PSIHOLOGIJA, 2011, Vol. 44 (4), 307–323 UDC 159.922.72.072-053.5 ; 371.26-053.5 ; 371.3:54

DOI: 10.2298/PSI1104307S

A formal approach to organization of educational objectives

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The organization of educational objectives plays an important role in curriculum development process, since it enables the sequencing of educational experiences. The main goal of this paper is to propose a framework for the formal representation of educational objectives, which enables the evaluation of organization of educational objectives. The model is based on domain ontology, Bloom's taxonomy and objectives organization in the competence-based knowledge space. The model is verified on the case study that evaluates the students' achievements in Chemistry field Solutions by conducting an informal knowledge test on the group of 199 14-year-old students of primary schools in the Republic of Serbia. The results obtained from the case study clearly indicate the necessity for including assessment of students' achievements in the organization of educational objectives. The proposed model enables evaluation of organization of educational objectives which could be further used for an iterative refinement of the organization of educational objectives.

Key words*: educational objectives, curriculum development, formal representation, knowledge space theory, ontology.*

Modern society is characterized by exponential progress in science and technology (Schummer, 1999; Tontini, 2004). It is obvious that the students in these fields could not rely only on the knowledge acquired through formal education, but would require continuous learning (Gilbert, Justi, van Driel, de Joung, & Treagust, 2004). The body of existing knowledge and its rapid development are in conflict with the limited teaching time and mental/physical capacities of the students which requests careful planning of the teaching process. Thereby, a definition of objectives is extremely important, since it directs all the other activities and allows determining to which extent the planned activities are implemented. All the activities and learning experiences in the educational process are planned in the curriculum which demands appropriate models of curricula that take into account mentioned constraints (Egan, 1978).

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CURRICULUM DEVELOPMENT PROCESS

Tyler's rationale is a classical model of the curriculum development (Tyler, 1949). It is a foundation for many modern curriculum development models and can be utilized in the formalization of the curriculum development process (Hlebowitsh, 2005; Wiggins & McTighe, 2005; Segedinac, Savić, & Konjović, 2010a). Tyler's rationale identifies four basic questions to be answered in the curriculum:

1. What educational purposes should the school seek to attain?
2. What educational experiences can be provided that are likely to attain these purposes?
3. How can these educational experiences be effectively organized?
4. How can we determine whether these purposes are being attained?

These questions correspond to the steps in the curriculum development: *selection of educational objectives*, *selection of educational experiences, organization of educational experiences,* and *evaluation of educational outcomes* (Tyrrell, 1974). The educational objectives are understood in accordance with Tyler's rationale as an explicit formulation of expected changes of behavior under the influence of the teaching process (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956). The selection of educational objectives plays a key role in the curriculum development, since all the other activities rely on carefully selected educational objectives (Kliebard, 1970). The selection of educational objectives includes *specification*, *classification* and *organization* of educational objectives (Segedinac et al., 2010a).

Specification of the educational objectives. Specification of the educational objectives is aimed at defining (select and represent) a domain knowledge to which educational objectives apply. Therefore, the problem of specification of educational objectives is essentially the problem of knowledge representation. Various types of knowledge call for different techniques of knowledge representation (Gasevic, Djuric, & Devedzic, 2009). Since the process of formal education usually defines educational objectives related to the exact declarative knowledge, it is appropriate to use domain ontology for specification of the educational objectives which is the case in this paper.

Classification of educational objectives. Classification of educational objectives is due to organize educational objectives into categories thus simplifying their management. A large number of taxonomies have been developed for that purpose. An overview of the most taxonomies used for the classification of educational objectives is given by Moseley and co-authors (Moseley et al., 2006).

The Bloom's taxonomy is an educational-logical-psychological classification system, with an emphasis on the educational aspect of classification of educational objectives. This classification observes changes that occur, as a result of education, in the cognitive, affective and psycho-motor spheres of personality. Therefore, the taxonomies of educational objectives have been developed for cognitive, affective and psycho-motor domain (Bloom et al., 1956; Krathwohl, Bloom, & Masia, 1973; Simpson, 1972). Since most of the educational objectives in formal education have been defined in the cognitive domain, particularly in the areas that are presently being intensively developed (e.g. sciences, engineering, technology), this paper focuses attention on the educational objectives of the cognitive domain.

Bloom‘s taxonomy of cognitive domain organizes cognitive skills into six main categories: *knowledge, comprehension, application, analysis, synthesis* and *evaluation.* The categories are hierarchically organized and all the educational objectives that rely on cognitive skills from higher category include educational objectives that rely on cognitive skills of all the lower categories. Accordingly, the assumption is that the educational objectives apply to the same domain knowledge**.** Furst warned about frequent inversions and overlapping that occurred among the categories (Furst, 1981). It has been noticed that, even when defining the taxonomy of the cognitive domain, it is not possible to make a sufficiently clear distinction among the categories.

Further revisions of the Bloom‘s taxonomy have been motivated by the development of educational sciences, especially by increasing attention devoted to educational activities. One of the most significant revisions of the Bloom’s taxonomy is proposed by Anderson et al (2001). The cognitive domain which is seen in the original Bloom‘s taxonomy as one-dimensional space is organized in two dimensions, *knowledge* and *cognitive process* dimensions. Here, the proposed categories correspond to the categories of cognitive process dimension, with an emphasis on cognitive activities. The categories of cognitive process dimension are *remember, understand, apply, analyze, evaluate* and *create*. The cognitive processes have been organized from simple to complex ones. The order of the last two categories of the original Bloom’s taxonomy has been inverted. The knowledge dimension is a modality in which the cognitive processes occur, i.e. it is a modifier of the cognitive processes. The categories of this dimension have been organized from a concrete to abstract ones, and they are *factual knowledge, conceptual knowledge, procedural knowledge* and *metacognitive knowledge*.

Organization of educational objectives. Organization of educational objectives is due to establish structures and relationships in a set of educational objectives, which describe how and in which order they are being achieved. Therefore, the organization of educational objectives enables sequencing of educational experiences (Hlebowitsh, 2005). The adopted classification of educational objectives can be the base for their organization, as it is the case in this paper.

Organization of educational objectives is the identification of structures and relations in the set of educational objectives for more efficient organization of the educational experiences and application of more efficient evaluation methods of the educational outcomes. Since the achievement of educational objectives in formal education is closely related to the development of problem solving skills (competencies), the set of educational objectives can be mapped to the set of problems (Segedinac et al., 2010a). It means that every problem can be annotated with the educational objectives that should be mastered in order to solve the problem, and that it is possible to design problems for each educational objective in order to test the achievement of the educational objective. Methods for the organization of the problems solved by a student are focused on the identification of preconditions in the set of problems. For the purposes of formal modeling of prerequisites in the set of problems, *knowledge space theory* has been developed. An extensive overview of the knowledge space theory is given by Falmagne and Doignon (2011).

*Knowledge space theory***.** The problems presented in the process of education are cumulative, and the solutions of simple problems are incorporated in the solutions of the more complex ones**.** Thus, it can be concluded from the fact that if a student is able to solve some problem, he or she will be able to solve the problems embedded in the original problem. Knowledge space theory provides a formal representation of the structure that describes containment of simple problems within the more complex ones.

The hierarchical structure of the problems presented with the knowledge spaces need not be simple (such as a simple series of questions in the test in which every question contains all the preceding questions), and it need not even have a logical structure that imitates the domain structure (Falmagne, Koppen, Villano, Doignon, & Johannesen, 1990). In addition to the logical structure of knowledge itself, the formation of the knowledge spaces is influenced by the instructional strategies and individual characteristics of students.

Knowledge space theory was originally developed for the purpose of simplifying the evaluation of educational outcomes by using preconditions in the set of problems to reduce the number of the test problems for an accurate identification of the students' achievement. Consequently, the techniques of adaptive testing have been developed (Falmagne & Doignon, 1988). Knowledge space theory was also applied in the generation of individual learning paths, and analysis and revision of the curriculum (Toth, 2007; Pirrone, Pilato, Rizzo, & Russo, 2005).

The basic concept of the knowledge space theory is a *knowledge state* – a set of problems that can be solved by a student. Knowledge state is defined in relation to the set of all the problems, namely a *domain*. The knowledge space theory presumes that the domain is discrete and finite.

Collection of all the knowledge states of a domain is a *knowledge structure* and it is defined as a pair (Q, K) where Q is a domain, and K is a collection of the knowledge states. A *knowledge space* is a knowledge structure for which the following axioms hold:

Q1. Q is an element of K, meaning that a student may be able to solve all the problems in the domain, and $\varnothing$ is an element of K, meaning that a student may be unable to solve any of the problems in the domain.

Q2. K is $\cup$-closed, meaning that by achieving new educational objectives, a student is always in some knowledge state.

Knowledge spaces, which are $\cap$-closed, are *quasi-ordinal knowledge spaces*. Such knowledge spaces can be uniquely presented by using quasi-ordinal *surmise relation*, which can be defined as follows: problem *a* surmises problem *b,* if from knowing that a student is able to solve problem *a* we can infer that student is able to solve problem *b*. In the quasi-ordinal knowledge spaces it is assumed that a student can solve the problem in one way only, namely with the application of exactly one set of preconditions. There are extensions of the surmise relation that allow the representation of the knowledge spaces in which the problems could be solved in different ways as well (Falmagne & Doignon, 2011). This paper is restricted to the quasi-ordinal knowledge spaces.

*Knowledge spaces and competences***.** Knowledge space theory belongs to the family of behavioral educational models (Steiner & Albert, 2008). Namely, knowledge space theory analyzes the hierarchical structure of the problems that students learn to solve, without considering students' cognitive processes involved in the solutions. Such approach has been adapted to the cognitive theories, so that the knowledge spaces are constructed on the basis of explicit representation of competences which students need to master in order to be able to solve the given problems (Albert & Held, 1999; Doignon, 1994; Düntsch & Gediga, 1995; Korossy, 1997).

The basic assumption of competence-based knowledge space theory is the existence of a set of fine grained competencies which can represent domain knowledge. The surmise relation is introduced into the set of competencies, as an analogue of the surmise relation in the set of problems. The set of educational experiences (problems, teaching materials and teaching activities) can be mapped to set of competencies. Starting from the surmise relation defined on the set of competencies and the mapping between the set of competencies and the set of learning experiences, it is possible to construct surmise relation on a set of educational experiences (Steiner & Albert, 2008). Segedinac and co-authors proposed that all educational experiences (assessment problems, educational materials and teaching activities) should be mapped in the same way – with a single mapping of collection of subsets of competencies to the set of educational experiences (Segedinac et al., 2010a). It is assumed that the set of competencies required for the usage of learning materials can be reconstructed relying on the set of fine grained competencies.

Falmagne and co-authors proposed to represent a set of skills S and a set of problems Q (Falmagne et al., 1990). Mapping $f(q): Q \rightarrow S$ for each problem q defines a set of skills necessary for solving the problem. Surmise relation is defined on a set of skills *S,* which implicitly defines surmise relation on the set of problems *Q*. Namely, if in order to solve problem *q*, a student needs all the skills necessary for solving the problem *q*' then *q* surmises *q*'. Accordingly, the quasi-ordinal surmise relation *P* in the set of problems is defined as:

$$qPq' \leftrightarrow f(q) \subseteq f(q')$$

This approach has been extended by Heller et al. (2005). In addition to the assessment problems, learning objects (atomic digital learning resources) have been analyzed as well. Three classes of entities have been defined:

1. A set of assessment problems *Q*
2. A set of learning objects *L*
3. A set of skills *S*

One surmise relation has been identified for each of these classes of entities, defining following structures:

1. Knowledge structure on the set *Q*
2. Learning structure on the set *L*
3. Competence structure on the set *S*

The knowledge structure is the basis for the adaptive techniques of students' achievement evaluation, while the learning structure combined with the set of learning objectives a student has achieved allows the creation of personalized learning paths.

The start point in the process of competence-base knowledge space construction is identification of competence structure. Afterwards, knowledge structure and learning structure are formed using appropriate mappings. Knowledge structure is formed by assigning to each assessment problem skills required for its solution. Learning structure is formed through two mappings: one which assigns to each learning material skills required for its usage, and the other which assigns to each learning material skills which will be developed by its usage.

*Algorithms for the construction of the knowledge spaces***.** A number of techniques have been developed for the construction of the knowledge spaces. According to Segedinac and co-authors these techniques can be roughly divided into three categories:

1. Techniques based on systematic interrogation of experts;
2. Techniques based on the analysis of solved tests;
3. Techniques which use the analysis of the problem-solving process (Segedinac et al., 2010b).

Techniques based on systematic interrogation of experts use special purpose algorithms to select appropriate combinations of questions presented to the experts. Such is the QUERY algorithm (Koppen, 1993). Cosyn and

Thiery propose to combine QUERY algorithm with the analysis of solved tests when constructing a knowledge space (Cosyn & Thiery, 2000). QUERY algorithm has the advantage of possibility to construct knowledge spaces before evaluating students' achievements, but also a serious disadvantage which is a need for continuous involvement of experts in the process of knowledge space construction.

Techniques based on the analysis of solved tests construct the knowledge spaces on the basis of the students' test results. Knowledge space cannot be directly observed, and it must be identified in the tests. Schrepp proposes Inductive Item Tree Analysis (IITA), a modification of Item Tree Analysis proposed by van Leeuwe, to be used for the construction of knowledge spaces (Schrepp, 2003; van Leeuwe, 1974). Inductive Item Tree Analysis is modified and corrected by Sargin and Uenlue (2009). Construction of the knowledge spaces so as to optimize the expectation of the counterexamples in the solved tests is proposed by Segedinac and co-authors (Segedinac, Savic, Konjovic, & Segedinac, 2010b). These techniques do not require participation of experts when constructing knowledge spaces, but they require existence of a set of the solved tests.

Techniques based on the analysis of the problem-solving process analyze the problems solved by the students through the sets of sub-problems. The technique that decomposes the problem into a set of motives, constructing a knowledge space by using the information about the motives necessary to solve the problem is proposed by Schrepp, Held and Albert (1999). Techniques based on the analysis of the problem-solving are suitable, since the knowledge spaces can be constructed prior to testing. Also, formalization of the analysis of the problem-solving can, to some extent, reduce a need for direct involvement of experts, since the experts are expected only to allocate the problems.

Technique where the observed competencies are involved in the problem-solving is proposed by Marte and co-authors (2008). Fine grained educational objectives are identified by the competencies which a student should master. Domain knowledge is represented by domain ontology, and cognitive processes are represented by using revised Blooms taxonomy. Starting from the domain ontology and taxonomy of cognitive processes, competence-based knowledge space is constructed by using the component-attribute approach (Albert & Held, 1994; Albert & Held, 1999). In this approach the components are interpreted as dimensions, while the attributes are interpreted as values assigned to those dimensions. Competence-based knowledge space is then constructed as a *Cartesian product* of the domain ontology and the set of cognitive processes. The obtained knowledge space reflects the assumption that, if two educational objectives test the same domain knowledge, the educational objective testing a lower cognitive process category will precede the educational objective testing a higher cognitive process category.

The aim of this paper is to propose the framework which approaches the organization of educational objectives by a formal means with the principal goal to research the relationship of organization of educational objectives relaying solely on the revised Bloom‘s taxonomy and organization of educational objectives which uses the analysis of students' achievements.

Methods

In order to achieve the stated goal, we have compared results of the methods for the organization of educational objectives in competence-based knowledge space which rely solely on the revised Bloom‘s taxonomy and the methods which use the analysis of test results. For that purpose an informal test of knowledge has been used in the research. The test was conducted on the group of 199 14-year-old students of primary schools in the Republic of Serbia.

Test construction and quality assurance procedures. The test is constructed according to the principles of the revised Bloom's taxonomy on a sample of the elementary-school educational contents of chemistry. The sample of the curriculum is the educational content *Solutions*. Educational objectives have been determined following the requirements of the curriculum for Chemistry for the seventh grade of elementary school education in the Republic of Serbia, and according to the recommended textbook (Curriculum regulations, 2009; Mandić, Korolija, & Danilović, 2009). Educational objectives in the examined educational contents relate to the following domain knowledge:

1. The concept of solution
2. Dissolving
3. Qualitative composition of solutions
4. Solvent and solute
5. Quantitative composition of the solution – mass percentage

Test questions have been designed according to the principles of the revised Bloom's taxonomy to examine the pupils‘ achievement in four categories of cognitive processes:

1. Remember
2. Understand
3. Apply
4. Creative Skills (analyze, evaluate and create).

The knowledge test that is used in this research consists of 19 multiple-choice test items. The test is designed with appropriate distractors embedded into the questions by taking into account that offered incorrect answers contain the probable pupils' errors. The authors have applied pre-test and post-test quality assurance procedures for multiple choice tests, as proposed by Bush (2006).

Pre-test quality assurance parameters were evaluated by the expert group prior to testing. The expert group was composed of two Chemistry teachers who taught the students that took the test, one external evaluator – a Chemistry teacher who conducted the test, two university professors specialized in Teaching Methods in Chemistry and one university professor specialized in Pedagogy. Following the extended view of educational material proposed by Pešikan and Ivić, the meaningfulness of test items' requirements, the diversity of test items, the usage of technical terminology in test items, and the length of sentences used in the test items were evaluated, in addition to validity (conformability of test items with the predefined educational objectives) and the compatibility of test items with the categories of revised Bloom's taxonomy (Pešikan & Ivić, 2005).

All evaluators share the opinion that the test is valid since the test items were constructed from the domain ontology (Figure 1.) derived from the curriculum and recommended textbook. The evaluators agree that the test items are relevant and appropriate for the students that took the test.

The following analysis approves test's compatibility with the categories of revised Bloom's taxonomy.

The category *Remember* involves one's ability to remember and reproduce the details or isolated information, models and organization and classification of the teaching contents, and to define basic terms used in the content sample. Test items 1, 3, 4, 6 and 7 measure this category. Items no. 1, 6 and 7 refer to the knowledge of isolated facts. In addition, the item no.1 refers to the knowledge of the fact that solutions are homogenous mixtures; the item no.6 refers to the knowledge of the facts about the ability of different substances to get dissolved in water, while the item no.7 refers to the knowledge of the fact that water is the most common solvent in nature. The test item no.3 and 4 refer to the knowledge of definitions. In the item no.3, the pupils are expected to know the definition of the notion of solubility, and in the item no.4, they are expected to know the definition of the notion of the mass percentages of the solution concentration.

The category *Understand* refers to understanding of the educational contents and the ability to transform the received information to another form. This category includes test item no. 8, 11, 13 and 15. Item no.11 refers to the conversion of the image presentation of the solution as a homogeneous mixture into the verbal expression. In the items no.8, 13 and 15, the pupils are required to interpret the information. In the item no. 8, the pupils are expected to interpret a dependence of solubility of two substances depending on the temperature (blue vitriol and salt), on the basis of the tabular presentation. Item no.13 refers to the interpretation of the rules on determining the solute and solvent as a components of the solution. Item no.15 requires the pupil to interpret a histogram presenting the content of the solute in solutions of different concentration.

The category *Apply* refers to the problem-solving situation when a pupil alone finds a route for the solution of the problem. This category includes test items no. 2, 5, 10, 12, 14 and 16. Item no. 2 measures the ability to apply knowledge to the quantitative relations of solute and solvent in the solution, where the problem situation is concerning dissolution of a large mass of solute in a small mass of solvent. Item no. 5 refers to the application of the rule stating that „akin dissolves in akin". In item no.10, the students are required to calculate the mass of solute and solvent in a given mass of solution of the mass percentage content. In item no. 12, the pupils are required to apply the knowledge on the dependence of solubility of non-polar gases in water in the problem situation relating to the solubility of oxygen in the sea water and thus conditioned distribution of the wildlife in the sea. Item 14 is designed as a problem situation in which a pupil should determine the solubility of sodium chloride at a given temperature from the data on the mass of the solute and the solvent mass in a saturated solution at a given temperature. In the item no. 16, the pupils are expected to calculate the mass percentage content of the solution based on the given mass of solute and the solvent mass.

The *Creative Skills* category includes the highest taxonomic categories: *analyze*, *evaluate* and *create*. The items in this category are designed as complex problem situations which require identification of elements of the problem situations and their synthesis into a new whole. This category includes test items no. 9, 17, 18 and 19. In item no.9, the students are expected to calculate the mass of solute which is necessary for the preparation of a given mass of the solution of the known content. The answer implies the analysis of quantitative relations of solute and solvent in the solution. Item no. 17 refers to the calculation of the mass percentage content of the solution after adding a given mass of solute to the mass of solution of the known content. Along with the analysis of the quantitative relations between solute and solvent in the initial solution, this item requires the synthesis of these parameters in the newly obtained solution. Item no. 18 refers to the calculation of the mass percentage content after addition of solvents to a given mass of solution of a given mass percentage concentration, and as the task given by item 17, it requires the analysis of the parts inside the whole, and their subsequent synthesis into the quantitatively new system. Item no. 19 requires from the pupils to solve the problem of calculation of the mass percentage concentration of the solution obtained by mixing the given masses of two solutions of the same substance of different mass percentage concentrations. This item requires the analysis of quantitative relationships of parts within the whole of the first and the second solution, and the synthesis of these parameters into new quantitative system of the third solution.

Table 1 presents the structure of the test by categories of the cognitive processes.

Table 1.
The structure of the test by categories of the cognitive processes

Cognitive process category	The percentage of test items which assess the cognitive process category
Remember	26.37%
Understand	21.05%
Apply	31.57%
Creative Skills	26.37%

The evaluators share the opinion that the test-items requirements are defined clearly and precisely, and that the requirements are not a hindering factor. The evaluators also agree that the test items are diverse and that the test items contain the appropriate amounts of textual, graphical and tabular representations.

Experts opined that the technical terminology is appropriate for the students' age. Explanatory sentences are short (maximum 20 words) in order to insure the items clarity.

Post-test quality assurance parameters are evaluated by statistical analysis of the test results. In addition to the basic statistical parameters and the frequency distribution of test results, reliability, discrimination index and difficulty index were computed. The reliability is calculated as Spearman-Brown coefficient from the correlation of odd and even test items. Items' difficulty, test difficulty index, items' discrimination, and the index of test discrimination were calculated by using item analysis between the groups of 25% most successful and 25% least successful students (McCown, Driscoll, & Roop, 1996).

Methods for further analysis of tests' results

In order to verify the hypothesis of Bloom's taxonomy the tests' results have been further analyzed using the knowledge spaces theory. For that purpose we have evaluated the knowledge space constructed by using solely revised Bloom's taxonomy as proposed by Marte and co-authors, and knowledge spaces constructed by techniques relying on the solved tests. The knowledge spaces were evaluated against the ability to explain the data obtained for student's achievements. Pearson's *chi-square test* is used for the evaluation of the goodness of fit of knowledge spaces. We have conducted the test for the expected number of counterexamples, which is calculated as proposed by Segedinac and co-authors (2010) and using the R programming language (The R Project for Statistical Computing, 2011). The software implementing the methods is publicly available (Segedinac, 2011).

Results and discussion

Tests analysis

The test used in this research is characterized with the main statistical parameters (number of respondents, achievement average, standard deviation, minimum, maximum, and range) given in the Table 2.

Table 2. Basic Statistical Test Indicators

Count	Average	Variance	Standard deviation	Minimum	Maximum	Stnd. skewness	Stnd. kurtosis	Sum
199	12.291	8.127	2.851	4.0	19.0	0.977	0.806	2446.0

The basic statistical parameters presented in Table 2 are in accordance with normal distribution thus qualifying the test for the further statistical analysis. The reliability has the value 0.72 which, considering the nature of the research, indicates acceptable reliability. Test items discriminations are in the range from 0.06 to 0.82. The discrimination index of the test is 0.39. Test items difficulties are in the range from 25% to 85%, except for two core items (item number 2 with difficulty of 94% and item number 5 with difficulty of 95%) which test the terminological knowledge for terms solution and solubility. Test difficulty index is acceptable as well and it is 65%.

An average achievement in the categories is in accordance with the expectations of Bloom's taxonomy. The achievement decreases when moving from lower to a higher category. This decline is particularly expressive for the category *Creative Skills* as shown in Table 3.

Table 3. The achievements by cognitive process categories

Cognitive process category	The percentage of correct answers
Remember	75.69%
Understand	70.60%
Apply	66.84%
Creative Skills	39.19%

Analysis of the Knowledge Spaces

Knowledge space theory is used in this paper in order to explore whether it is possible to organize educational objectives within the curriculum only on the basis of the revised Bloom's taxonomy or an alternative for the improvement of the organization of educational objectives exists. The content analysis of test items resulted in a domain ontology. Ontology is constructed on the basis of the proposed sequence of educational objectives in the applied curriculum, and it has been formed in accordance with the method proposed by Marte and co-authors (Marte et al., 2008). Figure 1 shows the domain ontology.

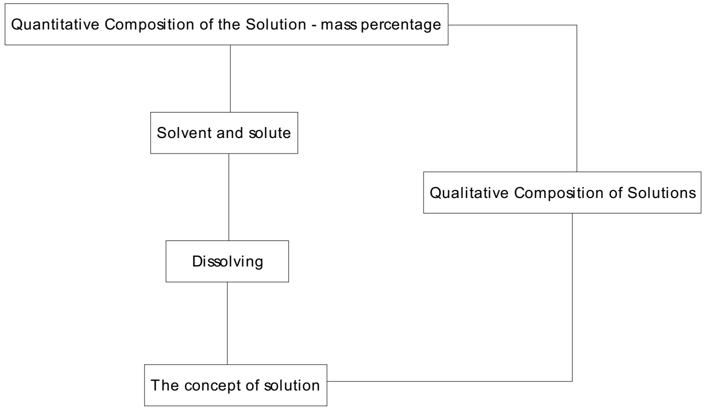

Figure 1. Domain ontology for the field *Solutions*

Afterwards, the knowledge spaces are constructed by applying following approaches: the approach proposed by Marte et al. (2008), algorithms proposed by Segedinac et al. (2010b), inductive item tree analysis, corrected inductive item tree analysis, and minimized corrected inductive item tree analysis. Following graphs represent the structure of the resulting knowledge spaces with rectangles denoting the items and lines denoting the surmise relation.

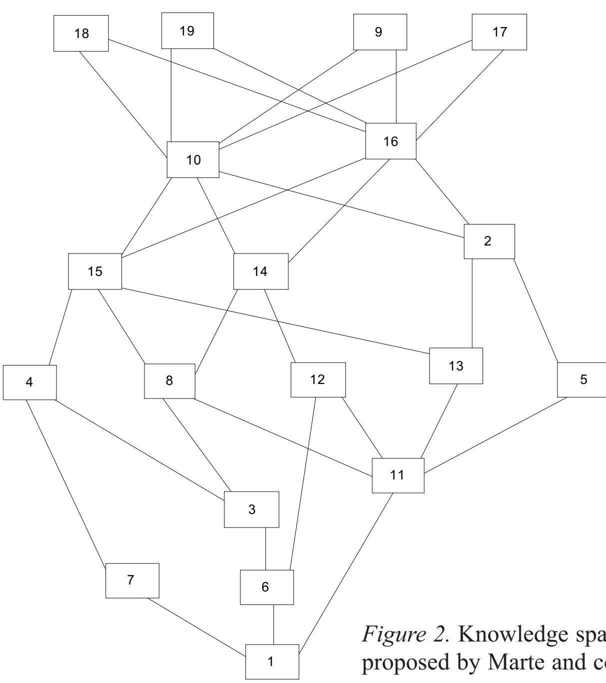

Figure 2. Knowledge space obtained by using algorithm proposed by Marte and co-authors (Marte et al., 2008)

The knowledge space resulting from the approach proposed by Marte et al. (2008) is shown by Figure 2.

Figure 3 shows the knowledge space constructed by the application of the algorithms proposed by Segedinac et al. (2010b). Figure 4 depicts (equal) knowledge spaces obtained by inductive item tree analysis, corrected inductive item tree analysis, and minimized corrected inductive item tree analysis.

The software implementations of all applied algorithms are publicly available (Segedinac, 2011; Sargin & Uenlue, 2010).

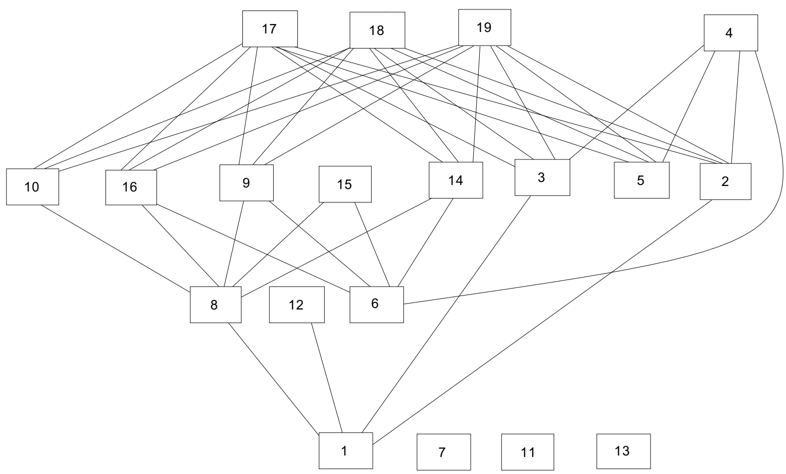

Figure 3. Knowledge space obtained by algorithm proposed by Segedinac and co-authors (Segedinac et al., 2010b)

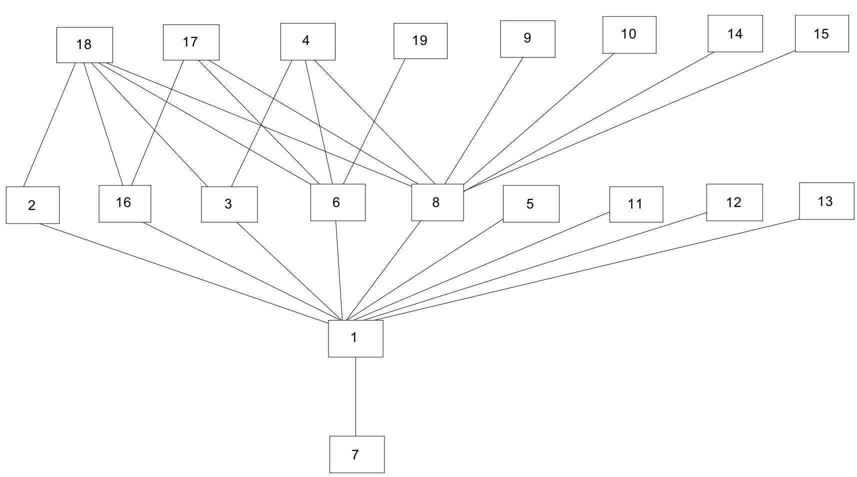

Figure 4. Knowledge space obtained by inductive item tree analysis, corrected inductive item tree analysis, and minimized corrected inducted item tree analysis

As mentioned, for the evaluation of the quality of knowledge spaces Pearson's chi-squared test has been used with 18 * 18 = 324 degrees of freedom. The obtained results of evaluation of the knowledge spaces are presented in Table 4.

Table 4. The Results of Chi-Square Test

Algorithms for the construction of knowledge spaces	X^2	p
Algorithm proposed by Marte et al. (2008)	5254.710	.000
Algorithm proposed by Segedinac et al. (2010b)	255.350	.998
Inductive item tree analysis, corrected inductive item tree analysis, and minimized corrected inductive item tree analysis	302.058	.804

Even though descriptive statistics shows that the average achievements on the conducted test are in accordance with the predictions of the Bloom's taxonomy, Table 4 shows that the knowledge spaces constructed by using only the revised Bloom's taxonomy and domain ontology do not have sufficient predictive power to explain the data obtained for student's achievements. In contrast, the knowledge spaces constructed by the application of algorithms which, in addition, use assessments of students' achievements have sufficient predictive power.

CONCLUSION

From the research conducted in this paper, two groups of conclusions can be drawn. The first group is addressed to scientific audience and the second one is addressed to educational policy makers and curriculum development practitioners.

The conclusions addressing the scientific audience are:

– It is possible to create a formal model of selection of educational objectives which includes students' achievements, based on domain ontology, educational taxonomy and knowledge space theory, such that verification of educational objectives organization is enabled.
– In order to simplify the use of such model for the practitioners and researchers the appropriate software tools should be developed.

The conclusions addressing the policy makers and practitioners are:

– Organization of educational objectives which includes assessment of students' achievements should be an integral part of the process of curriculum development.
– Verification of educational objectives organization could be facilitated by the proposed formal model, and organization of educational objectives could be iteratively refined in order to improve students' achievements.

Following the drawn conclusions, future research will follow two main lines.

The first line is development of the methodological framework for iterative improvement of the organization of educational objectives in the curriculum. This research will primarily comprise construction of algorithms for iterative revision of the organization of educational objectives. Such algorithms will be the basis for assisting in appropriate organization of educational objectives. The iterative construction of competence spaces over the set of educational objectives could also facilitate observation of the dynamics of achieving the educational objectives and, therefore, serve for researching the learning dynamics.

The second line is development of the software tool aimed at providing assistance to researchers, education policy makers, curriculum development practitioners and teachers. It will comprise development of the software services enabling user/context aware use of the methodological framework.

Acknowledgment

Results presented in this paper are part of the research conducted within the Project "Technology Enhanced Learning Infrastructure in Serbia", Grant No III 47003 of the Ministry of Education and Science of the Republic of Serbia.

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