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Developmental Differences in Metacognition and their Connections with Cognitive Development in Adulthood

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This study investigated developmental differences in some metacognitive variables in ill-defined problem solving and their possible connections with cognitive development in adulthood. Participants were 57 individuals of different ages (adolescents, young adults, mature adults and older adults). They solved one well-defined and six ill-defined problems while their thinking-aloud was taped. They then answered a metacognitive statements questionnaire. Differences in performance were statistically significant in all problems: the best results in interpolation and divergent production problems were achieved by the younger adult group and the best performance on most dialectical everyday problems was found in the mature adults' group. We found no significant differences between age groups in the on-line monitoring of the solving process. Accuracy in metacognitive statements was however significantly better in the mature adult and the younger adult groups. Awareness of and reflection on one's own mental processes showed a similar developmental pattern to relativistic/dialectical thought: low expression in adolescence, an increase in early adulthood, a peak in mature adulthood and a minor decline in later years.

KEY WORDS: metacognition; relativistic/dialectical thought; ill-defined problems; self-awareness.

INTRODUCTION

In this study we investigated developmental differences in metacognitive functioning and their possible connections with cognitive development in adulthood.

Several researchers of adult cognitive development agree that the mature adult has to develop more powerful cognitive structures in order to successfully solve complex problems, for example in the field of interpersonal relations, arts and sciences (Armon, 1984; Basseches, 1984; Fischer, 1980; Fischer, Hand, & Russel, 1984; Kohlberg, 1990; Labouvie-Vief, 1992; Pascual-Leone, 1984). Thus, Piaget's (1972) formal–logical thinking ought to be followed by the postformal stage.

Although formal operations presuppose logical consistency, postformal operations permit a subjective choice among more formal-operational subsystems, each of which is internally consistent. According to Labouvie-Vief (1992), the adaptive value of mature cognition is the result of interaction between systematic application of formal logic and practical reasoning, which integrate logic with experience and context.

There exist many theories about cognitive development after adolescence. At this point we will focus on two of these concepts: relativistic/dialectical thought (Sinnott, 1984, 1989; Kramer, 1989, 1990) and systematic/metasystematic thought (Commons, Armon, Richards, & Schrader, 1989; Richards & Commons, 1990). Richards and Commons (1990) present metasystematic thought as the ability for intersystemic comparison, transformation of systems and the determination of relations among systems, and these abilities enable us to operate at the postformal stage. According to Kramer (1990), the main characteristics of relativistic/dialectical thought

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also correspond to general features of postformal thought. These characteristics would be the acceptance of relativism, the acceptance and handling of contradiction and the integration of frames of reference or integration of systems.

In our research, the construct of relativistic/dialectical thought in problem solving was built on the characteristics which are mainly present in the work of Kramer (1989, 1990), and Sinnott (1984, 1989):

- Acceptance of relativism: recognition that personal perspective is only one of many potentially valid viewpoints on reality;
- Understanding and acceptance of contradiction and the ability to handle conflicting ideas and systems: the realization that contradiction and complexity may be inherent features of reality; tolerance is gained through an appreciation of the dialectic relationship between opposing systems;
- Integration of systems/frames of reference: a synthetic form of thinking which integrates several opposing systems into an abstract whole and actually transcends idiosyncratic perspectives (Kuhn, Cheney, & Weinstock, 2000).

It is possible to infer that this type of thinking is used mainly in cases where we recognize the given problem as ill-structured, not solvable with ordinary heuristics and when we are not sure about the theoretical origins of the problem or about the existence of a sole solution. Thus, the complex operations of relativistic/dialectical thought will be used predominantly in the solving of so-called ill-defined problems (Howard, 1983). Here, in the solution process the essence of a problem must be selected, the goal or goals must then be selected, and finally a solution or solutions must be generated and selected. Ill-defined problems from everyday life are mainly dialectic problems (Churchman, 1971). Characteristically they contain various and opposing assumptions. A solution usually lies in integrating diverse data and perspectives or in redefining the problem in such a way that opposing perspectives are synthesized into a new framework (Rescher, 1976).

Sinnott (1986) reported that relativistic thought at the information processing level causes the use of a larger problem space and expanded use of monitors. When we talk about planning and monitoring of the thinking process, we are in the field of using metacognitve processes.

According to Flavell (1979) metacognition concerns cognition of one's own cognition and takes the form of metacognitive knowledge and metacognitive experiences. Metacognitive knowledge (Schrader, 1999, 2003; Tappan, 1990) relates to information we recall from memory, whereas metacognitive experiences include feelings and ideas that occur *on line*. Metacognitive control includes planning and monitoring of the thinking process and self-regulation (Brown, Bransford, Ferrara, & Campione, 1983). Metacognition in the problem solving process includes metacognitive experiences – such as feelings of difficulty and evaluation of solutions, metacognitive knowledge about problems and strategies that may be used to solve specific problems, planning and monitoring of the thinking process, and self-regulation.

When concerned with the development of metacognitive processes, several cognitive developmental researchers will argue that, with age, persons become more reflective and self-aware. Labouvie-Vief (1994) states that maturation during adulthood may be adequately characterized by an inward orientation and Kuhn (2000) claims that in development, metacognition becomes more explicit, powerful and effective. As a result, mature adults most probably become more able than younger persons to regulate their cognitive functioning.

When adults are faced with ill-defined problems, they may possibly use also a higher-level monitoring, such as epistemic cognition (Kitchener, 1983, King & Kitchener, 2004), which includes the individual's knowledge about the limits of knowing, the certainty of knowing, and the criteria for knowing. Epistemic cognition is, together with metacognitive processes, needed for controlling cognitive processes in ill-defined problem solving. But for epistemic cognitive processes the on-line awareness is not enough, they presuppose also reflection on the reasoning process (Efklides, Demetriou, & Metallidou, 1994). Because the main components of epistemic cognition are included in relativistic/dialectical thought, it may be considered that the reflection on mental processes is connected with the development of relativistic dialectical/thinking.

Several authors mention self-reflective thought in the context of mechanisms of development in adulthood (Pascual-Leone, 1990; Levinson, 1990; Dittman-Kohli & Baltes, 1990; Baltes & Staudinger, 1994). They actually describe this concept more as reflection upon existential life experiences, which does not exactly correspond to metacognitive reflection.

It is however possible to assume that relativistic/dialectical thought requires explicit reflection on the thinking processes.

PROBLEM

This study investigates developmental differences in some metacognitive variables in ill-defined problem solving: metacognitive experiences (feelings of difficulty and evaluation of solutions), metacognitive knowledge about problems, metacognitive control (planning and monitoring of the solving process), awareness of and reflection upon the thinking process. Furthermore, possible connections between these variables and performance in problem solving and relativistic/dialectical thinking were also investigated.

METHOD

Participants

Fifty-seven individuals of different ages participated in the experiment;

Age group 1 (adolescents): 14 students in higher secondary education, eight female and six male, 16—17-years old, mostly from middle-class and upper middle-class families in the urban region; *age group 2* (younger adults): 15 university students, nine female and six male, 21–23-years old; *age group 3* (mature adults): 14 mature adults with university education, nine female and five male, 40–47-years old*; age group 4* (older adults): 14 elderly adults with university education, nine female and five male, 63–70-years old.

Instruments

(a) *Protocol with one well-defined control problem* (logical interpolation problem) *and six different ill-defined problems* (one divergent production and five complex dialectic problems from different areas of everyday life).

The problems are classified according to Wakefield's (1989) scheme (interpolation, divergent production and dialectic problems):

1. Interpolation problems: Closed problem and closed solution situation: the information provided in the problem statement sufficed for reaching a correct answer. The usual strategy is step-by-step solving (P1).
2. Divergent production problems: Closed problem and open solutions: these problems resemble creative thinking problems in the open-endedness of their solution but are more specific in regard to the operators needed to solve the problem (P2).
3. Dialectic problems: Open problem and open solutions: these problems do not give rise to only one correct solution. A solution usually lies in integrating diverse data and in synthesizing different perspectives into a new framework. Doerner (1983) characterized the solution process for problems of this kind as dialectic (P3, P4, P5, P6, P7).

Description of problems:

P1—the water jug problem (Atwood & Polson, 1976): the participant is required to divide 8 units of water into two equal parts using three jars holding 8, 5 and 3 units.

P2—What would happen if we did not forget anything? (Torrance, 1974)

P3—the grandmother problem (adapted according to Sinnott, 1989): the participant was asked to give a solution for the old grandmother, who was no longer able to live alone, and to explain how this would affect relationships in the family.

P4—the actress problem (adapted acc. to Fong, Krantz, & Nisbett, 1986): the participant had to decide on the basis of different arguments, which of the three actresses would get the role in a comedy.

P5—the story problem (according to Rezzori, 1958): the respondents were asked to supply an interesting and amusing end to a fragment story with different entanglements.

P6—the Livian war problem (Ladbeater and Kuhn, 1989): the participants had to compare two different descriptions of the same event.

P7—the memory problem (Jausovec, 1994): on the basis of several items of information, the respondent was asked to design a theory about memory explaining the memory's function, structure and capacity.

The problems used in the study were also analyzed using procedure of analyzing hierarchical complexity of tasks (Commons, Trudeau, Stein, Richards, & Krause, 1998; Commons, Danaher,

Miller, & Goodheart, 2005). The results showed that dialectic problems are mainly of the order of complexity that demands systematic or metasystematic thinking to successfully (see criteria for performance) perform on a task.

(b) The Metacognitive Statements questionnaire
   1. Metacognitive experiences: participants were asked to make statements regarding the difficulty of the problem and the evaluation of the solution. Feelings of difficulty were measured on a 5–point scale ranging from 1 (*very easy*) to 5 (*very difficult*).

      The evaluation of the solution was also measured on a 5–point scale ranging from 1 (*perfectly right solution*) to 5 (*totally wrong solution*).
   2. Strategies reported: participants had to indicate which strategies they used to solve a particular problem. They had to choose between the following strategies: step-by-step solving, hypothesis testing, trials and errors, insight, memory searching, solving by analogies, modeling (creating a model of a problem situation).
   3. Problem classification: participants had to classify every problem into a proper category—regarding the solution process and problem structure (see Wakefield's scheme)

(c) *Schema for classification of problem–solving behavior* from the thinking-aloud protocols (Bakracevic, 2000, 2001, according to Rowe, 1985):
   1. Repeated reading
   2. Focusing on ambiguities in text
   3. Communication with experimenter
   4. Creating a model of a problem situation, translating into another form (diagrams, schemes,. . .)
   5. Hypothesis testing
   6. Trials and errors
   7. Step by step solving
   8. Memory searching/recall
   9. Solving by analogies
   10. Insight (illumination)
   11. Metacognitive planning
   12. Metacognitive monitoring
   13. Statements about own abilities

Procedure

Participants solved the problems individually. They were asked to think aloud while solving the problems. Their thinking-aloud was taped. After every problem the participants filled in the above-mentioned metacognitive statements questionnaire in which they had to make statements about the difficulty of the problem, the evaluation of the solution, strategies used in problem solving and classification of the problem into a proper category.

Performance on the given problems (for criteria see below) and presence of relativistic/dialectical thought (for criteria see Introduction) in problem solving were estimated by two independent, previously trained evaluators. They also classified problem-solving behavior from thinking-aloud protocols according to the above-described scheme.

Concordance between estimators: $W = 0.81$ (performance on ill-defined problems); 88% accordant estimations of the presence of relativistic thought; 72% accordant estimations of strategies used in the solution process.

In order to test the ability to reflect efficiently on one's own thinking process the following procedure was used:

After solving a problem, the participant had to indicate in the metacognitive questionnaire which strategies he used in solving a particular problem, and afterwards, in the thinking aloud protocols, two previously trained evaluators checked if the statements were correct (Variable named Accuracy of strategy detection).

General criteria for the performance on dialectic problems (in the scoring process we applied criteria adapted for each problem):

0 points. . ./unsuccessful/no understanding of the relationships in the problem, or decision/resolution without arguments

1 point. . ./medium/understanding and consideration of the relationships in the problem, adequate resolution with simple arguments

2 points. . ./successful/understanding and consideration of the relationships in the problem, highly elaborated and/or original solution(s) with complex arguments, considering different aspects of the problem (in the actress problem, for example, quality of acting, business success, interpersonal relations, ethics, . . .)

Table I. Differences Between Age Groups in Performance on Seven Problems (Mean Ranks)

	Performance						
Age	P1	P2	P3	P4	P5	P6	P7
Adolescents	28.71	25.21	18.46	15.96	20.21	19.54	21.21
Young adults	33.40	44.53	27.70	32.27	35.00	31.33	39.20
Mature adults	35.36	24.00	34.00	41.11	36.93	39.54	33.64
Older adults	18.21	21.14	35.93	26.43	23.43	25.43	21.21
Chi square	9.02	18.27	9.44	17.00	10.65	11.13	12.92
Sign	.0290	.0004	.0239	.0007	.0137	.0110	.0048

Note. P1: Water-jug problem; P2: What would happen, if. . .; P3: Grandmother problem; P4: Actress problem; P5: Story problem; P6: Livian war problem; P7: Memory problem.

To examine possible developmental differences in variables described above, Kruskal–Wallis ANOVA was used.

HYPOTHESES

On the basis of presented literature and current research in adult development and metacognition we predict the following:

1. Concerning performance: Adolescents and younger adults will be more successful in solving the logical interpolation problem and the divergent production problem. Mature and older adults will perform better than other two groups on dialectic problems.
2. Relativistic/dialectical thinking will emerge in younger adulthood and will increase throughout the age-span studied.
3. Metacognitive variables:
   - It is expected that evaluations of success and estimations of difficulty will follow performance. Thus, evaluations of solution in the logical interpolation problem and divergent production problem will be higher (and perceived difficulty lower) in the adolescent and younger adults' group. Contrary, evaluations of solutions in dialectic problems will be higher (and perceived difficulty—feeling of mental effort—lower) in the mature and older adult's groups.
   - There should be no differences between the age groups in the amount of on-line monitoring and planning of the thinking process.
   - Older adults will make more statements about their own abilities during problem solving.
   - Accuracy of problem classification (metacognitive knowledge) will be better in younger and mature adults; the same will be true for accuracy of strategy detection (which includes partly metacognitive knowledge and reflection on the thinking process).
   - Accuracy of problem classification will improve performance on given problem.
   - Accuracy of strategy detection will be in positive correlation with performance and will also be significantly correlated with presence of relativistic/dialectical thinking in problem solving.

RESULTS

Performance

Kruskall–Wallis ANOVA showed significant differences between age groups in performance on all problems. See Table I.

The most successful group in solving the divergent production problem and the memory problem (P2, P7) was the students' group (significance of differences: $\chi^2 = 18.27$, $p < .0004$; $\chi^2 = 12.92$, $p < .0048$). In solving most everyday life problems (P4, P5, P6), the mature adults group proved to be best (significance of differences: $\chi^2 = 17.00$, $p < .0007$; $\chi^2 = 10.65$, $p < .0137$; $\chi^2 = 11.13$, $p < .0110$). The older adults performed better than other groups on the grandmother problem (P3; significance of differences: $\chi^2 = 9.44, p < .0239$), which mainly deals with family relations – an area in which the older adults are still very active.

Metacognitive Variables

Evaluation of Solutions and Feelings of Difficulty

By contrast with the results concerning performance, which showed significant developmental differences on all problems, no significant differences between age groups were found in feelings of difficulty, and only one significant difference (P1) in evaluation of solutions ($\chi^2 = 12.18$, $p < .0065$). The results suggest that older adults evaluated their performance on the logical interpolation task as less successful than other groups, which coincides with actual performance. In other tasks, metacognitive experiences did not exactly reflect the performance. To explain this relationship better, we analyzed the correlations between performance, feelings of difficulty and evaluations of solutions. It was found that evaluation is significantly connected with performance only in well-defined logical problem ($r = .44$, $p < .001$). Evaluation of the solution in ill-defined, dialectical problems is more strongly linked with estimations of difficulty ($r = .40$, $p < .01$, $r = .31$, $p < .01$, $r = .38$, $p < .01$, $r = .34$, $p < .01$, $r = .28$, n.s.; for P7, P6, P5, P4, P3, respectively) than with real performance ($r = .04$, $r = .15$, $r = .11$, $r = .22$, $r = .07$).

Metacognitive Planning, Monitoring and Statements About One's Own Abilities

Elderly adults made significantly more metacognitive statements about their own abilities during problem solving than did the others ($\chi^2 = 20.439$, $p < .0001$). See Table II. On the other hand, we found no significant differences between age groups in the amount of planning and monitoring of the problem solving process. Interestingly enough, there was a tendency that young adults, in our case students, spent more problem-solving time on monitoring the solution process than the other two adult groups, and especially adolescents (see Table II).

Table II. Differences Between Age Groups in Metacognitive Planning and Monitoring of Solving Process and in Metacognitive Statements About One's Own Abilities During Problem Solving (Mean Ranks)

Age	Planning	Monitoring	Statements
Adolescents	24.75	21.14	16.57
Young adults	33.87	35.73	28.90
Mature adults	27.07	29.29	26.07
Older adults	29.96	29.36	44.46
Chi square	2.44	5.61	20.43
Sign	.4856	.1318	.0001

Accuracy of Problem Classification and Accuracy of Strategy Detection

There were not many differences in the accuracy of problem classification, as can be seen in Table III. Differences in accuracy of classification were only found in the Livian war problem (P6), where younger and mature adults were much more accurate ($\chi^2 = 9.14$, $p < .0275$) than the other two groups. In general, accurate classification did not improve performance in solving a particular problem. In the case of the logical interpolation problem, however, it did. (P1; Kendall's $\tau = .304$, $p < .0095$).

In accuracy of strategy detection the mature adults and the student group were significantly better than the other groups ($\chi^2 = 19.52$, $p < .0002$). Accuracy in mature adults (mean rank 40.79) was better than in younger adults (mean rank 35.63) and these two groups were much more accurate than older adults (mean rank 22.68) and adolescents (mean rank 16.43). This variable was also highly correlated with the total performance ($r = .577$, $p < .0001$) and even higher with the presence of relativistic/dialectical thought in problem solving ($r = .591$, $p < .0001$).

Developmental curves of accuracy of strategy detection and relativistic/dialectical thought are shown on the Figs. 1 and 2.

DISCUSSION

The most obvious tendency in performance on the sole well-defined, logical interpolation problem is that performance in the older adult's group was much worse than in the other three groups. This finding goes along with most data from the research of cognitive ageing, which show a decline in many aspects of processing efficiency after mature adulthood, or even earlier (Salthouse, 1991). We noticed this decrease in intellectual functions that require computational power relatively late in development—in the group older than sixty. To make any conclusions about this phenomenon, we would certainly need more tasks, measuring these kinds of processes.

Performance results also suggested that the most creative group was the young adults' group.

Table III. Differences Between Age Groups in Accuracy of Problem Classification

	Number of right classifications						
Age	P1	P2	P3	P4	P5	P6	P7
Adolescents	7	1	2	5	4	2	7
Young adults	11	3	4	7	4	8	10
Mature adults	13	4	4	4	5	9	7
Older adults	11	2	6	1	7	4	9
Chi square	6.88	6.34	3.06	5.72	2.10	9.14	1.42
Sign	.0759	.0962	.3833	.1262	.5525	.0275	.6999

Note. P1: Water-jug problem; P2: What would happen, if. . .; P3: Grandmother problem; P4: Actress problem; P5: Story problem; P6: Livian war problem; P7: Memory problem.

Specifically, fluency as well as originality of ideas was strongest in early adulthood.

In everyday-life dialectical problems of comparable complexity, mature adults mainly overperformed other groups, except in two cases. Young adults were especially good in forming a memory—theory and the older adults proved to be best in solving complex problems from the field of family relations. Thus, despite the fact that mature adults are the most successful group in solving complex dialectical problems, younger and older adults also obtained very good results on some tasks. The largest gap between groups in successfully solving complex everyday life problems is between adolescence and young adulthood, even though the smallest age difference is between these two groups. However, we did hypothesize that relativistic/dialectical thinking would emerge in young adulthood and that it would increase throughout the age span studied. Analysis of problem solving protocols has shown the following developmental tendency of relativistic/dialectical thought: low expression in adolescence, a strong increase in early adulthood, the highest point in mature adulthood and a minor decline in later years. Thus, success in solving complex dialectic problem is very probably connected with the shift from strictly logical

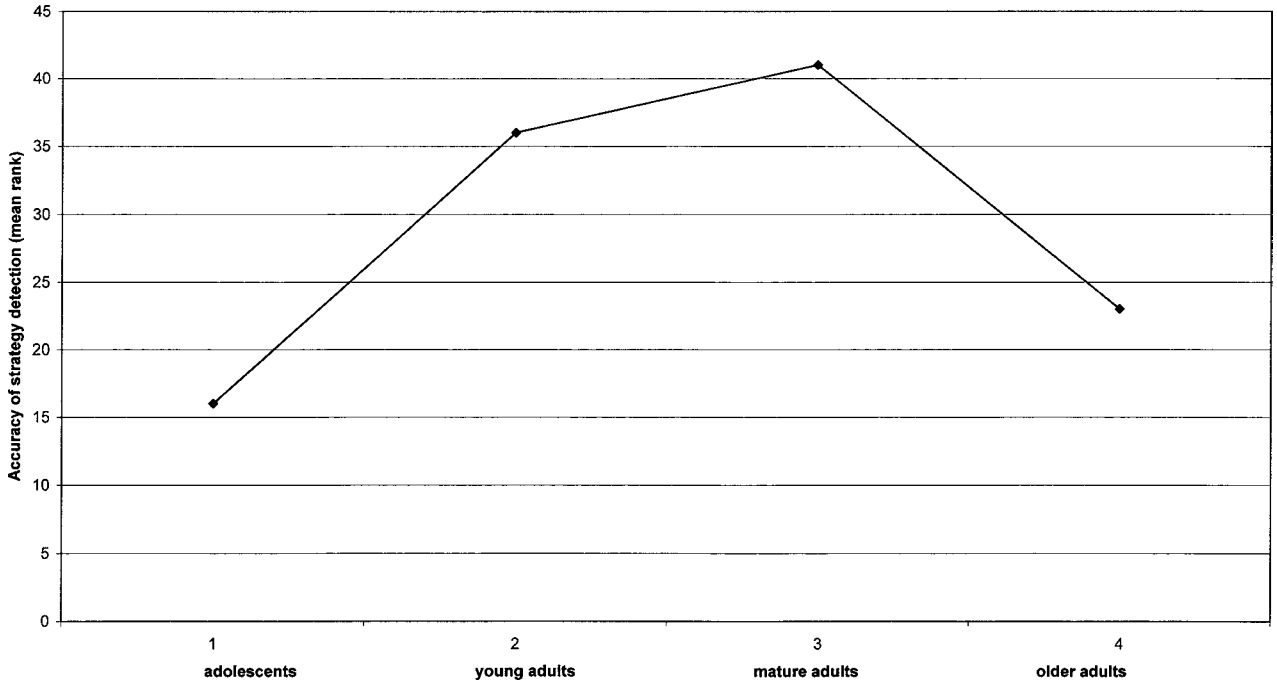

Fig. 1. Accuracy of strategy detection in four age groups.

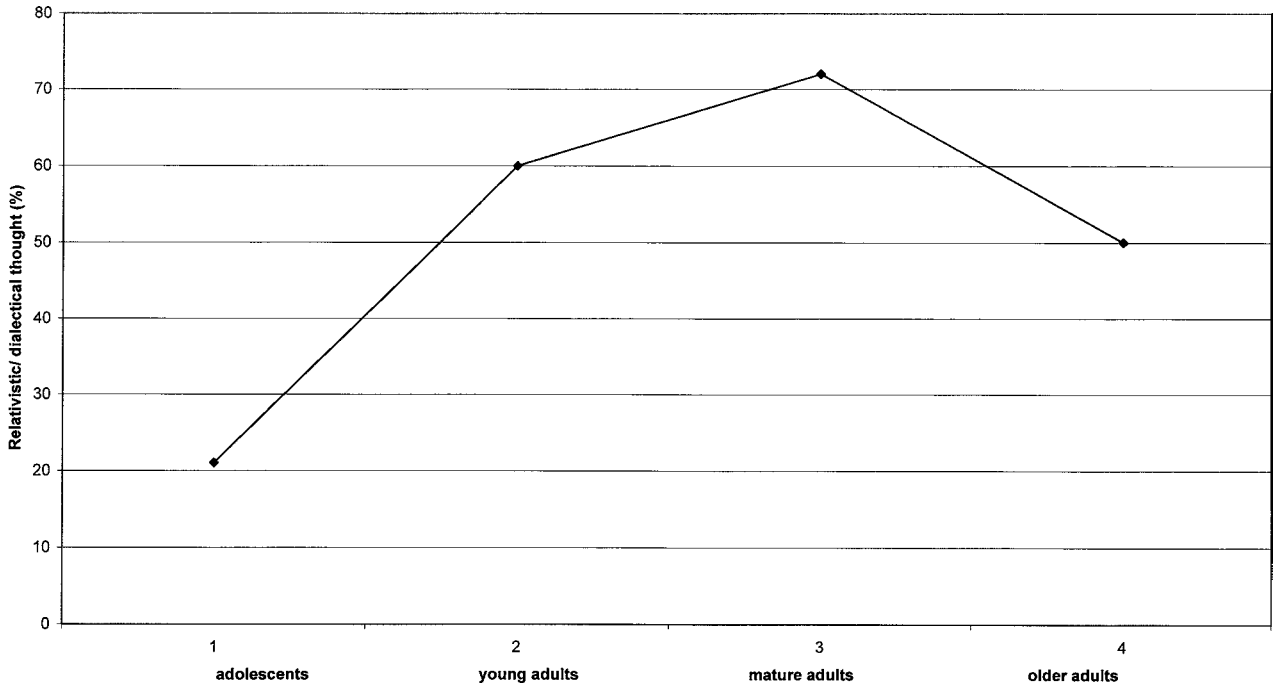

Fig. 2. Presence of relativistic/dialectical thought in four age groups.

to a dialectical approach to problems. It can also be assumed that once a person has become able to use this approach, success in different fields of everyday cognition varies according to experiences from the domain.

Metacognitive evaluations followed real performance only in the case of the well-defined logical interpolation problem. In ill-defined problems, evaluation of the solution was more linked with feelings of difficulty than with real performance. Thus, the solution was estimated as less adequate if the problem was perceived as more difficult, and vice-versa. The fact that we evaluate solutions on the basis of feelings of difficulty is not so surprising. Subjective feelings of satisfaction are often influenced by the feelings of difficulty experienced during processing (Efklides & Demetriou, 1993). It is however symptomatic that the correlations between these metacognitive variables and the performance on ill-defined problems were rather low.

The results made it clear that evaluation of solution in ill-defined problem solving is far more based on experiences during problem solving than on real performance. The reason for this could be related to the complexity and relative unclearness of solution criteria in problems of this type (several different solutions of the same quality are possible). Some authors (Metallidou & Efklides, 1999) state that since there are close interrelations between various feelings during the processing of a given problem, these experiences are not determined only by task features or performance, but they rather seem to form their own system. This is even more evident in ill-defined problems.

Concerning subjects' planning and monitoring of the thinking process we did not find significant developmental differences, although there was a tendency that younger adults spent more time on monitoring the solving process than the others. Nor were differences detected in pure metacognitive knowledge, which was shown mainly in the accuracy of problem classification. Here, accurate classification of the problem improved performance just in the case of single well-defined problem, which was included as a control problem in the testing battery. A rather significant difference in favor of older adults was obtained in statements about one's own abilities. Obviously, older adults are better aware of their own abilities in relation to the problem. Maybe the realization that reasoning power becomes weaker makes older persons more attentive to the functioning of their mind and this can enhance awareness about

cognitive processes. The most significant difference between the groups was the difference in accuracy of strategy detection, which includes metacognitive knowledge, awareness and reflection on one's own thinking process. On the basis of these data, we could suggest that the most important change in adulthood in the field of metacognition is happening in the ability to reflect precisely on our own thinking processes.

As we can see in Fig. 1, the developmental pattern in the accuracy of strategy detection is the following: low accuracy in adolescence, which increases in early adulthood, reaches the peak in mature adulthood and declines in late years. Therefore, it is possible to conclude that with age self-reflexivity becomes more focused and accurate – at least until mature adulthood. This would be in accordance with the suggestion that with development, the various aspects of cognition and self-awareness are better mapped onto each other so that self-understanding becomes more comprehensive and more differentiated and generally more accurate (Demetriou, 2003; Demetriou, Kazi, & Georgiou, 1999). It is also in tune with Labouvie-Vief's (1994) claim that adults become more self-reflective with age and Kuhn's (2000) findings that metacognition becomes more effective with development. As many authors have observed, highly developed skills and functions associated with self-understanding and self-management can even compensate for losses that occur with age at more fundamental levels of the mind (Baltes, Staudinger, & Lindenberger, 1999; Baltes & Staudinger, 2000; Hertzog & Dixon, 1994; Pascual-Leone, 1983; Labouvie-Vief, 1990).

There was also a high significant correlation found between adequate reflection on the thinking process and the presence of relativistic/dialectical thought in solving ill-defined problems. We can see in the figures that the developmental tendencies of both variables are very similar, although decline in later years is much smaller in presence of relativistic/dialectical thought than in metacognitive accuracy. This could lead us to the conclusion that a dialectical approach to problems becomes possible with the growth of self-reflexivity, so the reflection of mental processes could really be one of the factors influencing the development of relativistic/dialectical thought and thus enabling higher levels of cognitive development. However, interrelation between higher developmental stages and metacognitive accuracy must be researched more in detail. It seems that we have here the complex interaction between cognition and metacognition: when one becomes aware of alternative ways of solving a particular problem or alternative conceptions of reality, a dialectical approach becomes possible. This approach also raises a chance of going beyond problem solving automatisms and of becoming more aware of one's own thinking process.

In conclusion, better self-awareness of our own abilities, which increases up until old age and efficient reflection of the thinking process and problem solving strategies, which rises until mature adulthood are two of probably more strengths that enable adults to regulate their cognitive functioning according to the demands of problems in real life situations until late in life.

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