THE ARCHITECTURE OF A STANDARDISED MATHEMATICAL CREATIVITY TEST FOR DEVELOPMENTAL EVALUATION

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Abstract: This paper aims to analyses the architecture of a longitudinal assessment tool used in a strategic project to develop mathematical creativity involving *ex-ante*, *in itenere*, and the *ex-post* assessment sessions.

This analysis envisages the curriculum vision of the creativity test, the teleological configuration, the types of competencies to achieve, and the operational objectives of the evaluation. The matrix explaining the operational objectives with the objectives of the creativity test, design, pretesting, and the statement of each item is discussed. The table explaining correspondence between items and the objectives of the scale are elaborated with the correction scheme and the grading scale. The difficulty and discrimination coefficient for each item are calculated, and the evaluation criteria of the overall qualities (objectivity, applicability, fidelity, and validity) is explained.

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Keywords: developmental evaluation, table of specifications, difficulty coefficient, discrimination coefficient, qualities of a standardized test.

Introduction

Developmental evaluation (Patton, 2011), and noological learning (Ho, 2016) represent an emotional exercise for the teacher and students. Monitoring the evolutionary learning process of the students is different from result-based monitoring and includes operational monitoring (related to the operationalization of objectives): strategic monitoring (related to the structuring of the instructive-evaluative process); and action research (a spiral of steps, each of which is composed of action planning, and fact-finding about the result of the action) (Lewin, 1946).

Literature review

Guilford (1950, 1951) and Lowenfeld (1959) assert the transferability of creativity from one form to another (artistic, logical, literary, and social). Deliberate cognitive and emotional creativity and spontaneous cognitive and emotional creativity (Dietrich, 2004) have the potential to achieve specific performances. For e.g., mathematical creativity is a multifactorial construct based on deliberate and spontaneous cognitive creativity, whose sphere of action is the mathematical issues as a complex intellectual activity (Isaksen & Treffinger, 1985; Treffinger, 1995). Mathematical creativity is the application of behavioural and cognitive strategies (metamemory, meta-learning, metacognition), divergent thinking tools, and creative strategy in resolutive design (Guilford, 1967).

The major obstacle to problem-solving is the functional fixedness, which activates the operational, functional, and normative setting (Szekely, 1950), because the data are interpreted only from the perspective of the dominant features (explicit/denotative characteristics) (Davis, 2003) and restricts the stimulation of optimal cognitive patterns. The operational-cognitive factors majorly influence creative performance, such as problem-solving. The cognitive background is a construct structured on the declarative knowledge type as cognitive schemes, the procedural knowledge type as cognitive scenarios (Quillian, 1968), and the strategic knowledge as conditional knowledge (Malara & Navarra, 2003). The resolution involves the declarative knowledge for developing mathematical connections like concept-concept and concept-context to support innovative designs (Patton, 2011) and concept-representation for mathematical data modeling (Greeno & Hall, 1997). Comprehensive assessments in mathematics focuses on three key areas: traditional mathematical skills, conceptual understanding, and problem-solving, to report individual scores (Shannon, 1999) and determine how to create opportunities for each student to overcome their deficiencies (Massell et al., 1997). At present, the focus is more on skills and less on content (Albrecht, 2008), and on the re-evaluation of mathematics education, since it has real creative valences, training in divergent and critical thinking is provide by reconfiguring the qualities of productive thinking on another scale for horizontal and vertical mathematization (Treffers, 1987).

Developmental evaluation (innovative and emergent) (Patton, 2011) focuses on evolution (increase in capacity and competence), has rapid feedback, facilitates the structuring of the decision-making

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process in real-time, is based on procedural data, and can become a part of the pedagogical intervention. The model of the pair of formative evaluation-summative evaluation is at the heart of the developmental evaluation (Scriven, 1967).

Data and methodology

Architecture of a Mathematical Creativity Diagnostic Standardized Test: A tool of a multi-evaluation program for skills development.

This mathematical creativity diagnostic test (Havârneanu, 2012) for developmental evaluation is designed to be used at all the multi-assessment stages of the training program on creativity (Petrovici, Havârneanu, 2015). It is based on different development activities designed to develop mathematical creativity among students. Starting from the assertion that intelligence is learned like any other type of behavior (Feuerstein et al., 1980), recent studies reveal the crucial importance of creativity in education since it is considered that only through the convergence of bio-psycho-socio-educational factors can potential metamorphose into creativity and transform proximal development zone (Vîgotski, 1987) into an autonomy skills zone.

Implementing this strategic program to develop mathematical creativity envisages numerous *ex-ante* (diagnostic function), *in-itenere* (regulatory function), and *ex-post assessment* sessions with summative function by verifying students' learning outcomes, certifying teachers' skills, and establishing the program efficiency.

This justifies why the teachers must structure their instructive-educative-evaluative approach by the application of the creative heuristic strategies (which permanently accompany inferencing with verifying correctness), as well as of the strategic error management (by retroactive and proactive cognitive control), also called *ptaismology* (πταισματολογιο - with the meaning of culpability in Greek) who explain the mechanism of correcting the errors through understanding their etiology (Roback, 1955).

Curriculum vision of the Mathematical Creativity Test

The specialized curriculum of this program focuses on the enrichment and thorough understanding of strategies needed to solve specific tasks (Pressley & Afflerbach, 1995) and a mixed one, corroborating the curriculum focused on the development of cognitive processes and self-updating curriculum. In addition, it aims to develop creative thinking, based on the model conceived by Isaksen and Treffinger (1985) and Bloom's taxonomy (1963) updated by Anderson and Krathwohl (2001) by developing the main cognitive areas (remember, understand, apply, analyze, evaluate, and create).

Teleological configuration structured on the triangle of purposes for assessment of the educational quality

The teleological configuration of the evaluation tool understudy is structured on a triangle of goals to evaluate the educational quality. First, the assessment as support for learning is comprehensive, coherent, continuous, integrated, and comprises high-quality assessment tools (National Research Council, 2003). Second, the assessment for accountability, through projects and multidisciplinary approaches, which valorizes personal and relational responsibility through inter-evaluation and self-evaluation (Burger, 2000). Third, the assessment for certification, progress, and transfer. Given the specifics of the program (training in mathematical creativity), certification is not a goal but rather an indicator needed to accredit the program. Finally, this evaluation tool aims to identify progress and knowledge transfer indicators, considering that the mathematical creativity test is performed in parallel with the general creativity test.

Types of the competencies to achieve and operational objectives of the evaluation

The proposed pedagogical test was developed according to the methodology conceived by Evans, 1985, to assess the development level of creative thinking. The objectives of the evaluation were structured on different cognitive, creative, affective-volitional, and motivational-attitudinal skills. However, these are limited to the specific objectives of the mathematics course for the age group 10-12 years.

Operational Objectives of the test

The competencies mathematical creativity assessment focused on the quality of acquired knowledge (declarative, procedural, and conditional), which provides the framework for transfer learning (Tardif,

1992), cognition, and metacognitive regulation. This mathematical creativity competencies test formulated cohesive objectives, operationalized based on the procedure developed by Mager (1977), and verified by guiding from the criteria formulated by Lebrun and Berthelot (1994).

Table 1: The table of correspondence between the competencies to achieve and acquired knowledge and skills

Competencies to achieve	**Examples of acquired knowledge and skills**
Use elements of logic to justify steps in solving problems	- Distinguishing inadvertent elements from the statement. - Deduction of new information based on existing and related information. - Inferring complete logical reasoning. - Argumentation of the made inferences.
Investigate the truth value of a statement by constructing examples of counterexamples	- Reorganization of the information in the statement to notice any inaccuracies. -Validation of some information deduced from the statement by building some examples/ counterexamples.
Build problems from a partial statement	- Identify the essential information in the partial statement and complete it to build an exhaustive statement. - Generalizing the information in the statement and building a new problem, starting from the partial statement.
Identify essential information from a mathematical statement presented in various forms	- Notifying the relevant elements of a configuration. - Transformation and reorganization of the mathematical statement to allow the polarization of meaningful units. - Comparing the information in the statement with certain related knowledge and notifying the relevant ones. - Discrimination of meaning-generating information.
Present clearly, correctly, and concisely in writing the methods/ operations used to solve a problem	-Identifying and noting in abbreviated mathematical language the problem statement. - Transcription of some mathematical statements in the form of hypothesis and conclusion. - Understanding and applying methods in as varied contexts as possible. -Argumentation of the approach to solving a problem.
Expressing practical problems through mathematical operations	- Identify situations that can be translated into appropriate mathematical language. -Conversion of problems from mathematical language to the common language and vice versa.
Show perseverance in solving a problem and participate with new ideas in finding solutions	- Applying several methods in solving a problem. - Use of various methods to decode meaningful units from a mathematical statement. - Building alternative strategies for finding solutions to a problematic situation.

Source: Author

Proposed Operational objectives

O1: To reorganize the information according to various criteria.
O2. To structure as many as possible solutions, based on the quick associations between the relevant information from the statement.
O3. To differentiate between explicit and implicit information from the text.
O4. To produce as many solutions as possible based on their classification and selection criteria.
O5. To generate the solution by intuiting the need to rethink the issue, moving from the two-dimensional plane to the three-dimensional space.
O6. To build the solution by using constructive imagination in structuring a new configuration.
O7. To structure the solution by using creative imagination that facilitates breaking out of the stereotype.
O8. To differentiate between information given in the text.
O9. To distinguish inadvertent elements.
O11. To validate the information that correctly completes the designed solution.

Design, pretesting, and selection of the statement for each item

The standardized test required a pre-test before finalizing the item statements. The pre-test was performed on a group of 356 students, non-volunteers in the age group of 10 to 12 years. Stratified

random sampling was used; the stratification variables were: age (10-12 years), type of school (country school, neighborhood school, elite school), and gender. It should be noted that the students participating in the pre-test did not participate in the subsequent tests.

Matrix of the objective-items correspondence and table of the item-objectives correspondence as important tools involved in designing standardized docimological (δοκίμολογικ- with the meaning of probationary in Greek*) tests*

Table 2: The matrix of the objectives-items correspondence

Objectives of the evaluation	**Items involved in the objectives' operationalization**
O_1 Reorganization of information	I_1- I_{15}
O_2Recognition of as many as possible solutions, based on quick associations	I_1, I_2, I_3
O_3 Differentiate between explicit and implicit information from the text	I_1-I_{15}
O_4 Producing as many solutions as possible, based on their own classification and selection criteria	I_4, I_5, I_6
O_5 Generating the solution by intuiting the need to rethink the issue	I_7
O_6 Building the solution by using constructive imagination	I_8
O_7 Structuring the solution by using creative imagination that facilitates breaking out of the stereotype	I_9
O_8 Differentiation of information in the text	I_1-I_{15}
O_9 Arguing the solution	I_{10}, I_{11}, I_{12}
O_{10} Distinguishing inadvertent elements	I_{13}, I_{14}, I_{15}
O_{11}Validation of information that correctly completes the designed solution	I_1-I_{15}
Source: Author	

Table 3: The table of the item-objectives correspondence

Item	**I_1**	**I_2**	**I_3**	**I_4**	**I_5**	**I_6**	**I_7**	**I_8**	**I_9**	**I_{10}**	**I_{11}**	**I_{12}**	**I_{13}**	**I_{14}**	**I_{15}**
Objectives	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1	O_1
	O_2	O_2	O_2	O_3	O_3	O_3	O_3	O_3	O_3	O_3	O_3	O_3	O_3	O_3	O_3
	O_3	O_3	O_3	O_4	O_4	O_4	O_5	O_6	O_7	O_8	O_8	O_8	O_8	O_8	O_8
	O_8	O_8	O_8	O_8	O_8	O_8	O_8	O_8	O_8	O_9	O_9	O_9	O_{10}	O_{10}	O_{10}
	O_{11}	O_{11}	O_{11}	O_{11}	O_{11}	O_{11}	O_{11}	O_{11}	O_{11}	O_{11}	O_{11}	O_{11}	O_{11}	O_{11}	O_{11}
Source: Author															

Elaboration of the correction scheme and the matrix of the grading scale

The elaboration of the grading scale for each item is a complex procedural activity, which minimizes the effects of the evaluators' subjectivity and ensures the accuracy of the test. The grading scale was developed by combining the holistic and analytical methods. The holistic method, used in the case of subjective items, involved establishing a scale that includes categories of answers that correspond to different grading intervals (Dick & Carey, 1996). On the other hand, the analytical method structures the correction grid in a table of specifications, specifying the correspondence between the response unit and its grading.

Table 4: The matrix of the grading scale

Areas of the cognitive domain/ The score for each item	**Remember**	**Understand**	**Apply**	**Analyze**	**Evaluate**	**Create**	**Total**
Items for fluency testing	1	1	3	1	2	1	9
Items for flexibility testing	1	1	1	3	1	2	9
Items for originality testing	1	2	1	1	1	3	9
Items for elaboration testing	1	1	2	1	3	1	9
Items for sensitivity testing	1	3	1	2	1	1	9
Source: Author							

The table of specifications in concordance with the taxonomy of the cognitive field developed by Bloom (1963) and updated by Anderson & Krathwohl et al. (2001)

Table 5: The table of specification

Contents / Scores	Remember			Understand		Apply	Analyze		Evaluate	Create	Total
	Know the terminology	Know the conventions	Know the Methods	Transpose	Extrapolate		Elements search	Relations Search			
Item 1						1	1		1		3
Item 2						1			1	1	3
Item 3			1	1		1					3
Fluency	0	0	1	1	0	3	1	0	2	1	9
Item 4				1				1		1	3
Item 5								1	1	1	3
Item 6			1			1	1				3
Flexibility	0	0	1	1	0	1	1	2	1	2	9
Item 7					1			1		1	3
Item 8					1				1	1	3
Item 9		1				1				1	3
Originality	0	1	0	0	2	1	0	1	1	3	9
Item 10				1				1	1		3
Item 11			1	1					1		3
Item 12						1			1	1	3
Elaboration	0	0	1	2	0	1	0	1	3	1	9
Item 13						1	1			1	3
Item 14				1				1	1		3
Item 15					1	1		1			3
Issues sensitivity	0	0	1	1	1	1	1	2	1	1	9

(Source: Author)

Results and Discussion

Proofreading and grading of the tests in the pre-testing

The proofreading and grading of the test ensured a coherent vision, objectivity, and equidistance of the test scale. First, a technique called comparison by groups of works was used to check and grade the entire set of works; the work was grouped according to the scores given for each set of items in the range 8-9, then in the range 7-8, etc. After that, another technique of pairs was used to compare the works in each group and re-ranking if necessary. Finally, the comparisons were made between groups; the best work in the group was compared with the weakest work in the upper group and the weakest work in the group with the best work in the lower group. The histograms were prepared for the two evaluation sessions. The Gauss's bell shape confirms that there are no evaluation errors and stereotypes in grading (Pygmalion effect, halo effect; effect of contagion; stereotype effect; succession/contrast effect; forced distribution effect).

Figure 1: The results of the initial mathematical creativity test

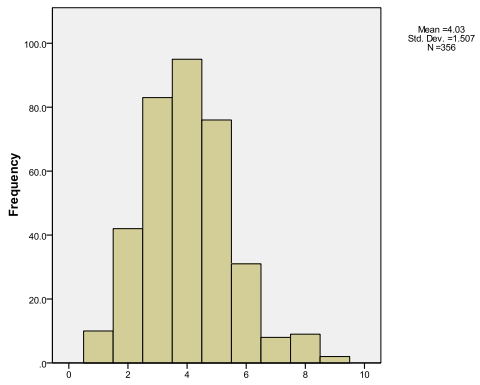
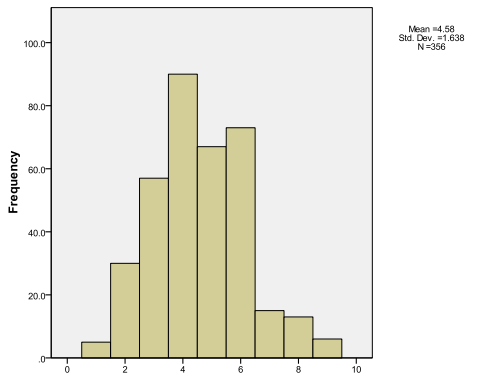


Figure 2: The results of the final mathematical creativity test



Source: Author

Calculation of the difficulty[2] and discrimination coefficients

The pre-test checked the qualities of each item by calculating the difficulty coefficient (as the percentage of subjects who correctly solved it) and the discrimination coefficient (as the difference between the percentage of the top fifth of the ranking subjects and the percentage of the bottom fifth of the ranking students) (Lord, 1952). This analysis changed the structure of the test, eliminating the items considered too easy or difficult, considering that they are irrelevant to the study. For e.g., the items on the scale to test creative mathematical thinking have a coefficient of difficulty between 25% - 75%, and the values of the discrimination coefficients at least 25%.

Evaluation of the overall qualities of the test

The pre-test verified the overall qualities of the test. It confirmed the objectivity (explicit character and the clarity of the items allows for obtaining comparable scores in the case of competent evaluators), applicability (adequacy of the items to the targeted contents, to the volume of time and material resources necessary for its application), fidelity, and validity of the test.

The fidelity of this evaluation tool was demonstrated (Havârneanu, 2012) in four different ways (Gliner & Morgan, 2000): test-re-test fidelity was revealed by the stability coefficient (comparable results were obtained when applying the test to the same subjects at a sufficiently long time interval - 7 months); fidelity by alternative forms revealed by the equivalence coefficient (the same subjects obtained comparable results after testing and retesting by a similar test, obtained by exchanging the order of the items); fidelity by the method of halving the value of the correlation coefficient (comparable results were obtained by each of the two halves of the sample) and the internal fidelity or homogeneity revealed by the value of the coefficient of internal consistency (all items relate to each other, and each item relates to the total result obtained by the subjects). The validity of this evaluation tool was confirmed (Havârneanu, 2012) by analyzing the following types of validity: content validity by the expert method, competitive criterion validity by the validity content coefficient (the results obtained by the students in the general creative thinking test and the mathematical creative thinking test are correlated, in each of the two evaluation sessions), the predictive criterion validity by the value of the concordance coefficient, as well as the construct validity conceptual (Anastasi, 1976; Evans, 1985) demonstrated by exploratory and confirmatory factor analysis that the items corresponding to the rating of fluidity, flexibility and originality are closely correlated, contributing 45.74% to the variation of scores, and the items corresponding to the rating of elaboration and sensitivity to the problems is a second correlation group, contributing 37.8% to the variation of results.

Conclusions

The architecture of an assessment tool for the formative evaluation of a differentiated and vocational training program is complex and aims at the following: to develop a unified vision of the specialized curriculum and to develop the contents for the training program; the conception of a teleological configuration that follows the triangle of the goals for qualitative approach for educational evaluation; to structure the competency framework to be achieved; the construction of the reference objectives and of the examples of knowledge and skills necessary to be acquired; the operationalization of the proposed objectives; the design of the statements of the items; the correlation of the operational objectives with the objectives of the test for diagnostic the level of qualities of mathematical creativity; the realization of the table of the item-objectives correspondence; the design of the matrix of the objective-items correspondence; the elaboration of the correction scheme and of the grading scale; the structuring of the table of specifications; the design, pretesting, and final establishment of the statement of each item; the proofreading and grading of the tests in the pre-testing stage; the calculation of the difficulty and discrimination coefficients; the elaboration of the matrix of the difficulty coefficient and of the discrimination coefficient for each item; the evaluation of the overall qualities of the test (objectivity, applicability, fidelity, and validity).

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[2] ScorePak®FAQ arbitrarily classifies item difficulty as easy if the index is 85% or above; moderate if it is between 51 and 84%; and hard if it is 50% or below.

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