Odgojne znanosti
Vol. 11, br. 1, 2009, str. 53-71
Izvorni znanstveni članak

CONCEPT MAPS AS DIAGNOSTIC TOOLS IN ASSESSING THE ACQUISITION AND RETENTION OF KNOWLEDGE IN BIOCHEMISTRY

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Abstract *– This paper shows the possibility of applying concept maps as diagnostic tools in assessing knowledge. The authors introduce the terms "ideal knowledge structure", "desired knowledge structure" and "real knowledge structure" as milestones in indicating levels of acquired knowledge. The role of concept mapping in the diagnostics of knowledge was tested in the secondary-school teaching of biochemistry. The pedagogical experiment was performed with secondary-school students form Novi Sad (Serbia). Students were tested in two biochemical topics (nucleic acids and protein synthesis) and concept maps were created for the results of each student after final and retention tests. A comparison of the desired knowledge structure and the real knowledge structure revealed the possible application of concept maps: in establishing the level of acquired knowledge; in illustrating students' efforts and ability to learn biochemical content; and as indicators of the level of the retention of knowledge and of the efficiency of the applied teaching method. Through concept maps, teachers can evaluate their own performance and gain important feedback on their own work.*

Key words: *concept map, knowledge structure, learning ability, retention of knowledge, biochemistry*

Introduction

Concept maps (CM) are valuable tools for assessing the effectiveness of the conceptual changes provoked by didactical activities conducted in the classroom. Concept mapping is associated with the work of Buzan (1974) and later with Novak and Gowin (1984). The latter work was based on the theories of David Ausubel, who stressed the importance of prior knowledge in being able to learn about new concepts. Novak concluded that meaningful learning involves the assimilation of new concepts and propositions into existing cognitive structures.

Concept mapping is a technique to represent knowledge in graphs. Knowledge graphs are networks of concepts. These networks consist of nodes (points/vertices) and links (arcs/edges). The nodes represent concepts and the links signify the relations between the concepts. Concept mapping allows you to understand the relationships between ideas by creating a visual map of the connections. The suggested structure was to place a key concept (or node) in the middle of a page and surround this with closely related concepts (or nodes) linked by lines and some words to make the connection. The process was repeated with each of the new nodes and so on until a "picture" of the knowledge and understanding structure was revealed.

Concept mapping can be done for several purposes:

- to generate ideas (brainstorming, etc.);
- to design a complex structure (long texts, hypermedia, large websites, etc.);
- to communicate complex ideas;
- to aid learning by explicitly integrating new and old knowledge;
- to assess understanding or diagnose misunderstanding.

Concept maps have a number of very practical applications for students. They are a handy way to take notes during lectures and are excellent aids for group brainstorming. They assist in planning the studies and also provide useful graphics for presentations and written assignments. They also help refine one's creative and critical thinking. Concept maps have been used in a range of learning processes such as planning, study, note-taking, revision, problem solving, and even for assessment.

Concept maps are apparently gaining in popularity as potential assessment tools (Pendley et al., 1994; Regis et al., 1996; Edmondson, 2000; Stoddart et al., 2000; Nicoll et al., 2001). Azevedo and Lando (2006) showed that concept maps proved to be an efficient tool that allowed the teacher to follow up the building of knowledge by the student, according to the idea of conceptual development and of concept formation from previous mental structures in the learner (Piaget, 1980). Their investigation showed that over a period of time there was an aggregation of new elements on all the later maps of all students. Both students with less previous knowledge (fewer representations on the initial map) and those with greater previous knowledge demonstrated an expansion on the final concept map, as well as progress concerning the interrelation of concepts, indicating a more complex level of conceptualisation.

Johnson and Otis (2006) investigated the possibility of using concept maps created by students as an assessment tool. However, their finding proved that there was no significant relationship between the quality (complexity) of the concept map and the students' assessment score. They observed that "poor" maps (those with few nodes, weak linkages and indistinct layering) were created both by students who did not have a good grasp of the scenarios and so their maps were sparse, ill-connected and unsatisfactory, and also by students who did not need a complex map, and for whom a simple, apparently "poor" map was quite sufficient to act as a "set of keys" to unlock their memory and reasoning store and activate a large body of knowledge and understanding. Moreover, some students delivered messy, ill-constructed, but node-rich maps which, in spite of the confusing way they appeared, served as a powerful tool for the constructor of the map. The authors concluded that a map is a very personal thing, idiosyncratically constructed for the sole benefit of the individual student. It is likely to be misconstrued by an outsider, by anyone trying to assess what appears on paper, and thus cannot be used as an assessment tool in measuring student knowledge.

In the present paper, we postulate that concept maps can still serve as a diagnostic tool for the assessment of student knowledge – but not maps designed by students in the process of learning. We suggest that the assessment of knowledge acquisition can be achieved by comparing concept maps created by teachers before and after delivering lectures to their students. For this purpose, the authors introduce the terms "ideal knowledge structure", "desired knowledge structure" and "real knowledge structure" as milestones in indicating the levels of acquired knowledge in secondary-school biochemistry.

"Ideal knowledge structure" (IKS) is a very detailed and very complex concept map containing all the knowledge on a certain topic currently known to the scientific world. Understandably, such maps can be created and used only by experts in the certain scientific field and have little or no relevance to secondary-school education.

"Desired knowledge structure" (DKS) is a less minute, but still a rather detailed concept map comprising all the relevant facts, ideas, concepts, and relations between items which are constructed on the basis of the official educational plans and programmes and contained in corresponding secondary-school textbooks. Students are expected to learn all this content in order to achieve the highest grade.

"Real knowledge structure" (RKS) is a concept map, more or less complex, constructed for the individual student. It shows the knowledge that the student possesses at a certain moment and it is drawn on the basis of the student's results, no matter which instrument was used in assessment (colloquium, test, etc.).

DKSs are usually constructed by teachers for their subjects or for topics within a subject. They can also be found in textbooks, where authors position them at the beginning of a chapter, as an overview of the content provided, or at the end of the chapter, as a reminder of the lessons covered.

RKS can be created both by teachers, in the process of evaluating students' performance, or even their own performance, and by students according to the teacher's instructions. They serve as useful tools for students to gain an objective insight into their quantum and quality of knowledge of a given topic.

Methodology

Aim of the work

The authors suggest that concept maps can be used to assess both teachers' and students' performance, and also the efficiency of the teaching methods applied in the educational process. The following working hypotheses were postulated:

1. Concept maps created after testing students on a certain topic correspond to their level of acquired knowledge.
2. Such concept maps can illustrate students' efforts and ability to learn biochemical content.
3. Real knowledge structures can indicate the level of the retention of knowledge.
4. Concept maps can illustrate the efficiency of the applied teaching method.
5. Through concept maps, teachers can evaluate their own performance and gain important feedback on their own work.

In order to validate these hypotheses, the following tasks had to be performed:

1. To create a concept map for the desirable knowledge structure (DKS) for the biochemical topic "Nucleic acids and biosynthesis of proteins".

2. To conduct a pedagogical experiment on the efficiency of two teaching methods – the frontal and the problem-based, computer-assisted method (using the software "Exper", created by the author):
   a) to conduct initial testing of fourth grade students in the "Laza Kostic" grammar school in Novi Sad (Serbia) in order to unify the experimental and control groups in relation to their previous knowledge of chemical and biochemical concepts;
   b) to conduct final testing to assess the students' acquisition of knowledge of the given topic;
   c) to conduct re-testing after a period of time, to assess the students' retention of knowledge.
3. To create and analyse CMs for each student on the basis of the previously designed DKS.

1. Desired knowledge structure

Thorough analysis of the educational programme and the textbook for grammar school biochemistry revealed that the following educational content should be included in the DKS:

A) Nucleic acids: composition of nucleic acids; structure, properties and functions of DNA; structure and function of RNA.

B) Biosynthesis of proteins: replication of DNA, inhibition of biosynthesis, mutations.

The educational content of chemistry in the fourth year of the grammar school comprises a total of 64 school hours (45 minutes). The topic "Nucleic acids" is studied during 4 classes. The content is distributed as follows:

1. Structural elements of DNA and RNA (2 hours);
2. Functions of nucleic acids (1 hour);
3. Biosynthesis of proteins (1 hour).

Since the structural units of nucleic acids are studied for the first time in the fourth grade, greater attention is given to this content in the programme and the textbook, while the content on the functions of nucleic acids and biosynthesis of proteins is studied to a lesser extent. The desired knowledge structure map was constructed according to the educational programme and the textbook, including all the positive and negative aspects of such content distribution (e.g. lack of data on the regulation of the process of protein biosynthesis, and the role and function of rRNA, which are only superficially mentioned in the textbook).

The following concept map was constructed for the desired knowledge structure for the given topic (Figure 1), containing all the concepts and relationships which the students are supposed to learn:

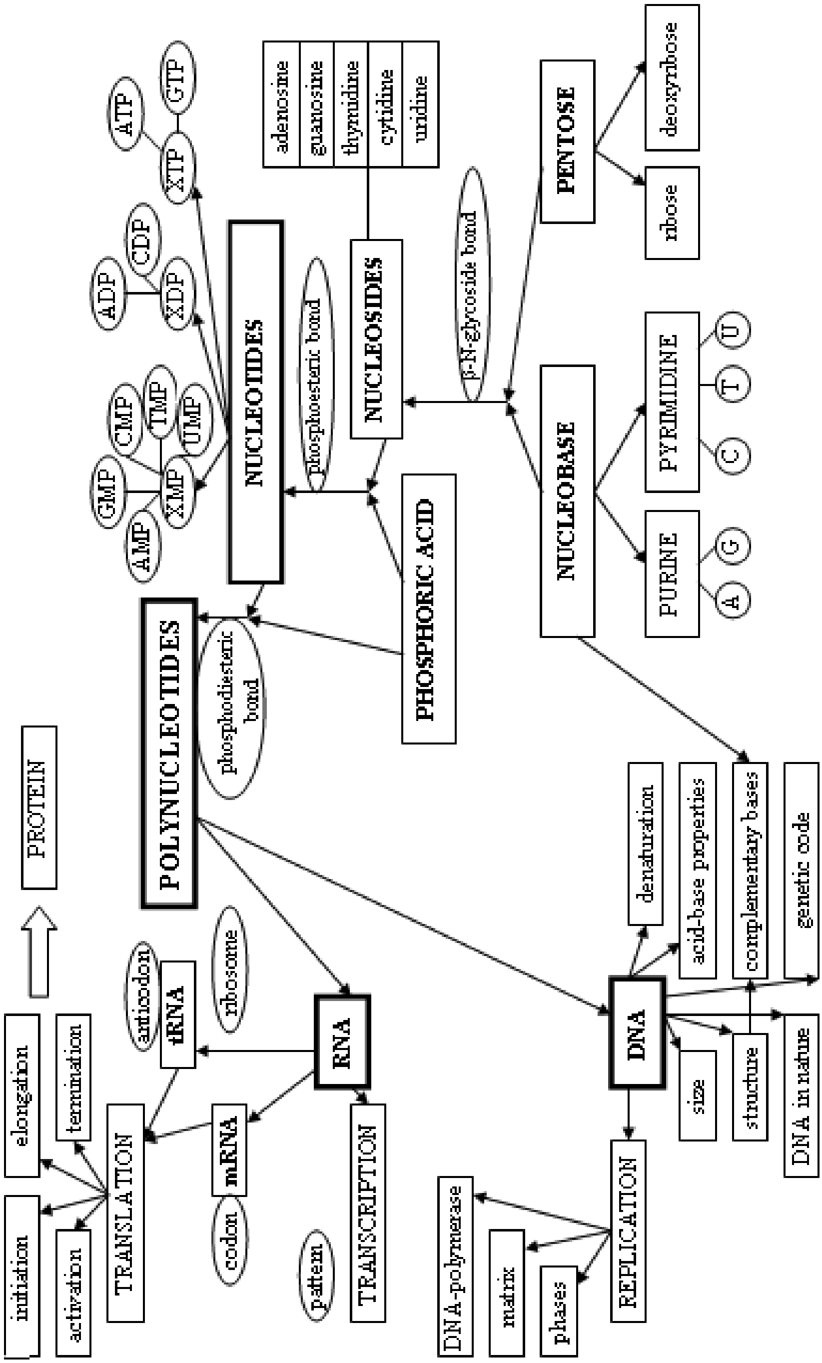


Figure 1. Concept map of the desired knowledge structure for the topic "Nucleic acids and biosynthesis of proteins"

All other concept maps for individual students were created with reference to this DKS.

2. Pedagogical experiment

The experiment was conducted in 2003/2004 in the "Laza Kostic" Grammar School in Novi Sad (Vojvodina, Serbia), with fourth grade students who studies cover biochemical educational content. The sample chosen was a group sample with two parallel groups (two classes to which students were randomly assigned for administrative purposes). The first group acted as a control group (C), and the second as an experimental group (E). The groups were unified with regard to previous chemical and biochemical knowledge by initial testing, which was conducted a month prior to the experimental teaching. Problems in the initial test differed in the measured levels of knowledge, and were constructed according to Bloom's taxonomy. The statistical parameters of the initial testing are given in Table 1.

Table 1. Basic statistical parameters of the initial testing

	C	**E**
Number of students (N)	35	30
Arithmetic mean (M)	11.76	12.97
Standard deviation (σ)	4.12	3.54
Standard error of arithmetic mean (σ_M)	0.70	0.65
t-test (significant value = 2.00)	1.26	

Testing of the significance of the difference of the arithmetic mean indicates that these two groups were unified at a significance level of 95%.

Experimental teaching was conducted in two classes. The control group was taught in the traditional way, using the verbal and frontal method. Students in the experimental group studied by themselves, at their homes, using the author-created software "Exper", created according to the principle of problem-based learning. The software is available from the authors in electronic form. After this experiment was completed, all students were informed of the time of the final testing.

The final test was an informal test constructed with the aim of measuring the quantum and quality of knowledge. It consisted of fourteen problems comprising all important concepts in the investigated topic of nucleic acids and biosynthesis of proteins, and was based on the desired knowledge structure, shown in Figure 1. The final test was also used to investigate knowledge retention, which was conducted two months after the experimental teaching.

3. Analysis of concept maps

After the final testing and retesting, concept maps were drawn for each student. They were analysed in comparison with the DKS. Some CMs were chosen to be presented in this paper in a semi-random fashion. Distribution curves were created for the scores achieved by the experimental and control groups. The scores were divided into three subgroups – students with low, average and high scores, and one representative was randomly chosen from each subgroup.

Results and Discussion

Our results show that concept maps can provide important visual feedback to teachers on both the students' performance and their own performance, and also on the efficiency of the teaching methods they apply in the educational process.

1. Application of concept maps in assessing students' level of knowledge acquisition

a) Evaluating students' knowledge

Real concept maps are a good indicator of the students' achievement. Figures 2.a, 2.b, and 2.c were drawn for the three representatives from the same class, and each was randomly chosen from the subgroups of students with low, average and high scores.

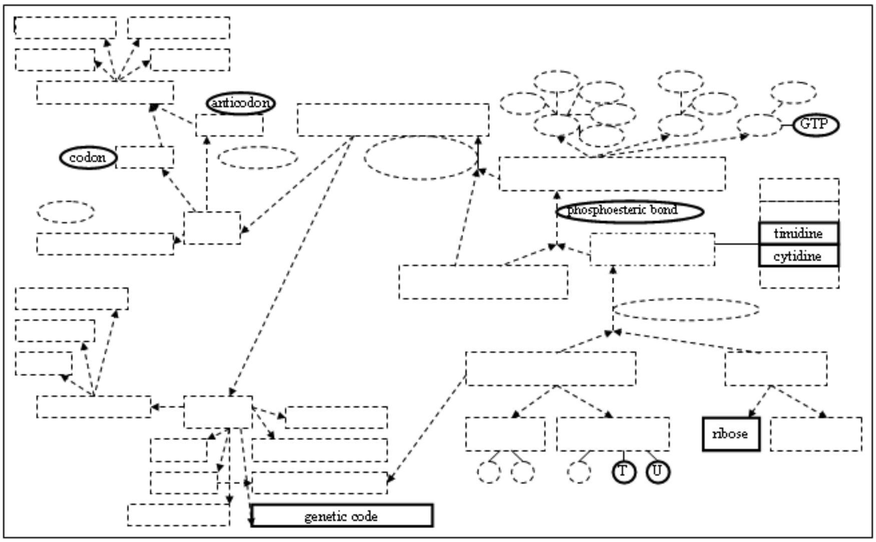


Figure 2.a. Real knowledge structure of student C1

As expected, there is a significant difference in the complexity of maps drawn according to the results of the test between students with different scores, which is in accordance with the number of points they achieved. However, the CM can help teachers not only to grade students, but also to immediately see which content presents a problem.

The concept map shown in Fig. 2.a corresponds to a student with a very low score (7.5 points). It is very simple, containing only a few isolated items, “islands”, with no relationship between them. This indicates that this student has hardly any knowledge of the educational content.

Fig. 2.b represents the result of a student from the group with average scores (34.5 points). This is a more complex map, containing approximately half of the required items. It is obvious from the CM that this student has a certain knowledge of the basic facts, but did not acquire any knowledge of the more complex structures of nucleosides. In addition, this student has no knowledge of the linkage of nucleotide constituents, the relationship between the DNA and RNA structure, and the process of protein biosynthesis.

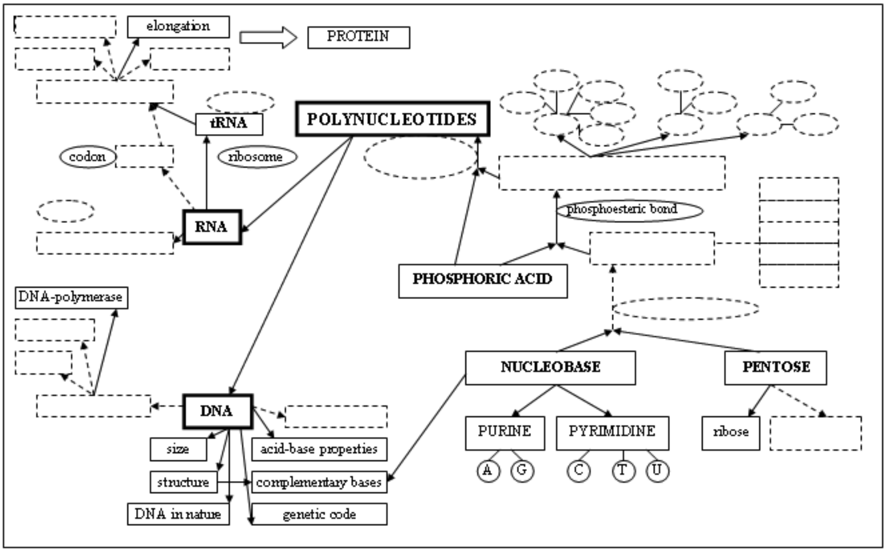


Figure 2.b. Real knowledge structure of student C2

Fig. 2.c is a CM which corresponds to students with the highest score in his class (73 points). This map contains far more items; however, this student still has an incomplete knowledge of some basic constituents of nucleic acids and very sparse knowledge of the chemical bonds between them. He is familiar with the biochemical process of protein biosynthesis, but some mechanisms remain unknown.

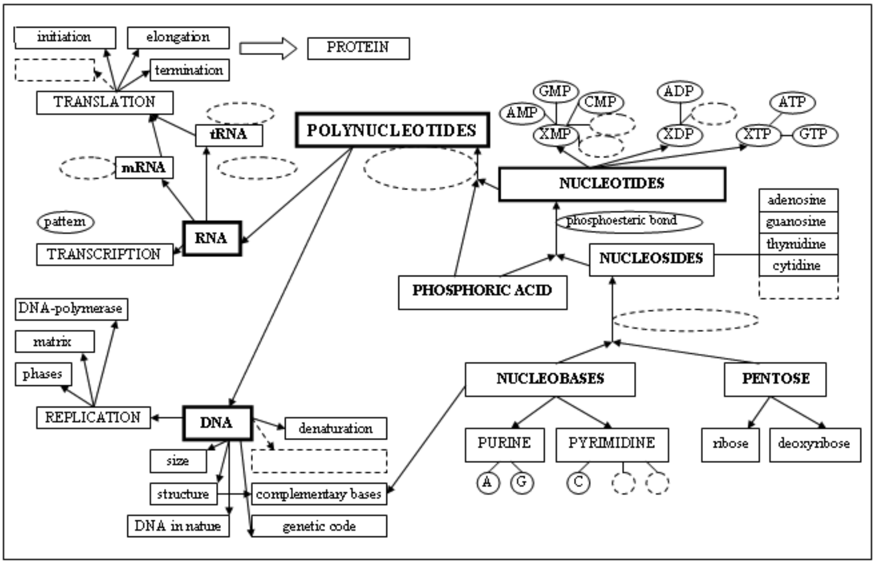


Figure 2.c. Real knowledge structure of student C3

b) Diagnosis of student performance

Concept maps can be used in the diagnostics of a student's capability to grasp abstract concepts, and also of the effort he or she has put into understanding the educational content. The following three figures (Figs. 3.a, 3.b, and 3.c) represent the results of three randomly chosen students with similar

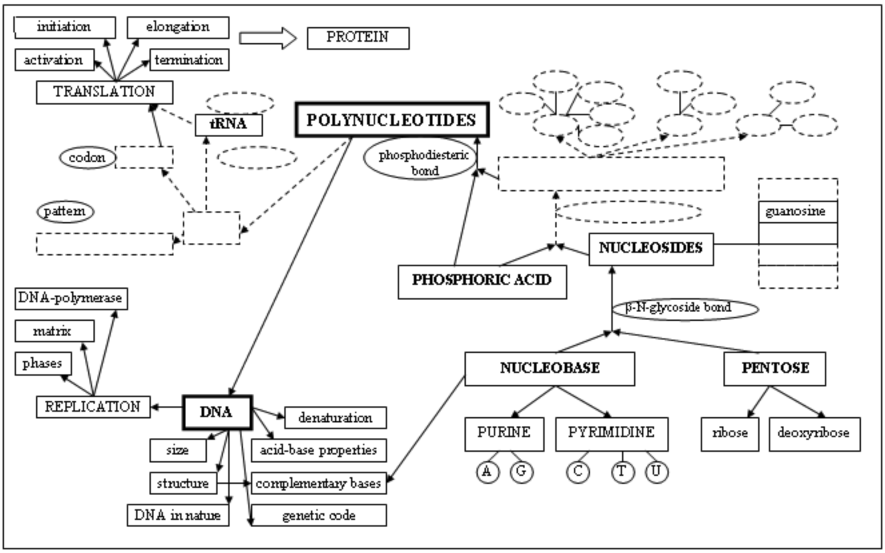


Figure 3.a. Real knowledge structure of student E1

scores (60, 62.5, 62.5, respectively). Although the points are practically equal, the corresponding knowledge structures differ significantly.

Fig. 3.a shows the real knowledge structure of a student who has obviously put a lot of effort into studying all the content from the given topic. However, some content of a more complex nature is still missing, thus indicating that this student has trouble understanding higher chemical structures and some complex processes that occur in a nucleus.

Fig. 3.b represents a concept map of a student who has obviously only superficially studied the educational material. There are gaps in his knowledge structure which relate both to facts and definitions, and to more complex structures and processes. The student can recognise and write some structures of nucleosides and nucleotides, but not all; he knows some facts about DNA, and some parts of the biochemical pathways. This map indicates a student who understands biochemical concepts, but has not put in enough effort to learn the given material.

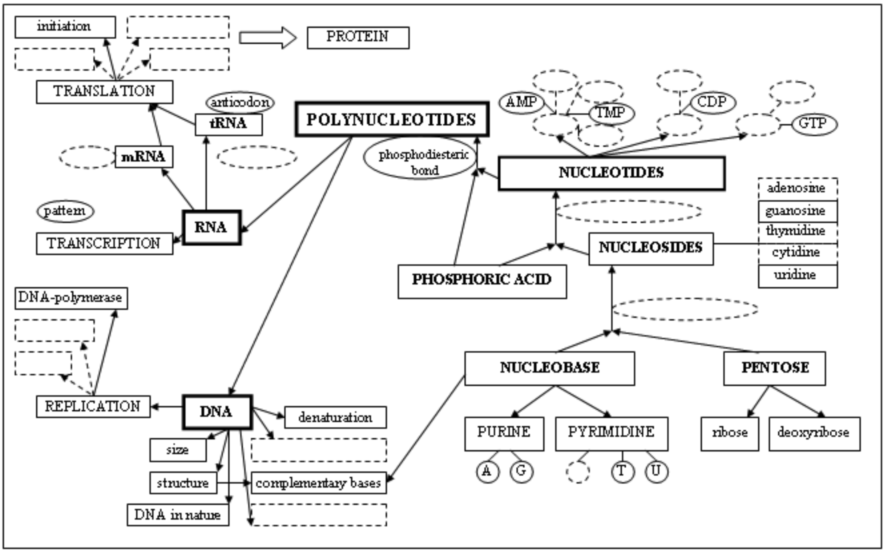


Figure 3.b. Real knowledge structure of student E2

Fig. 3.c is a CM which corresponds to a student who studied only part of the educational material. The right-hand side of the map contains information on basic constituents of the nucleosides and nucleotides, and this student shows an excellent knowledge of these facts and concepts. The following content (structure and role of DNA) has many gaps, and this student practically does not have any knowledge of the role of RNA and the process of DNA replication. Such a CM may indicate a student who understands concepts and

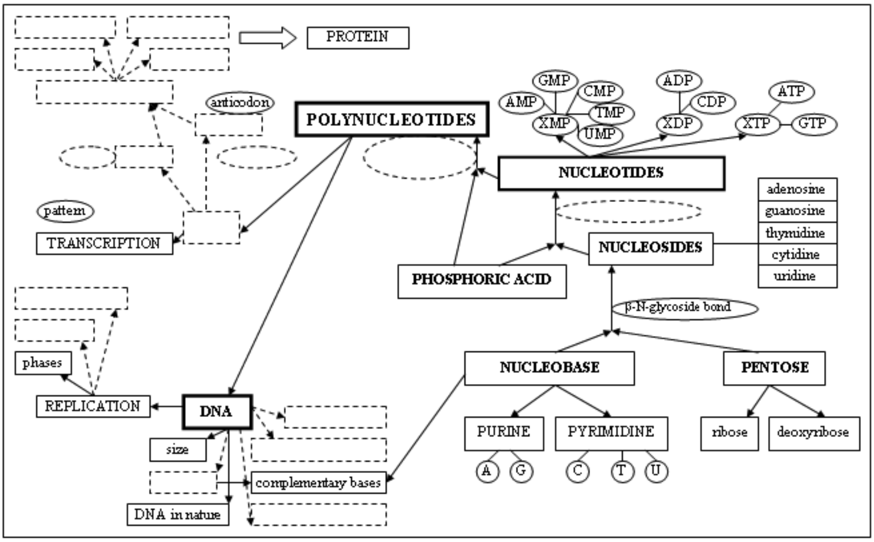


Figure 3.c. Real knowledge structure of student E3

structures, both simple and complex, but has, at a certain point, given up learning (other obligations and lack of time can be some plausible explanations).

Concept maps representing real knowledge structures can be used by teachers to determine which students are capable of induction and deduction and of understanding abstract concepts, and which students have trouble in learning such concepts; the maps can also help them identify "the lazy ones", and deal with them accordingly (e.g. give them extra assignments in order to make up for what they have previously only skimmed over).

These findings show that the first working hypothesis (*The concept maps created after the testing of students on a certain topic correspond to their level of acquisition of knowledge)* and the second working hypothesis *(Such concept maps can illustrate the student's efforts and ability to learn biochemical content*) proved to be correct.

2. Application of concept maps in assessing the student's level of knowledge retention

Figures 4.a and 4.b represent concept maps constructed for the same student – results of testing immediately after studying the given educational material, and later – after retesting the same content. This student scored 73 points in final testing, and 52 points in retesting.

These two maps show that after two months this student had forgotten certain chemical structures and that he was unable either to recognise and name the structural formulae, or to draw them himself. Some knowledge remained the same (knowledge of the facts on DNA, or the lack of knowledge on β-N-

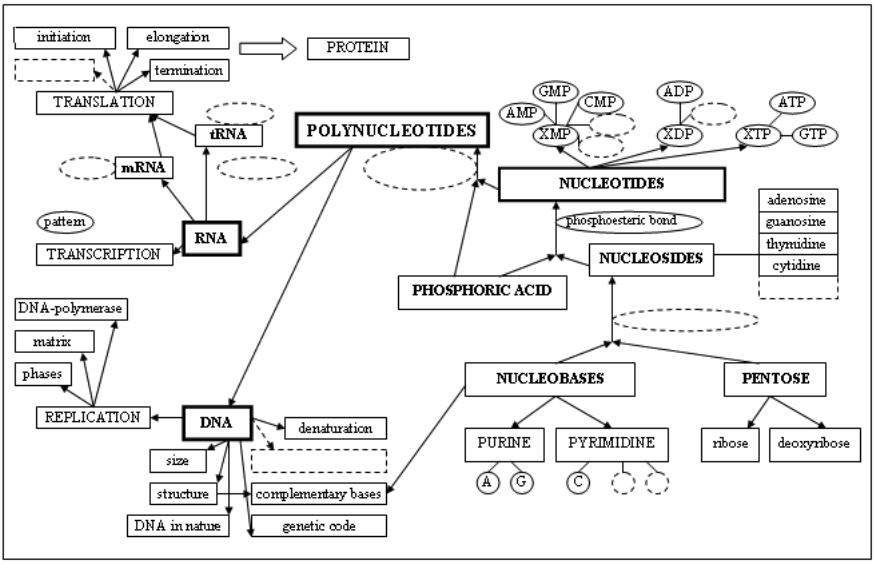


Figure 4.a. Real knowledge structure of student E4 after testing

glycoside and phosphodiesteric bonds), and there were gaps in the knowledge of certain phases of the biochemical processes of replication and translation. An analysis of the real knowledge structures for all other students after testing and retesting (not shown here for the sake of space) shows a similar pattern of remembering/forgetting the same facts and concepts.

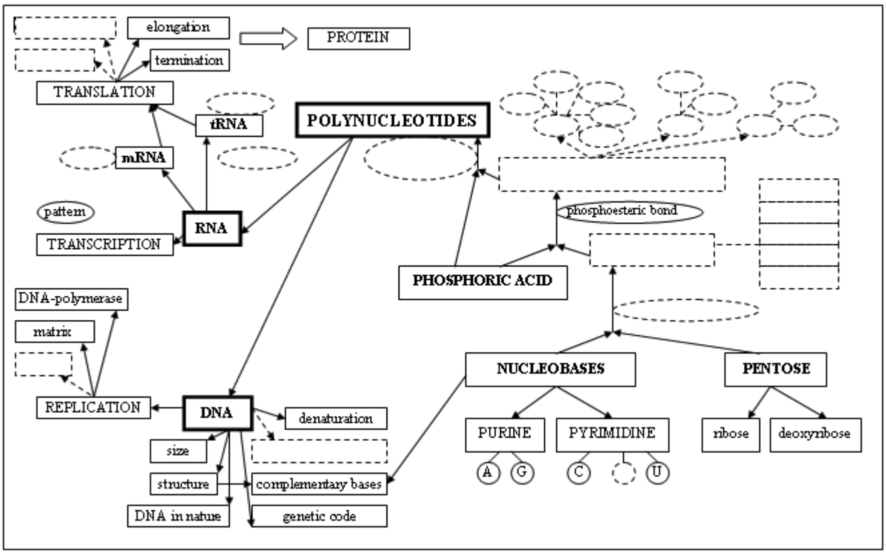


Figure 4.b. Real knowledge structure of student E4 after retesting

This example indicates that concept maps can be a powerful tool for teachers in identifying educational content which is more easily forgotten by their students, so that they can adjust their lesson plans and insist more on these facts and concepts during lessons.

These findings show that the third working hypothesis (*Real knowledge structures can indicate the level of retention of knowledge*) proved to be correct.

3. Application of concept maps in assessing the efficiency of new educational methods

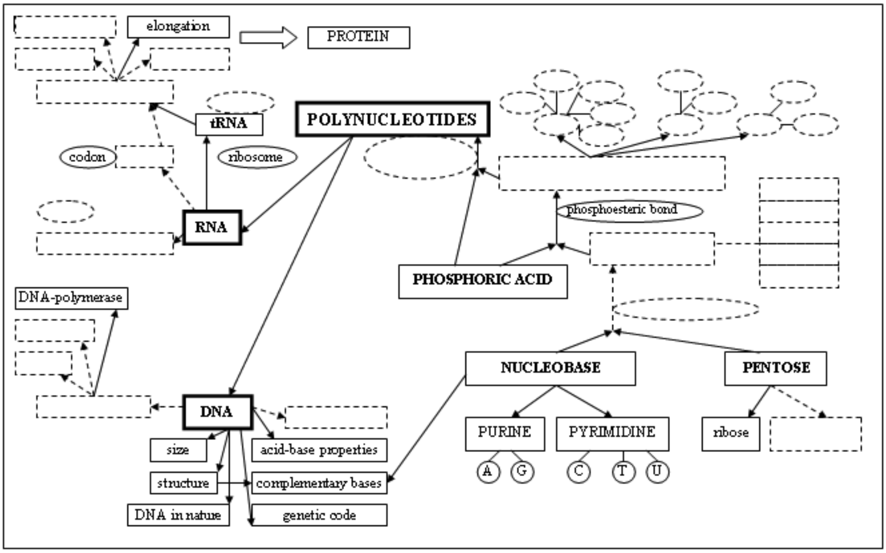
Figures 5.a, 5.b, 6.a and 6.b represent the real knowledge structures of students from two different classes who have been taught using different educational methods. The first two students were randomly chosen from the groups of students with average scores from the control class – the class which was taught using the traditional frontal, monologue and dialogue method (5.a), and from the experimental class which studied individually, using the author-created problem-based software for the topic "Nucleic acids" (5.b). The second two maps represent the results of two students randomly chosen from the subgroups of high achievers from the control (6.a) and the experimental group (6.b).

From Figure 5.a it can be observed that there are serious gaps in the knowledge structure of this average student (who achieved 34.5 points in the final test). These gaps include:

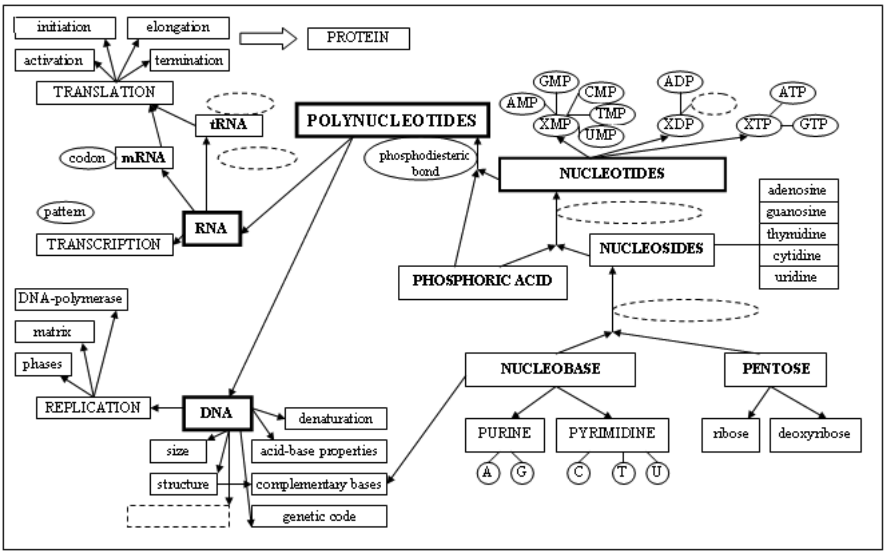
- basic facts and structures (this student has practically no knowledge of nucleosides and nucleotides and the chemical bond which links their basic constituents);
- some chemical properties of DNA;
- complete ignorance of the processes of replication, transcription and translation (both facts and abstract concepts).

Figure 5.b represents the knowledge structure of the student with a score of 83.5 points, which puts him in the middle portion of his class – students with average scores. His knowledge structure comprises many more items, lacking knowledge only of chemical bonding in nucleosides and nucleotides, finding DNA in nature and some steps in the transport of genetic information.

Similar results are observed for top-scorers from both classes (Figure 6). The student chosen from the top-third of the results from the control class scored 73 points. This student was taught frontally, and though his score is one of the best of his class, there are still gaps observed in his real knowledge structure, related to some basic constituents (nucleobases) and bonds in nucleosides and polynucleotides, as well as to the chemical (acid-base) properties of DNA, the concepts of codon and anticodon, and one phase of translation in the protein biosynthesis.

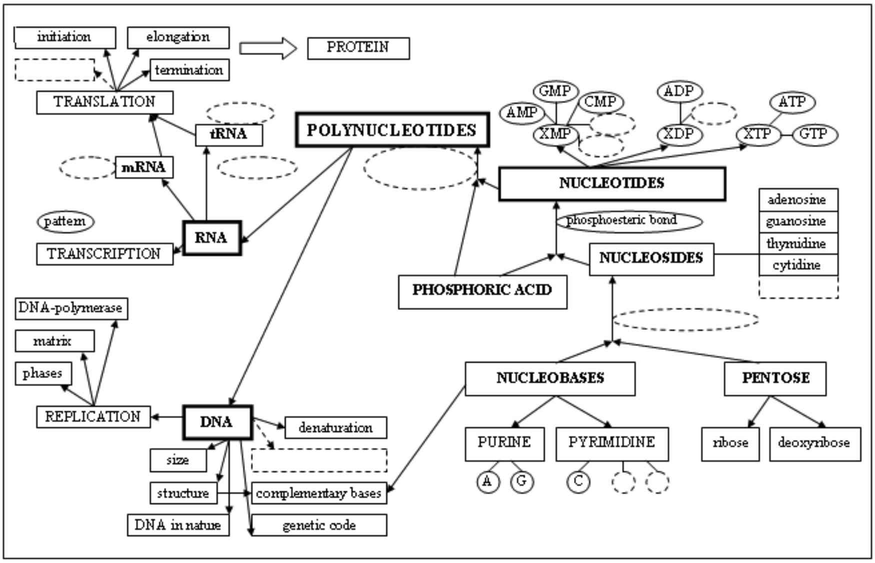


(a)

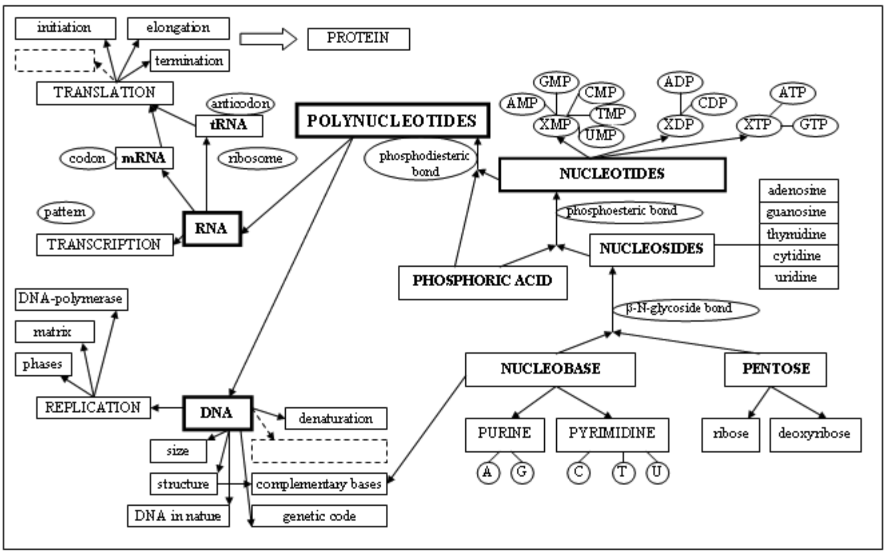


(b)

Figure 5. Real knowledge structure of average scorers taught
(a) using the traditional frontal method (control class);
(b) using problem-based, computer-assisted learning (experimental class)



(a)



(b)

Figure 6. Real knowledge structure of top scorers taught
(a) using the traditional frontal method (control class);
(b) using problem-based, computer-assisted learning (experimental class)

The high-scorer from the experimental class had an excellent score – 97 points, and the concept map which corresponds to his knowledge structure is practically identical to the desired knowledge structure.

These examples show how, simply by comparing and analysing the concept maps of the students' real knowledge structures, the most efficient teaching method can be identified. These findings are in accordance with the analysis of the statistical parameters of the testing results in both the experimental and control classes (Table 1).

Table 2. Statistical parameters of the final testing

	C	E
Number of students (N)	35	30
Arithmetic mean (M)	32.55	91.54
Standard deviation (σ)	17.97	8.09
Standard error of arithmetic mean (σ_M)	3.23	1.39
t-test (significant value = 2.00)	16.76	

The arithmetic mean in the experimental group is almost three times larger than the average score in the control group, which is also clear from the RKC in the above-given examples and the number of items found in the CMs. The value of the t-test of 16.76 indicates that a statistically significant difference exists between the experimental and control groups in the efficiency of the applied teaching methods.

These findings show that the fourth working hypothesis (*Concept maps can illustrate the efficiency of the applied teaching method*) therefore proved to be correct.

4. Application of concept maps in assessing the teacher's performance

An analysis of all the concept maps reveals certain weaknesses and gaps which consistently appear in all the real knowledge structures of almost all the students in both experimental and control groups. These topics include:

- chemical bonds between the constituents of nucleotides (the β-N-glycoside bond, phosphoesteric and phosphodiesteric bonds);
- concepts of the codon and anticodon relation to the RNA role;
- phases of translation in the process of DNA replication.

These gaps appear in the CMs directly due to the teachers' performance. Since the same experimenter conducted the frontal teaching and created the applied software, it is clear that the teacher did not dedicate enough time and effort to these topics. Thus, concept maps of RKS can serve as a valuable instrument for teachers to evaluate their own work and to gain feedback on the students' achievements in a certain topic.

These findings show that the fifth working hypothesis (*Through concept maps, teachers can evaluate their own performance and gain important feedback on their own work*) proved to be correct.

Acknowledgements

The research presented in this paper was supported by the Ministry of Science and Environmental Protection of the Republic of Serbia (Project No. 140009).

REFERENCES

Ausubel, D. (1968). Educational psychology: A cognitive view. New York: Holt, Rinehart, and Winston.

Azevedo, A.M., Lando, V.R. (2006). Concept Maps as a Strategy to Assess Learning in Biochemistry Using Virtual Dynamic Metabolic Diagrams (Dmdv). Concept Maps: Theory, Methodology, Technology Proc. of the Second Int. Conference on Concept Mapping. A. J. Cañas, J. D. Novak, Eds. San José, Costa Rica.

Buzan, T. (1974). Use your head. London: BBC Books.

Edmondson, K.M. (2000). Assessing science understanding through concept maps. In: Mintzes J.J., Wandersee J.H. and Novak J.D., Assessing science understanding: a human constructivist view. San Diego: Academic Press.

Johnstone, A.H., Otis, K.H. (2006). Concept mapping in problem based learning: a cautionary tale. Chemistry Education Research and Practice, 7 (2), 84-95.

Nicoll, G., Francisco, J. S. & Nakhleh, M. (2001). An Investigation of the Value of Using Concept Maps in General Chemistry. Journal of Chemical Education, 78(8), 1111-1117.

Novak, J. D., & Gowin, D. B. (1984). Learning how to learn. New York and Cambridge, UK: Cambridge University Press.

Pendley, B. D., Bretz, R. L. & Novak, J. D. (1994). Concept Maps as a Tool to Assess Learning in Chemistry. Journal of Chemical Education, 71(1), 9-15.

Piaget, J. (1980). Adaptation and Intelligence. London: University of Chicago Press.

Regis, A, Albertazzi, P. G, and Roletto, E. (1996). Concept Maps in Chemistry Education. *Journal of Chemical Education*, 73, 1084-1088.

Stoddart T., Abrams R., Gasper E. and Canaday D. (2000). Concept maps as assessment in science inquiry learning – a report of methodology. *International Journal of Science Education,* 22, 1221-1246.

KONCEPTNE MAPE KAO DIJAGNOSTIČKO SREDSTVO U PROCJENI USVAJANJA I RETENCIJE ZNANJA U BIOHEMIJI

Jasna Adamov, Mirjana Segedinac, Stanko Cvjetičanin

Sažetak – *U ovom radu prikazana je mogućnost primjene konceptnih mapa kao dijagnostičkog sredstva u procjeni učeničkog znanja. Autori uvode nove termine: „idealna struktura znanja", „poželjna struktura znanja" i „realna struktura znanja" kao pokazatelje nivoa usvojenosti znanja. Uloga konceptnih mapa kao dijagnostičkog sredstva testirana je u oblasti gimnazijske nastave biokemije. U pedagoškom eksperimentu sudjelovali su gimnazijalci iz Novog Sada (Srbija). Ispitivano je njihovo poznavanje nastavnih sadržaja iz dvije nastavne teme (nukleinske kiseline i biosinteza proteina). Kreirane su konceptne mape realne strukture znanja za svakog učenika nakon finalnog testa i testa retencije znanja. Usporedbom mapa poželjne i realnih struktura znanja ustanovljene su moguće primjene konceptnih mapa: u određivanju nivoa usvojenosti znanja; u ocjeni uloženog truda i sposobnosti učenika da usvoji biokemijske sadržaje; kao indikatora nivoa retencije znanja; kao mjere efikasnosti primijenjene nastavne metode. Radom s konceptnim mapama nastavnici mogu ocijeniti svoje rezultate i steći uvid u vlastiti rad.*

Ključne riječi: *biokemija, konceptne mape, struktura znanja, sposobnost za učenje, retencija znanja*