols or signs; *Unconventionality-d*: unconventional use of given fragments; *Speed*: drawings

that are made within a certain time limit and show a score above a certain value score extra points. The score of the CRT consisted of the sub-scores *Relations* and *Components and Specifications. Relations* scores the logical complexity of relations in complete and incomplete matrices. Relations are typically transformations from one component of the matrix to another. We identified a total of twelve relations. Three for the CPM: *Four Identical Components*; *Continuous Pattern*; and *Symmetry*. One for the SPM: *Indication of Mathematical Operation*. Three for the CRT: *Idiosyncratic and Semantic Coherence*; *Indication of Form, Texture, Amount or Orientation;* and *Groups of Three Components*. An additional five for the SPM were taken and partly modified from Carpenter, Just, and Shell (1990): *Change*; *Increase and Decrease*; *Combination*; *Succession*; and *Disappear and Remain*. We analyzed the matrices of CPM, SPM, and CRT for the relations they contained. Scoring of a relation created in the CRT is done in several steps. First, we listed the relations that apply to the item and for each relation marked the components it covered. Next, for each relation we assigned an index value i = 1, 2, … to all first appearances of the marked components, starting from the top-left cell of the item, proceeding from left to right through each row from top to bottom. Third, passing through the matrix in the same order as previous, we accumulate a score, in which the first encounter of a component is scored with a value identical to its index; each next time we encounter a component again, we assign the same score as previously, incremented with 1 when it occurs in a row different from where it has previously been encountered, and with another 1 when it occurs in a column in which it has not previously been encountered. The resulting score is the sum total of all values assigned to components of the matrix. The sub-score *Components* scores the number of different components and the sub-score *Specifications* scores the occurrence of different pictorial specifications (textures and line styles) and transformational specifications (size, orientation, number, and location). These specifications were scored when they did not express a relation. The categories *Non Figurative* and *Figurative* indicated matrices which featured components of a geometrical and a figurative character, respectively.

Results

First, we present results of interrater reliability of the CRT for type and complexity of relations. Next, we present the correlations between test scores reflecting three types of cognitive processes; one which mainly features convergent thinking (CPM and SPM), one which mainly features divergent thinking (TCT-DP), and one in which both types of thinking play a role (CRT). Thirdly, we present to what extent Relations in the items created in the CRT reflected those featured and solved in the CPM and SPM. Finally, we present results of the increasing complexity of matrices created, according to number of relations applied within the matrix.

Interrater reliability Subsets of items of the CRT were scored independently by different raters and interrater reliability was calculated with Cohen's *Kappa, K,* for type of relations and with Pearson correlations, *r,* for the CRT sub-scores. Results ranged from $K = .93$ in the first study ($n = 95$), to $K = .94$ in the second study ($n = 69$), and from $r = .99$, $p < .01$ for sub-score *Relations*, to $r = .91$, $p < .01$ (both 2-tailed) for sub-score *Components and Specifications*.

Test Scores Results of test scores between SPM and CRT over all grade levels did not show a significant correlation. They did show a correlation in some grade levels; in the first study in Grades 3 and 6, and in the second study in Grade 1. In the second study, as expected, the CRT sub-score *Relations*, which according to our theory represents convergent thinking, showed a correlation with the SPM ($r = .192$, $p < .01$; partial correlation corrected for TCT-DP: $r = .213$, $p < .01$). The CRT sub-score *Components and Specifications*, which according to our theory represents divergent thinking, showed a correlation with the TCT-DP ($r = .147$, $p < .05$; partial correlation corrected for SPM: .153, $p < .05$). Furthermore, scores of SPM and TCT-DP showed a correlation, $r = .225$, $p < .05$, but, as expected from the assumption that in the CRT the sub-scores represent different thinking abilities, no correlation was found between the CRT sub-scores *Relations* and *Components and Specifications*, $r = .016$, $p = .823$.
Moreover, as expected, there were no correlations between *Relations* and TCT-DP, and between *Components and Specifications* and SPM. The latter results hold also for partial correlation analyses. From this we may infer that convergent and divergent thinking play a role in the Creative Reasoning Task and that both can be scored on one end product.

Relations Featured, Solved, and Created in the CPM Condition Frequencies of relations solved and created showed that Young Nursery School children (age in years $M = 4.64$) solved three of the four relations presented but generated a different relation, Relation 1, *Idiosyncratic Coherence*. Older Nursery School children (age in years $M = 5.68$) preferred an additional relation, Relation 3, *Continuous Pattern*. This focus shifts at Grade 1 (age in years $M = 6.73$) to Relation 2, *Four Identical Components* and at Grade 2 and 3 (age in years $M = 7.79$ and $M = 8.81$, respectively) to *Continuous Pattern*. The dominance of *Idiosyncratic Coherence*, shows that creative reasoning in the youngest children is dominated by rules that are not deducible logically and clearly arise from an individual interpretation.

Relations Featured, Solved, and Created in the SPM Condition Relation 3, *Continuous Pattern* is the most frequently created relation by children of the higher grades (Grade 4, age in years $M = 9.80$ to Grade 6, $M = 11.91$). Deleting a piece in an overall pattern, whether figurative or non figurative, may be the first abstract relation that plays a

role in generative problem solving. The results of the chi-square tests for independence over the frequencies of relations solved and created in both conditions were significant, *p-values* smaller than .05 to .001. In the second study we observed identical results.

Components Results of chi-square tests of *Components and Specifications* in CPM and SPM condition followed those for *Relations.* Figurative components were generated by children in both studies although the solving test does not feature these types of components. In the first study the percentage of children who applied figurative components decreased significantly with grade level, r_s = -.671, n = 8, p < .05, one tailed (r_s Spearman Rank correlation).

Relations in the SPM and created in the CRT as a function of school grade Second study: we observed that only one relation, *Combination*, showed an increase with grade in both SPM and CRT. Other relations showed either, a decrease in SPM in combination with an increase in CRT, for instance *Pattern Completion*; an increase in SPM was observed for the relations *Change* and *Succession*; a decrease in SPM was observed for the relation *Increase and Decrease*; a decrease in CRT was observed for the relations *Idiosyncratic Coherence*, *Four Identical Components*, and *Symmetry.* (Spearman Rank correlations of frequencies over grade, p < .05). For both studies we concluded that SPM and CRT did not show the same trends with grade in the frequency of occurrence of different relations.

Number of Relations Applied per Item Complexity in the SPM matrices as measured by number of relations increased over the series of SPM items, r_s = .900, n = 5, p < .05. We found a corresponding increase in complexity over grade levels in matrices created in the CRT in the first study, r_s = .964, n = 8, p < .01. Components increasingly show variety in number, in size and orientation. In the second study increases in complexity failed to reach significance due to lack of power, r_s = .258, n = 4, p = *.371*.

Conclusions and Discussion

We compared across grade levels the performance on the Creative Reasoning Task (CRT), with that on the Progressive Matrices test (CPM and SPM), and the Test of Creative Thinking-Drawing Production (TCT-DP). We used the CRT to measure convergent and divergent thinking, which we consider to play an integrated role in ill defined problem spaces. CRT and SPM operated on the same problem domain; nevertheless, operations used in both tasks differed as a function of the differences in problem spaces. Whereas the SPM uses convergent operations, both divergent and convergent operations are needed for the CRT. The absence of correlations across school grades, therefore, implies that in creative processes as tested by the CRT, convergent and divergent operations do not occur as additive process components, but play an integrated role throughout the process (Jaarsveld & van Leeuwen, 2005.

Correspondence In addition to contrasts between the tests, similarities were observed in development. Across school grades, we observed increasing complexity in problem solving and problem creation. In the SPM we observed an increase over series of items combining several rules. In the CRT there is a parallel increase in the number of relations applied per item created. Children in more advanced grades also used more components, with an increasingly rich variety of specifications.

Differences Although relations applied in the creating task often featured in the solving task, almost within all grades performance on both tasks was uncorrelated; in the CRT grades were characterized by a preference for specific types of relations. Another difference between both tasks was the absence of concordant increases or decreases over age levels in the application of certain types of relations. *Combination* was the only one of 12 relations that showed an increase in both tasks. Finally, in creating, figurative components were more persistently preferred, despite the non figurative character of CPM and SPM items. Participants preferred to introduce rules and other elements from their individual episodic/semantic knowledge domains, as opposed to what they encountered in the problem solving task. This difference cannot be understood as a discrepancy in knowledge domain. Creative problem solving, therefore, does not depend entirely upon classical problem solving skills.

Cognitive Development Perspectives Even though the material of the SPM is non figurative, relations created in the CRT tend to be expressed in figurative mode. Singer-Freeman and Goswami (2001) observed that three to four year old children understand proportional equivalence, even when the materials (pizza and chocolates) to be matched are not isomorphic. Young children, therefore, do not solve analogy problems on the basis of relational similarities but on the basis of associations (Piaget, Montangero, & Billeter, 1977). Young children in solving CPM items have the opportunity to learn that matrix components belong together according to certain relationships. They proceeded in the CRT to arrange components according to different, self-defined relationships.

Whereas children were able to solve most relationships, per grade one type of relation was predominantly applied in the CRT. Zelazo, Frye, and Rapus (1996) observed that knowing a rule in the card sorting task does not imply that it will be used correctly after a new sorting rule has been introduced. These authors observed a change in the ability to switch to a new rule between the age of three and five years old and explained this among others, in terms of the implicitness of rule representation. It could be that representations formed in a well-defined problem space are not understood at a sufficiently explicit level to be carried over to an ill-defined space.

The observed shifts with grade level in rules preferably applied in the CRT seem to correspond to Piaget's

developmental stages. According to Piaget, children between the ages of four and seven years old are in the intuitive thought phase, which is a sub-phase of the preoperational phase. In this phase children develop Conservation (the awareness that altering the state of a substance, does not change it's properties) and Centration (the focusing on one characteristic). In our study these children applied relationships of the types: Idiosyncratic Coherence and Four Identical Components. These are relationships that mostly feature one characteristic.

Piaget considered children between seven and eleven years old to be in the concrete operational phase. In this phase children's ability to think abstractly develops and they learn to understand the concept of reversibility. In our study these children predominantly applied variations of the relationship Continuous Pattern, a relationship which does not require abstract thinking. Deleting a piece from an overall pattern, as application of this rule requires, might be the first abstract operation in this phase.

Although creative productions, therefore, seem to follow Piagetian stages, two observations need to be made: First, despite these overall restrictions, children applied more complex relationships in small frequencies, in the CRT. Second, the contrast between rules used in solving SPM items and those applied in the CRT is not a matter of *decalage*. Piagetian stages are in evidence in the CRT, but not in the SPM. They are not reflected in classical problem solving but in creative reasoning, which characteristically requires the integration of divergent and convergent reasoning.

Limitations of the CRT The CRT is still in an early stage of development. In its current form, there are several issues that restrict its practical utility. Before the CRT can be administered the SPM has to be completed. This task serves, amongst other things, to make participants acquainted with the particular structure of the matrices problems. Without this phase we would have needed extensive instructions, which renders the task more algorithmic and, therefore, might decrease creative production (Amabile, 1987). To have a solving task precede a generation task is consistent with the general observation that nothing is invented from scratch; creativity implies using old elements in new contexts and seeing relations that no one saw before (Barron, 1981; Boden, 1990; Indurkhya, 1992; Torrance, 1987). Familiarity with the relevant domain and experience with a variety of methods are a prerequisite for generating solutions (Voss & Post, 1988). For the current study, SPM data were needed anyway. If one is interested only in CRT performance, however, future developments of the test should include a certain number of matrices, specifically constructed to contain the same relations that feature in the SPM. These new matrices, then, are expected to provide participants with an identical solving experience as in the SPM. Moreover, the current CRT asks participants to generate one item only. This was done in order to tap individual abilities at the moment where they had reached the maximum level of apprehension according to SPM. However, children may not achieve to their maximum abilities in this single item. For this reason, we are currently investigating the effect of including multiple CRT items in the task.

With the Creative Reasoning Task, we were able to answer the question whether individuals who have just solved SPM items in which certain transformations featured, apply these same transformations when they design a new matrix. We found that relations featuring in the solving task differed from those applied in the problem creating task. It was concluded that creative reasoning, as measured by the CRT, does not reflect SPM solving ability, and that both cognitive abilities develop rather independently from each other from Kindergarten to Secondary school.

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