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Cognitive Load at Different Levels of Chemistry Representations

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Abstract

The purpose of this study was to examine students' achievements and cognitive loads at different levels of chemistry representations. The research was carried out among students majoring in chemistry teaching. A test was used as a measuring instrument for knowledge evaluation. Each task contained three subtasks, in macroscopic, sub-microscopic and symbolic domain. Each subtask in the test was followed by a seven point Likert scale (ranging from 'extremely easy' to 'extremely difficult') for the evaluation of cognitive load. A parallel analysis of the obtained results has shown that students' evaluations of cognitive load are in accordance with the accomplishments achieved on the test. Students have estimated that the greatest cognitive load corresponds to sub-microscopic level, which resulted in the lowest achievements. The results have also shown that there are no major differences in the average students' achievements in macroscopic and symbolic level, which are also in line with the evaluated cognitive load. Hence, it can be concluded that the students are able to review the cognitive processes and to evaluate the difficulty of the task.

Key words: *chemical concepts; cognitive load; evaluation; triplet relationship.*

Introduction

Chemistry Representations

Chemical substances can be portrayed at several levels which are usually known as – *macroscopic, sub-microscopic and symbolic*. They are linked and all together contribute to the meaningful learning and understanding (Devetak et al., 2009; Johnstone, 1982; Johnstone, 2000; Raviolo, 2001; Treagust et al., 2003; Tsaparlis, 1997). The macroscopic level commonly refers to the properties of chemical substances and processes that can be experienced with the senses such as: colour, smell, physical state or colour change, precipitate formation, release of gas. According to some authors (Gilbert & Treagust, 2009; Nakhleh & Krajcik, 1994), it also includes perceptible properties that can be measured, such as: temperature, mass, density, etc. The sub-microscopic level can be described by the idea of the particulate nature of matter, i.e. it refers to the structure of atoms, molecules, ions or electron movements. According to Gilbert & Treagust (2009) this level of representation provides the explanations of the phenomena experienced with the senses. The symbolic level includes representations that enable more effective explanations of phenomena at the macroscopic and sub-microscopic level. Symbolic representations of chemical concepts include: chemical symbols, chemical formulas, chemical equations, reaction mechanisms, Newman and Fischer projections, Lewis structures, graphs, etc. (Gkitzia et al., 2011). A variety of symbolic representations, models and dynamic audiovisual representations enable students to get closer to the abstract but essential knowledge of the substance structure. Talanquer has recently pointed out the ambiguities in terminology and interpretations of the triplet relationship and highlighted the issue of the various visual representations (Talanquer, 2011). Namely, if they are regarded as signs, we might say they belong to the symbolic level. However, if they are regarded as models which have a descriptive or explanatory role, we might say they belong to the sub-microscopic level. Therefore, it is worth mentioning that in this research sub-microscopic level has been regarded as the level of theoretical models and ideas about what the world might look like at the level of particles. Iconic representations have not been used in this research.

Studies have shown that students of all ages and even some teachers have the problem in transferring knowledge from one level to another (Boo, 1998; Gabel, 1998). Also, numerous reports in the field of science education found that students do not understand the essence of chemical terms. The concept of particulate nature of matter, which is essential for learning and understanding of chemistry, is stated as a possible cause (Adadan et al., 2009; Ozmen, 2011). In the papers written by Adadan et al. (2009), Devetak et al. (2009) and Ozmen (2004; 2011) it was pointed out that students tend to form misconceptions and alternative concepts, which could be explained by the competition of the theoretical context of the particulate nature of matter with the observations that students make in their everyday lives. As understanding the matter at the sub-microscopic level requires the understanding of its particulate nature, this step is the hardest one for students and that is the reason why students very often transfer visible macroscopic properties of a substance to its sub-microscopic particles. Namely, research findings continuously report that students tend to attribute visible properties such as: colour, smell, shape, physical state or hardness to atoms and molecules, *videlicet*, that students expect sub-microscopic particles to act like tiny copies of the observable macroscopic system (Rappoport & Ashkenazi, 2008). Many students believe that molecules of water can be hot and cold, that they are spherical, or that they can have several different forms within a system, as well as that naphthalene molecules smell (cited in Adadan, 2006) or that sulphur atoms are yellow (cited in Chittleborough, 2004). Many students choose the apparently easier way by staying at the level of perception, while the only way to create logical connections and develop chemical thinking is the sub-microscopic way. Chittleborough et al. (2002) report that students are able to connect macroscopic properties with the symbolic level as an outcome of their laboratory experience, but still a majority of them fail to comprehend the sub-microscopic reality.

Bunce and Gabel (2002) carried out a survey in order to investigate whether teaching with sub-microscopic representations leads to better achievements in the three selected topics. Research was conducted with two groups – experimental and control. The control group was taught using only two levels of representations (macroscopic and symbolic) while the experimental was taught using all three levels (macroscopic, sub-microscopic and symbolic). The results showed significant improvement in students' achievements in favour of the experimental group. Hence, it is important that teachers during instruction do not avoid the sub-microscopic level. On the contrary, it should be emphasized more and, more importantly, it should be combined with the macroscopic and symbolic levels since qualitative teaching and meaningful learning require constant interplaying among these three levels.

Cognitive Approach to Learning

The cognitive orientation began to revolutionize psychology in the late 1950s and 1960s with the works of Miller (1956) and Neisser (1967), and along with the empirical studies a number of theories and models have been developed. Cognitive theories of learning and intellectual development have enriched psychology with new ideas: how to acquire knowledge and skills and how to form the already existing knowledge. According to this orientation, learning is regarded as an active and constructive process directed towards a certain goal. Although cognitive psychology does not dispute traditional principles of learning, it sets new principles for more complex forms which include deep understanding of the relationships among the abundant and diverse information.

The cognitive load theory is a concept that reflects the relationship between the structure of information and cognitive characteristics of students. According to this theory, human beings are limited in the amount of information that can be processed simultaneously (Chandler & Sweller, 1991). Human cognitive architecture enables the inter-reactions of single elements which are comprised of a singular piece of information in a variety of ways. The information present in human memory varies in a continuum from low to high interactivity. Each element of low interactivity can be learned and understood individually, without considering other elements. The elements of high interactivity can be learned individually, but cannot be understood until all inter-reacting elements are processed simultaneously. As a result, elements of high interactivity are difficult to understand (Sweller et al., 1998). Each teaching material imposes certain cognitive load, which, according to Sweller (2010), can be divided into three categories – intrinsic, extraneous and germane cognitive load.

The most obvious cognitive load is the one which we clearly experience when learning complex materials. As a result of the cognitive activity, there is a modification of the existing or creation of new cognitive structures in the long-term memory. This load is called the intrinsic cognitive load, because it is caused solely by the degree of complexity of the task, or materials being processed (Kalyuga, 2009).

The volume of the cognitive load is determined by the degree of interactivity between the individual task elements and elements of the existing base of knowledge in a long-term memory. Each individual is characterized by its own base of knowledge in a long-term memory. Depending on the acquired schemes, materials that are very complex for one individual may be very simple for the other (Sweller, 2010). When the elements of the task are being processed simultaneously or when the content has a high degree of interactivity among elements, high cognitive load will be imposed, even when the number of inter-reacting elements is relatively small. As the intrinsic cognitive load is essential for the achievement of specific learning goals (understanding of the problem, construction of higher structures of knowledge and their flexibility), it must be within the capacity of working memory.

Contrary to the intrinsic cognitive load, which is imposed by the intrinsic nature of information that should be adopted, the extraneous cognitive load is imposed by the manner in which the information has been presented during instruction (Sweller et al., 2011). It means that the extraneous cognitive load is caused by cognitive activities that originate from external factors such as the form of multimedia presentation, order of the tasks set or design of the teaching situation. For instance, when the related text, graphics or audio elements are separated in time or space, their integration will require intensive processes of searching and revoking of certain elements during the processing of others. Such processes can significantly increase the load of working memory.

The third source of cognitive load is the so-called germane load, which is different from the other two due to its positive attitude towards learning because it occurs as a result of direction of cognitive resources towards automation and adoption of the schemes rather than other mental activities (Moreno & Park, 2010).

According to Kalyuga (2009), germane cognitive load is caused by various cognitive activities that lead to the increment of the cognitive load, but at the same time they improve the process of learning and increase students' motivation (except in cases where the total cognitive load exceeds the capacity of working memory).

Approaches to measuring the cognitive load could be divided into categories along two dimensions, objectivity (subjective or objective) and causal relation (direct or indirect). The objectivity dimension classifies the measuring approach according to the applied method (self-reported data, observations of behavior, physiological conditions, performance) while the casual relation classification is based on the type of relation of the phenomenon observed by the measure and the actual attribute of interest. Consequently, there are: direct objective methods which include techniques such as: dual-task methodology, eye tracking techniques and brain activity measures; indirect objective measures which are related to physiological factors such as: cardio-vascular indicators, EEG, linguistic indicators and interaction measures; direct subjective measures which refer to the self-reported stress level and indirect subjective measures which refer to the self-reported mental effort (Brünken et al., 2003; Kalyuga, 2009). While some authors give priority to the objective measurements (Brünken et al., 2003), others believe that the subjective measurements are sufficiently reliable and have high correlation with the objective measurements (Eggemeier, 1998). Furthermore, contrary to the objective approaches, the subjective approaches are simpler and more practical. In the subjective assessments of cognitive load the rating scales which measure the perceived cognitive load are commonly used. They are based on the assumption that the learners can reliably and validly evaluate the amount of the cognitive load they are faced with in the particular situation (Brünken et al., 2010; Kalyuga et al., 1999; Pass & Merriënboer, 1994).

In order to achieve effective learning, it is necessary for the total sum of the three types of cognitive load to be within the limits of the working memory capacity, therefore, the factors that reduce cognitive load are of a fundamental importance for the processes of learning and understanding. Multiple representations have recently become of a great interest for researchers due to their significance for meaningful learning (Ainsworth, 2006; Bodemer & Faust, 2006; Meij & Jong, 2003; Seufert, 2003). According to Seufert & Brünken (2006), learning with multiple representations is a highly demanding cognitive process, because the acquisition of knowledge from multiple representations requires the creation of suitable links among the corresponding elements in different representations, but despite that fact, their usage leads to a deeper understanding of the subject matter.

Purpose and Goals of the Research

Studies have shown that students and even some teachers who are expected to help students adopt chemical concepts have difficulties in understanding them at different levels of knowledge representations. In particular, difficulties arise in the transition from one level to another, as the learner has to process a large number of elements at the same time, creating additional mental effort and high cognitive load (Boo, 1998; Gabel, 1998). Hence, we conducted a study among students majoring in chemistry teaching in order to examine their achievements and cognitive loads in macroscopic, sub-microscopic and symbolic levels of chemistry representations.

In this study, we have measured achievements and the perceived cognitive loads of the task at macroscopic, sub-microscopic and symbolic levels respectively in order to determine whether there is a significant difference among the levels. Besides, this work is intended to provide us with an insight into how much each of the individual levels of representation is loaded in order to continue working on the optimization of the learning process by using chemistry triplet relationship.

The research hypotheses prior to the investigation were formulated as the null hypotheses in the following manner:

- There is no statistically significant difference in students' achievements at different levels of representation of knowledge in chemistry.
- There is no significant difference in assessments of the perceived cognitive load at different levels of representation of knowledge in chemistry.

Methodology

Participants

Forty-three students majoring in chemistry teaching at the Faculty of Sciences, University of Novi Sad participated in the study. It is worth noting that all participants had passed courses in general chemistry, Inorganic Chemistry and Organic Chemistry I, while twenty-six of them (60.47 %) had passed the course in Organic Chemistry II. All students who participated in the study had attended courses (such as Chemical Bonding and Molecular Structure and higher courses of Organic Chemistry) the contents of which largely require the creation of mental theoretical models, as well as the course Methodology of Chemistry Teaching, where they had become familiar with the term *triplet relationship*.

Measures

A test of twenty tasks was used to measure achievement. It consisted of twelve tasks in the field of general and inorganic chemistry and eight tasks in the field of organic chemistry. Each task contained three subtasks, one in the macroscopic, one in the sub-microscopic and one in the symbolic domain.

To measure cognitive load, each subtask was followed by seven-point Likert scale that required the respondents to rate items ranging from "extremely easy" (1) to "extremely difficult" (7). The highest possible score on the test was 60 points, i.e. 20 points for each level.

The test was characterized by pre-test and post-test quality assurance parameters according to the model described in Segedinac et al. (2011). The pre-test was evaluated by the expert group, which consisted of two research assistants and two university professors specialized in Methodology of Chemistry Teaching. Based on the diversity of tasks, the terminology used, sentence lengths and meaningfulness of the tasks requirements, the evaluators had estimated that the test was valid. Namely, the evaluators have estimated that the used terminology was suitable for chemistry students and that the sentences were of appropriate length, thus providing the clarity. Experts agreed that the test questions were diverse as the test included the textual, graphic, tabular and combined type questions. Also, the evaluators had confirmed that the task requirements were meaningful and clear.

The post-test quality assurance parameters were provided by the statistical analysis of the test results. In addition to the basic statistical parameters, reliability of achievements and cognitive load calculated as *Cronbach's* alpha, were computed. Further statistical analysis of the tests results comprised one-way analysis of variance (ANOVA), as we had analysed three variables – achievements and cognitive load at the macroscopic, sub-microscopic and symbolic level, respectively.

Test results were statistically analysed by the software packages STATGRAPHICS Centurion XV and IBM SPSS Statistics 19.

Results and Discussion

Descriptive statistics for the measures of achievement and perceived cognitive load is presented in Table 1. Distributions of the results can be characterised as normal, thus qualifying the test for further statistical analysis. The reliability obtained for levels of achievement has the value 0.87 which, considering the nature of the research, indicates good reliability and 0.94 for cognitive load, which indicates excellent reliability. The maximum score achieved on the test was 42.63 (71.05 %), the minimum was 13.12 (21.87 %) and the average score was 23.01 (38.35 %).

Table 1.
Descriptive statistics for test achievement and perceived cognitive load (N = 43)

	Value							
Parameter	Total		Macroscopic		Sub-microscopic			Symbolic
	A	CL	A	CL	A	CL	A	CL
Average	23.01	4.28	9.85	3.94	4,52	4.96	8.63	3.94
Standard deviation	6.92	0.81	2.74	0.87	2.68	0.97	2.31	0.84
Minimum	13.12	2.33	4.58	2.05	0.00	3.05	4.47	1.85
Maximum	42.63	5.72	15.83	5.40	12.67	7.00	14.33	5.45

The maximum value of cognitive load on the test was 5.72, which, according to the Likert scale corresponds to assessment "very difficult". The minimum value of cognitive load on the test was 2.33, which corresponds to assessment "easy". The average load value was 4.28, which corresponds to assessment "neither hard nor easy".

The parameters of the test results for achievements by levels correspond to normal distribution as well, except in the case of the sub-microscopic level, where students' achievements are significantly shifted towards lower scores. A parallel analysis of achievements by levels has shown that the highest average achievement was made at the macroscopic level – 9.85 (49.52 %). The students made the lowest average achievement at the sub-microscopic level - only 4.52 (22.60 %), which is in line with earlier findings that the sub-microscopic level is the one associated with the highest level of abstraction. Students have made a noticeably greater achievement – 8.63 (43.15 %) at the symbolic level compared with the achievement at the sub-microscopic level, which is consistent with the conclusions of Davidowitz et al. (2010) and Papaphotis & Tsaparlis (2008) that students are able to use templates and algorithms without proper reasoning and conceptual understanding.

If we take a look at the maximum values for achievements by levels, it is evident that the lowest result corresponds to the sub-microscopic level. The alarming fact is that the student, who has achieved the best score, has earned only 12.87 points, i.e. 63.35 %. It is also important to note that there are students who failed to do correctly a single task which belonged to this specific domain.

The parameters of the test results for the assessment of cognitive load at different levels correspond to normal distribution. The analysis has shown that the assessment of cognitive load is in accordance with the accomplishments achieved on the test. Students have estimated that the greatest cognitive load corresponds to the sub-microscopic level (4.96), which resulted in the lowest achievements. Results have shown that students rated tasks at this level as difficult. We also found that the evaluated cognitive loads for the macroscopic and symbolic level (3.94 and 3.94) are in accordance with the achievements. Tasks at the macroscopic and symbolic level have been classified by students in the ”neither difficult nor easy” category.

Macroscopic tasks generally require involvement of the lower cognitive processes that usually correspond to the lower categories of the Bloom’s taxonomy while the sub-microscopic tasks, on the contrary, generally require involvement of the higher cognitive processes (Tsaparlis, 2009). However, even when the sub-microscopic task is defined in the same category according to the revised Bloom’s taxonomy (Anderson et al., 2001) as macroscopic or symbolic task, subjective assessment of cognitive load indicates that the greatest perceived cognitive load corresponds to this particular level.

In the following section of this paper we will present a few examples of the test tasks and highlight the typical mistakes.

At the macroscopic level of Task 3 students were expected to know which of the given compounds (2-propanol and acetone) has a higher boiling point. At the sub-microscopic level students were asked to explain the difference in the boiling points between alcohols and ketones with the same number of carbon atoms. At the symbolic level students were required to present the given compounds by structural formulas.

This task showed that some students have formed misconceptions about the boiling process. Namely, they believe that a bond breaking within the molecules occurs during the process of boiling and that due to the presence of a double bond more energy for breaking in the molecule of acetone is required. As a result, acetone has a higher boiling point than the 2-propanol. Only 5.81 % of students managed to explain the differences in the boiling points with the hydrogen bonds formed between the molecules of alcohol.

There is an agreement between the students’ assessments of cognitive load and their achievements in this task.

At the macroscopic level of Task 5 students were asked to rank the compounds the names of which were provided in order of the increasing acidity (acetic acid, ethane, ethanol). At the sub-microscopic level students were required to explain the differences in acidity by structural differences between the molecules of the given compounds. At the symbolic level they were asked to present the given compounds by structural formulas.

Although a large number of students have successfully solved this task at the macroscopic level, very few of them (3.49 %) succeeded in explaining the differences in acidity by structural differences in the molecules of the given compounds. The majority of those who had answered this question at the macroscopic level correctly formed the answer relying on the knowledge about a compound belonging to a certain class. Namely, they concluded that acetic acid is the most acidic, as it belongs to the class of carboxylic acids, which are more acidic than alcohols and alkanes. Similarly, ethane is the least acidic, as it belongs to the least acidic class of compounds – alkanes.

The assessment of cognitive load in this task is in line with the students' achievements.

At the macroscopic level of Task 10 students were supposed to recognize the visible change that occurs when solid iron (II) sulphate is added into acidified solution of potassium permanganate. At the sub-microscopic level students were supposed to recognize what had occurred in the reaction at the particle level while at the symbolic level they were supposed to write a chemical equation that describes the previously mentioned chemical reaction. A large percentage of students (88.37 %) knew that during the reaction solution becomes colourless, but only 30.16 % of them knew that the mentioned change is the result of the reduction of permanganate ions. A slightly larger percentage of students (37.21 %) knew how to write the equation of the chemical reaction correctly, which indicates that some students are able to write and balance the chemical equation using the schemes and algorithms, whereas they do not understand what the chemical equation stands for.

As it has been previously mentioned, and as is obvious from this example, students, even those who are in their final year, do not possess an appropriate level of familiarity with the chemical concepts at the sub-microscopic domain.

ANOVA analysis

The obtained results for achievements and cognitive load were processed by one-way analysis of variance (ANOVA). ANOVA was performed in order to determine whether the differences in achievements as well as in cognitive load among levels are significant. The ANOVA results for achievements and cognitive loads are presented in Table 2. Insight into the results has shown that the P-value of the F-test is lower than 0.05 for both the achievements and cognitive load, thus indicating that differences among the levels are significant. Therefore, both null hypotheses can be disproved at the 95.0 % confidence level.

Table 2.
ANOVA results for achievements and cognitive load

Source	Sum of squares		Df		Mean Square		F-Ratio		P-Value	
	A	CL	A	CL	A	CL	A	CL	A	CL
Between groups	671.19	11790.60	2	2	335.59	5895.29	50.33	18.67	0.0000	0.0000
Within groups	840.15	39777.00	126	126	6.67	315.69				
Total (Corr.)	1511.34	51567.60	128	128						

A-achievement; CL-Cognitive Load

To determine which values are significantly different from others, Tukey's test was performed. The obtained results are summarised in Table 3.

Table 3.
Results of Tukey's test

Contrast	Sig.		Difference	
	A	CL	A	CL
Macroscopic-Submicroscopic	*	*	5.33186	-20.4186
Macroscopic-Symbolic			1.21953	-0.27907
Submicroscopic-Symbolic	*	*	-4.11233	20.1395

**statistically significant difference*

It can be noted that there are statistically significant differences both in achievement and cognitive load between the macroscopic and sub-microscopic as well as between the sub-microscopic and symbolic level, while there are no statistically significant differences neither in achievement nor in the cognitive load between the macroscopic and symbolic level.

The results obtained by this research are consistent with the previous findings that the sub-microscopic level is characterized by the highest level of abstraction, and that the chemical contents at this domain are unappealing for students. The results have also shown that there are no major differences in the average students' achievements at the macroscopic and symbolic level, which are also in line with the evaluated cognitive load. Hence, it can be concluded that students are able to review the cognitive processes and to evaluate the difficulty of the task.

Thereby, we would like to highlight the importance of the constant interplay among the macroscopic, sub-microscopic and symbolic level in chemistry teaching. Even though this form of teaching imposes high cognitive demands on learners, teachers should not ignore or favour certain levels because these three domains together lead to the formation of a flexible system of chemical knowledge which is one of the main objectives of education in the field of chemistry.

Conclusion

In this study we examined students' achievements and evaluation of cognitive load at different levels of knowledge representations in chemistry – the macroscopic, sub-microscopic and symbolic. In this study the test was used as a measuring instrument for the evaluation of knowledge and the Likert scale as a measuring instrument for the evaluation of cognitive load. The results have shown that there are statistically significant differences in students' achievements at the macroscopic, sub-microscopic and symbolic level. The null hypothesis of statistically non-significant differences is refuted at the 95 % confidence level. The highest average achievement of students was made at the macroscopic level (49.3 %) and the lowest at the sub-microscopic level (22.6 %). The average students' achievement at the symbolic level is 43.2 %.

The null hypothesis of statistically non-significant differences among cognitive load evaluations at the macroscopic, sub-microscopic and symbolic domain is refuted at the 95 % confidence level. According to students' evaluation, the greatest cognitive load corresponds to the sub-microscopic level (4.96), which, according to the Likert scale, corresponds to the assessment "difficult". Students have estimated that the macroscopic and the symbolic levels carry the same cognitive load (3.94), which, according to the Likert scale, corresponds to the assessment "neither difficult nor easy".

Since the obtained results once again showed that the sub-microscopic level is the most difficult level for students and the one associated with the highest cognitive load, the question is whether and how cognitive load could be reduced. Future research will focus on the sub-microscopic level and different modes of representation within this level in order to determine how certain modes of representation affect the amount of the perceived cognitive load. Furthermore, the analysis of the perceived cognitive load in the conceptual and declarative knowledge, as well as the analysis of the perceived cognitive load in the function of the complexity of the problem will be the issues the future research will focus on. In addition, it should be examined how the language of science in textbooks and of teachers in their communication with students contribute to the forming of misconceptions in the sub-microscopic domain.

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References

Adadan, E. (2006). *Promoting High School Students' Conceptual Understandings of the Particulate Nature of Matter Through Multiple Representations*. (Doctoral dissertation, The Ohio State University in Ohio). Ohio: School of the Ohio State University in Ohio.

Adadan, E., Irving, K.E., & Trundle, K.C. (2009). Impacts of multi-representational instruction on high school students' conceptual understandings of the particulate nature of matter. *International Journal of Science Education*, *31*(13), 1743-1775.

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction*, *16*(3), 183-198.

Anderson, L., Krathwohl, D., Airasian, P., Cruikshank, K., Mayer, R., Pintrich, P., Raths, J., & Wittrock, M. (2001). *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*, *Complete Edition*. New York: Longman.

Bodemar, D., & Faust, U. (2006). External and mental referencing of multiple representations. *Computers in Human Behavior*, *22*(1), 27-42.

Boo, H.K. (1998). Students' understandings of chemical bonds and the energetics of chemical reactions. *Journal of Research in Science Teaching*, *35*(5), 3-12.

Brünken, R., Plass, J.L., & Leutner, D. (2003). Direct measurement of cognitive load in multimedia learning. *Educational Psychologist*, *38(*1), 53-62.

Brünken, R., Seufert, T., & Paas F. (2010). Measuring Cognitive Load. In J.L. Plass, R. Moreno & R. Brünken (Eds.), *Cognitive Load Theory* (pp. 181-182). New York: Cambridge University Press.

Bunce, D.M., & Gabel, D. (2002). Differential effects on the achievement of males and females of teaching the particulate nature of chemistry. *Journal of Research in Science Teaching*, *39*(10), 911-927.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction*, *8*(4), 293-332.

Chittleborough, G.D. (2004). *The Role of Teaching Models and Chemical Representations in Developing Students' Mental Models of Chemical Phenomena*. (Doctoral dissertation, Curtin University of Technology in Perth). Perth: Science and Mathematics Education Centre in Perth.

Chittleborough, G.D., Treagust, D.F., & Mocerino, M. (2002). *Constraints to the development of first year university chemistry students' mental models of chemical phenomena*, Proceedings of the 11th Annual Teaching Learning Forum. Perth, Australia.

Davidowitz, B., Chittleborough, G., & Murrey, E. (2010). Student-generated submicro diagrams: a useful tool for teaching and learning chemical equations and stoichiometry. *Chemistry Education Research and Practice*, *11*(3), 154-164.

Devetak, I., Vogrinc, J., & Glažar, S.A. (2009). Assessing 16-year-old students' understanding of aqueous solution at sub-microscopic level. *Research in Science Education*, *39*(2), 157-179.

Eggemeier, F.T. (1998). Properties of Workload Assessment Techniques. In P.A. Hancock & N. Meshkati (Eds.), *Human Mental Workload* (pp. 41-62). Amsterdam: Elsevier.

Gabel D. (1998). The Complexity of Chemistry and Implications for Teaching. In B.J. Fraser & K.G. Tobin (Eds.), *International Handbook of Science Education* (pp. 233–248). Dordrecht: Kluwer Academic Publishers.

Gilbert, J.K., & Treagust, D.F. (2009). Introduction: Macro, Submicro and Symbolic Representations and the Relationship between Them: Key Models in Chemical Education. In J.K. Gilbert & D.F. Treagust (Eds.), *Multiple Representations in Chemical Education* (pp. 1-8). Netherlands: Springer.

Gkitzia, V., Salta, K., & Tzougraki, C. (2011). Development and application of suitable criteria for the evaluation of chemical representations in school textbooks. *Chemistry Education Research and Practice*, *12*, 5-14.

Johnstone, A.H. (1982). Macro- and micro- chemistry. *School Science Review*. 64(227), 377-379.

Johnstone, A.H. (2000). Teaching of chemistry – logical or psychological?. *Chemistry Education: Research and Practice in Europe*, *1*(1), 9-15.

Kalyuga, S. (2009). *Managing Cognitive Load in Adaptive Multimedia Learning*. New York: Information Science Reference.

Kalyuga, S., Chandler, P., & Sweller, J. (1999). Managing split-attention and redundancy in multimedia instruction. *Applied Cognitive Psychology, 13*(4), 351-371.

Meij, J., & Jong, T. (2003). *Learning with Multiple Representations: Supporting students' translation between representations in a simulation-based learning environment*. EARLI conference, Padua, Italy.

Miller, G.A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*(2), 81-97.

Moreno, R., & Park, B. (2010). Cognitive Load Theory: Historical Development and Relation to Other Theories. In J.L. Plass, R. Moreno & R. Brünken (Eds.), *Cognitive Load Theory* (p. 17). New York: Cambridge University Press.

Nakhleh, M.B., & Krajcik, J.S. (1994). Influence of level of information as presented by different technologies on students' understanding of acid, base and pH concepts. *Journal of Research in Science Teaching*, *31*(10), 1077–1096.

Neisser, U. (1967). *Cognitive psychology*. New York: Appleton-Century-Crofts.

Ozmen, H. (2004). Some student misconceptions in chemistry: a literature review of chemical bonding. *Journal of Science Education and Technology*, *13*(2),147-159.

Ozmen, H. (2011). Turkish primary students' conceptions about the particulate nature of matter. *International Journal of Environmental and Science Education*, *6*(1), 99-121.

Papaphotis, G., & Tsaparlis, G. (2008). Conceptual versus algorithmic learning in high school chemistry: the case of basic quantum chemical concepts. *Chemistry Education Research and Practice*, *9*(4), 323-331.

Pass, F.G.W.C., & Merrienboer, J.J.G. (1994). Variability of worked examples and transfer of geometrical problem-solving skills: a cognitive-load approach. *Journal of Educational Psychology, 86*(1), 122-133.

Rappoport, L.T., & Ashkenazi, G. (2008). Connecting levels of representation: emergent versus submergent perspective. *International Journal of Science Education*, *30*(12),1585-1603.

Raviolo, A. (2001). Assessing students' conceptual understanding of solubility equilibrium. *Journal of Chemical Education*, *78*(5), 629-631.

Segedinac, M., Segedinac, M., Konjović Z., & Savić G. (2011). A formal approach to organization of educational objectives. *Psihologija*, *44*(4), 307-323.

Seufert, T. (2003). Supporting coherence formation in learning from multiple representations. *Learning and Instruction*, *13*(2), 227-237.

Seufert, T., & Brünken, R. (2006). Cognitive load and the format of instructional aids for coherence formation. *Applied Cognitive Psychology*, *20*(3), 321-331.

Sweller, J. (2010). Cognitive Load Theory: Recent Theoretical Advances. In J.L. Plass, R. Moreno & R. Brünken (Eds.), *Cognitive Load Theory* (pp. 40-41). New York: Cambridge University Press.

Sweller, J., Merrienboer, J.J.G., & Pass, F.G.W.C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*(3), 251-296.

Sweller, J., Ayres, P., & Kalyuga, S. (2011). Cognitive Load Theory. In J.M. Spector & S.P. Lajoie (Eds.), *Explorations in the Learning Sciences, Instructional Systems and Performance Technologies* (pp. 76). Dordrecht: Springer.

Talanquer, V. (2011). Macro, Submicro, and Symbolic: The many faces of the chemistry "triplet". *International Journal of Science Education*, *33*(2), 179-195.

Treagust, D.F., Chittleborough, G., & Mamiala, T.L. (2003). The role of submicroscopic and symbolic representations in chemical explanations. *International Journal of Science Education*, *25*(11), 1353-1368.

Tsaparlis, G. (1997). Atomic and molecular structure in chemical education: a critical analysis from various perspectives of science education. *Journal of Chemical Education*, *74*(8), 922-925.

Tsaparlis, G. (2009). Learning at the Macro Level: The Role of Practical Work. In J.K. Gilbert & D.F. Treagust (Eds.), *Multiple Representations in Chemical Education* (pp. 109-136). Netherlands: Springer.

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Kognitivno opterećenje na različitim razinama kemijskih prikaza

Sažetak

Svrha ovog istraživanja bila je ispitati postignuća studenata i kognitivno opterećenje na različitim razinama kemijskih prikaza. Istraživanje je provedeno među studentima koji će u budućnosti biti nastavnici kemije. Mjerni instrument koji se koristio za vrednovanje znanja bio je test. Svaki zadatak sastojao se od tri podzadatka, u makroskopskoj, submikroskopskoj i simboličkoj domeni. Svaki podzadatak sadržavao je Likertovu skalu od sedam stupnjeva, koja je omogućavala ispitanicima da ocijene tvrdnje ovisno o tome smatraju li da su one „iznimno lagane", pa sve do onih za koje smatraju da su „iznimno teške". Paralelna analiza dobivenih rezultata pokazala je da je način na koji su studenti vrednovali kognitivno opterećenje bila u skladu s njhovim postignućima na testu. Studenti su smatrali da je najveće kognitivno opterećenje ono vezano uz submikroskopsku razinu, što je rezultiralo njihovim najslabijim postignućima. Rezultati su također pokazali da ne postoje značajne razlike u prosječnim postignućima studenata na makroskopskoj i simboličkoj razini, što je također u skladu s vrednovanim kognitivnim opterećenjem. Stoga se može zaključiti da su studenti sposobni proučiti kognitivne procese i procijeniti težinu zadatka.

Ključne riječi: *kemijski pojmovi; kognitivno opterećenje; trostruka veza; vrednovanje.*

Uvod

Kemijski prikazi

Kemijske tvari mogu se prikazati na nekoliko razina koje se obično nazivaju makroskopskom, submikroskopskom i simboličkom. Sve su one međusobno povezane i zajedno doprinose smislenom učenju i razumijevanju (Devetak i sur., 2009; Johnstone, 1982; Johnstone, 2000; Raviolo, 2001; Treagust i sur., 2003; Tsaparlis, 1997). Makroskopska razina obično podrazumijeva svojstva kemijskih tvari i procese koji se mogu iskusiti osjetilima, kao što su: boja, miris, fizička svojstva ili promjena boje, stvaranje taloga, ispuštanje plinova. Prema nekim autorima (Gilbert i Treagust, 2009; Nakhleh i Krajcik, 1994), ona također podrazumijeva i vidljiva svojstva koja se mogu mjeriti, kao što su: temperatura, masa, gustoća, itd. Submikroskopska razina može se opisati idejom o čestičnoj prirodi tvari, tj. ona podrazumijeva strukturu atoma, molekula, gibanje iona ili elektrona. Prema Gilbertu i Treagustu (2009), ta razina prikaza omogućava objašnjenje fenomena koji se mogu iskusiti osjetilima. Simbolička razina podrazumijeva prikaze koji omogućavaju detaljnija objašnjenja fenomena na makroskopskoj i submikroskopskoj razini. Simbolički prikazi kemijskih pojmova obuhvaćaju kemijske simbole, kemijske formule, kemijske jednadžbe, reakcijske mehanizme, Newmanove i Fischerove projekcije, Lewisove strukture, grafove itd. (Gkitzia i sur., 2011). Raznovrsni simbolički prikazi, modeli i dinamični audiovizualni prikazi omogućavaju studentima da si približe apstraktno, ali neophodno znanje o strukturi tvari. Talanquer je nedavno upozorio na nejasnoće u terminologiji i interpretacijama trostruke veze i istaknuo problem različitih vizualnih prikaza (Talanquer, 2011). Naime, ako se one smatraju znakovima, tada možemo reći da pripadaju simboličkoj razini. Međutim, ako se smatraju modelima koji imaju deskriptivnu i eksplanatornu ulogu, tada možemo reći da pripadaju submikroskopskoj razini. Stoga, treba spomenuti da se u ovom istraživanju submikroskopska razina smatra razinom teorijskih modela i ideja o tome kako bi svijet mogao izgledati na razini čestica. Prikazi iona nisu se koristili u ovom istraživanju.

Studije su pokazale da učenici različite dobi, a čak i neki nastavnici, imaju problema s prijenosom znanja s jedne razine na drugu (Boo, 1998; Gabel, 1998). Također, brojna izvješća koja se tiču obrazovanja u području znanosti pokazala su da učenici ne razumiju bit kemijskih termina. Pojam čestične prirode tvari, koji je neophodan za učenje i razumijevanje kemije, smatra se mogućim uzrokom toga (Adadan i sur., 2009; Ozmen, 2011). U radovima Adadana i sur. (2009), Devetaka i sur. (2009) i Ozmena (2004, 2011) istaknuto je da učenici obično stvaraju pogrešne predodžbe i alternativne pojmove, što bi se moglo objasniti nadmetanjem teorijskog konteksta čestične prirode tvari s opažanjima učenika u njihovu svakodnevnom životu. Kako razumijevanje tvari na submikroskopskoj razini zahtijeva razumijevanje njezine čestične prirode, ovaj je korak najteži za sve studente, pa je to i razlog zbog kojega studenti vrlo često prenose vidljiva makroskopska svojstva tvari na njezine submikroskopske čestice. Naime, rezultati istraživanja neprestano pokazuju da učenici pripisuju vidljiva svojstva poput boje, mirisa, oblika, fizičkog stanja ili čvrstoće atomima i molekulama, tj. da učenici očekuju da se submikroskopske čestice ponašaju kao manje kopije vidljivog makroskopskog sustava (Rappoport i Ashkenazi, 2008). Mnogi učenici smatraju da molekule vode mogu biti vruće i hladne, da su okruglog oblika ili da mogu imati nekoliko različitih oblika u sustavu, kao i da molekule naftalena imaju miris (navedeno u Adadanu, 2006) ili da su atomi sumpora žute boje (navedeno u Chittleboroughu, 2004). Mnogi učenici odabiru očito lakši put tako što ostaju na razini percepcije, dok je jedini način da se stvore logične veze i razvije kemijski način razmišljanja onaj na submikroskopskoj razini. Chittleborough i sur. (2002) navode da su studenti sposobni povezati makroskopska svojstva sa simboličkom razinom kao rezultat njihova laboratorijskog iskustva, no i dalje većina njih ne uspijeva shvatiti submikroskopsku stvarnost.

Bunce i Gabel (2002) proveli su istraživanje da bi ispitali dovodi li nastava u kojoj se koriste submikroskopski prikazi do boljih postignuća u tri odabrane teme. Istraživanje je provedeno s dvije skupine – eksperimentalnom i kontrolnom. Kontrolnu skupinu podučavali su koristeći samo dvije razine prikaza (makroskopsku i simboličku), dok su eksperimentalnu podučavali koristeći sve tri razine (makroskopsku, submikroskopsku i simboličku). Rezultati su pokazali značajno poboljšanje u postignućima studenata u eksperimentalnoj skupini. Stoga je važno da nastavnici tijekom nastave ne izbjegavaju submikroskopsku razinu. Naprotiv, ona bi se više trebala naglašavati i, što je važnije, trebalo bi je kombinirati s makroskopskom i simboličkom razinom jer kvalitetno podučavanje i smisleno učenje zahtijevaju stalno međusobno djelovanje te tri razine.

Kognitivni pristup učenju

Kognitivna orijentacija pokrenula je revoluciju u psihologiji u kasnim pedesetima i šezdesetima prošloga stoljeća radovima Millera (1956) i Neissera (1967), te su uz empirijska istraživanja razvijene i mnogobrojne teorije i modeli. Kognitivne teorije učenja i intelektualnog razvoja obogatile su psihologiju novim idejama: kako steći znanje i vještine i kako oblikovati već postojeće znanje. Prema toj orijentaciji učenje se smatra aktivnim i konstruktivnim procesom usmjerenim na određeni cilj. Iako kognitivna psihologija ne osporava tradicionalne principe učenja, ona postavlja nove principe za njegove kompleksnije oblike koji uključuju dublje razumijevanje veza između mnogobrojnih i raznolikih informacija.

Teorija kognitivnog opterećenja je pojam koji odražava vezu između strukture informacija i kognitivnih osobina učenika. Prema toj teoriji, ljudska su bića ograničena količinom informacija koje mogu istodobno obraditi (Chandler i Sweller, 1991). Ljudska kognitivna arhitektura omogućava međusobno djelovanje pojedinih elemenata koji se sastoje od jedne jedine informacije na različite načine. Informacija koja je prisutna u ljudskoj memoriji može varirati u kontinuumu od niske do visoke interaktivnosti. Svaki element niske interaktivnosti može se naučiti i razumjeti zasebno, bez razmatranja drugih elemenata. Elementi visoke interaktivnosti mogu se naučiti zasebno, no ne mogu se razumjeti dok se svi elementi koji su u međusobnoj vezi ne obrade istodobno. Kao rezultat toga, elemente visoke interaktivnosti teško je razumjeti (Sweller i sur., 1998). Svaki nastavni materijal nameće određeno kognitivno opterećenje koje se, prema Swelleru (2010), može podijeliti na tri kategorije – intrinzično, ekstrinzično i povezano kognitivno opterećenje.

Najočitije kognitivno opterećenje jest ono koje možemo jasno iskusiti kada učimo kompleksne sadržaje. Kao rezultat kognitivne aktivnosti javlja se promjena u postojećim ili stvaranje novih kognitivnih struktura u dugoročnom pamćenju. To opterećenje naziva se intrinzičnim kognitivnim opterećenjem zato što ga isključivo uzrokuje stupanj kompleksnosti zadataka ili materijal koji se obrađuje (Kalyuga, 2009).

Opseg kognitivnog opterećenja određuje se stupnjem interaktivnosti između pojedinačnih elemenata zadatka i elemenata postojeće baze znanja u dugoročnom pamćenju. Ovisno o usvojenim shemama, materijali koji su vrlo kompleksni za jednog pojedinca mogu biti vrlo jednostavni za nekog drugog pojedinca (Sweller, 2010). Kada se elementi zadatka istodobno obrađuju ili kada sadržaj ima visok stupanj interaktivnosti među elementima, nametnut će se visoko kognitivno opterećenje, čak i kada je broj elemenata koji sudjeluju u toj interakciji relativno malen. Kako je intrinzično kognitivno opterećenje neophodno za postizanje specifičnih ciljeva učenja (razumijevanje problema, stvaranje viših struktura znanja i njihova fleksibilnost), ono mora biti unutar kapaciteta radne memorije.

Nasuprot intrinzičnom kognitivnom opterećenju, koje se nameće intrinzičnom prirodom informacija koje bi se trebale usvojiti, ekstrinzično kognitivno opterećenje nameće se načinom na koji se informacije predstavljaju tijekom nastave (Sweller i sur., 2011). To znači da je ekstrinzično kognitivno opterećenje izazvano kognitivnim aktivnostima koje potječu iz vanjskih faktora, kao što su oblik multimedijalnih prezentacija, poredak skupina zadataka ili način na koji je nastava osmišljena. Na primjer, kada su povezani tekst, grafika ili audio elementi odvojeni u vremenu ili prostoru, njihova će integracija zahtijevati intenzivne procese pretraživanja i poništavanja nekih elemenata prilikom obrade nekih drugih elemenata. Takvi procesi mogu značajno povećati opterećenje radne memorije.

Treći izvor kognitivnog opterećenja je takozvano povezano kognitivno opterećenje, koje se od druga dva razlikuje po svojem pozitivnom stavu prema učenju jer se ono događa kao rezultat usmjeravanja kognitivnih izvora prema automatiziranju i usvajanju šablona, a ne prema drugim mentalnim aktivnostima (Moreno i Park, 2010).

Kako navodi Kalyuga (2009), povezano kognitivno opterećenje uzrokovano je raznolikim kognitivnim sposobnostima koje vode povećavanju kognitivnoga opterećenja, ali istodobno i poboljšavaju proces učenja i podižu stupanj motivacije učenika (osim u slučajevima gdje ukupno kognitivno opterećenje nadilazi kapacitet radne memorije).

Pristupi mjerenju kognitivnog opterećenja mogli bi se podijeliti u kategorije prema dvjema dimenzijama – objektivnosti (na subjektivne i objektivne) i kauzalnim odnosima (direktne ili indirektne). Dimenzija objektivnosti klasificira pristup mjerenju ovisno o metodi koja se primjenjuje (podaci o samoprocjeni, promatranje ponašanja, psihološki uvjeti, uspješnost), dok se klasificiranje kauzalnim odnosima temelji na vrsti odnosa promatranog fenomena mjerenjem i stvarnim atributom interesa. Kao rezultat postoje: direktne objektivne metode koje uključuju tehnike poput: metode simultanih zadataka, tehnike vizualnog praćenja i mjerenje aktivnosti mozga; indirektna objektivna mjerenja povezana s fiziološkim faktorima kao što su: kardiovaskularni pokazatelji, EEG, lingvistički pokazatelji i mjerenja interakcije; direktna subjektivna mjerenja koja se odnose na samoprocjenu stresnog stanja, i indirektna subjektivna mjerenja koja se odnose na samoprocjenu stupnja mentalnog napora (Brünken i sur., 2003; Kalyuga, 2009). Dok neki autori daju prednost objektivnim mjerenjima (Brünken i sur., 2003), drugi smatraju da su subjektivna mjerenja dovoljno pouzdana i da imaju visok stupanj korelacije s objektivnim mjerenjima (Eggemeier, 1998).

Štoviše, za razliku od objektivnih pristupa, subjektivni pristupi su jednostavniji i praktičniji. U subjektivnom procjenjivanju kognitivnog opterećenja obično se koriste skale ocjenjivanja koje mjere promatrano kognitivno opterećenje. One se temelje na pretpostavci da učenici mogu pouzdano i valjano procijeniti stupanj kognitivnog opterećenja s kojima se suočavaju u određenoj situaciji (Brünken i sur., 2010; Kalyuga i sur., 1999; Pass i Merriënboer, 1994).

Da bi se postiglo efektivno učenje, neophodno je da ukupan zbroj sve tri vrste kognitivnog opterećenja bude unutar granica kapaciteta radne memorije. Stoga su faktori koji reduciraju kognitivno opterećenje od temeljne važnosti za procese učenja i razumijevanja. Višestruki prikazi odnedavno su u fokusu interesa istraživača zbog svoje važnosti za smisleno učenje (Ainsworth, 2006; Bodemer i Faust, 2006; Meij i Jong, 2003; Seufert, 2003). Prema Seufertu i Brünkenu (2006), učenje uz višestruke prikaze iznimno je zahtjevan kognitivni proces, jer usvajanje znanja iz višestrukih prikaza zahtijeva stvaranje odgovarajućih veza između odgovarajućih elemenata u različitim prikazima, no usprkos toj činjenici njihova upotreba vodi dubljem razumijevanju teme.

Svrha i ciljevi istraživanja

Studije su pokazale da učenici, pa čak i neki nastavnici od kojih se očekuje da pomognu učenicima kako bi usvojili kemijske pojmove, imaju poteškoća u razumijevanju tih pojmova na različitim razinama prikaza znanja. Posebno se teškoće javljaju u prijenosu znanja s jedne razine na drugu, jer tada učenik mora obraditi velik broj elemenata istodobno, stvarajući dodatni mentalni napor i veliko kognitivno opterećenje (Boo, 1998; Gabel, 1998). Stoga smo proveli istraživanje među studentima koji će postati nastavnici kemije, da bismo ispitali njihova postignuća i kognitivno opterećenje na makroskopskoj, submikroskopskoj i simboličkoj razini kemijskih prikaza.

U ovom istraživanju zasebno smo mjerili postignuća i uočeno kognitivno opterećenje zadacima na makroskopskoj, submikroskopskoj i simboličkoj razini, da bismo odredili postoji li značajna razlika među razinama. Osim toga, cilj je ovoga rada pružiti uvid u to koliko je svaka pojedinačna razina prikaza opterećena, da bismo nastavili rad na optimizaciji procesa učenja korištenjem trostruke veze u kemiji.

Hipoteze istraživanja prije ispitivanja bile su formulirane kao nulte hipoteze na sljedeći način:

- Ne postoji statistički značajna razlika u postignućima studenata na različitim razinama prikaza znanja u kemiji
- Ne postoji značajna razlika u procjeni opaženog kognitivnog opterećenja na različitim razinama prikaza znanja u kemiji.

Metodologija

Sudionici

U istraživanju su sudjelovala 43 studenta Prirodno-matematičkog fakulteta Univerziteta u Novom Sadu koji će postati nastavnici kemije. Važno je istaknuti da su svi studenti položili kolegije: *Opća kemija*, *Anorganska kemija* i *Organska kemija*

I, dok ih je 26 (60,47 %) položilo kolegij iz *Organske kemije II*. Svi studenti koji su sudjelovali u istraživanju pohađali su nastavu iz kolegija (kao što su *Kemijske veze* i *Struktura molekula*, kao i viši kolegiji iz *Organske kemije*) čiji sadržaj uvelike zahtijeva stvaranje mentalnih teorijskih modela, zatim kolegij *Metodika nastave kemije*, gdje su upoznati s terminom *trostruka veza*.

Mjerenja

Za mjerenje postignuća korišten je test od dvadeset zadataka. Sastojao se od dvanaest zadataka iz područja opće i anorganske kemije i osam zadataka iz područja organske kemije. Svaki zadatak sastojao se od tri podzadatka – jednog u makroskopskoj, jednog u submikroskopskoj i jednog u simboličkoj domeni.

Da bi se izmjerilo kognitivno opterećenje, iza svakog podzadatka slijedila je Likertova skala od sedam stupnjeva, koja je od ispitanika tražila da ocijene tvrdnje na skali od „iznimno lagano" (1) do „iznimno teško" (7). Najviši mogući rezultat na testu iznosio je 60 bodova, tj. po 20 bodova na svakoj razini.

Test je bio karakteriziran parametrima osiguranja kvalitete na predtestu i posttestu, prema modelu koji su opisali Segedinac i suradnici (2011). Predtest je procijenila stručna skupina koju su činila dva znanstvena novaka i dva sveučilišna profesora specijalizirana za područje Metodike nastave kemije. Na temelju raznovrsnosti zadataka, korištene terminologije, duljine rečenica i smislenosti zadataka, stručna skupina ocijenila je test valjanim. Stručnjaci su procijenili da je korištena terminologija odgovarajuća za studente kemije i da su rečenice prikladne duljine, čime se postiže jasnoća. Složili su se da su pitanja u testu raznolika jer je test uključio tekstualna, grafička, tabelarna i kombinirana pitanja. Također, potvrdili su da su zahtjevi u zadacima smisleni i jasni.

Parametri osiguranja kvalitete u posttestu bili su omogućeni statističkom analizom rezultata testa. Uz osnovne statističke parametre, izračunati su pouzdanost postignuća i kognitivno opterećenje, dobiveni uz pomoć Cronbachove alfe. Daljnja statistička analiza rezultata testa sastojala se od jednosmjerne analize varijance (ANOVA), jer smo analizirali tri varijable – postignuća i kognitivno opterećenje pojedinačno za svaku razinu: makroskopsku, submikroskopsku i simboličku.

Rezultati testa bili su statistički analizirani softverskim paketima STATGRAPHICS Centurion XV i IBM SPSS Statistics 19.

Rezultati i rasprava

Deskriptivna statistika za mjerenje postignuća i opaženog kognitivnog opterećenja prikazana je u Tablici 1. Distribucija rezultata može se opisati kao normalna, što čini test valjanim za daljnju statističku analizu. Pouzdanost dobivena za razine postignuća ima vrijednost 0,87, što, uzimajući u obzir prirodu istraživanja, ukazuje na dobru pouzdanost, te vrijednost 0,94 za kognitivno opterećenje, što upućuje na odličnu pouzdanost. Najbolji rezultat postignut na testu bio je 42,63 (71,05 %), dok je najniži bio 13,12 (21,87 %). Prosječan rezultat bio je 23,01 (38,35 %).

Tablica 1.

Najviša vrijednost kognitivnog opterećenja na testu bila je 5,72, što, prema Likertovoj skali, odgovara ocjeni „vrlo težak". Najniža vrijednost kognitivnog opterećenja na testu bila je 2,33, što odgovara ocjeni „lagan". Prosječna vrijednost opterećenja bila je 4,28, što odgovara ocjeni „ni težak ni lagan".

Parametri rezultata testa za postignuća po razinama također odgovaraju normalnoj distribuciji, osim u slučaju submikroskopske razine, gdje su postignuća studenata znatno pomaknuta prema nižim vrijednostima. Paralelna analiza postignuća po razinama pokazala je da je najviše prosječno postignuće ostvareno na makroskopskoj razini – 9,85 (49,52 %). Studenti su ostvarili najniže prosječno postignuće na submikroskopskoj razini – samo 4,52 (22,60 %), što je u skladu s ranijim istraživanjima koja su pokazala da je upravo submikroskopska razina ona koja je povezana s najvišim stupnjem apstrakcije. Studenti su ostvarili vidljivo bolja postignuća – 8,63 (43,15 %) na simboličkoj razini u usporedbi s postignućima na submikroskopskoj razini, što je u skladu sa zaključcima Davidowitza i sur. (2010) i Papaphotisa i Tsaparlisa (2008), koji govore da studenti mogu koristiti predloške i algoritme bez pravoga razmišljanja i konceptualnog razumijevanja.

Ako pogledamo maksimalne vrijednosti postignuća po razinama, očito je da najniži rezultat odgovara submikroskopskoj razini. Zabrinjava činjenica da je student koji je ostvario najbolji rezultat imao samo 12,87 bodova, tj. 63,35 %. Također je važno istaknuti da ima i studenata koji nisu uspjeli riješiti ni jedan jedini zadatak koji je pripadao toj specifičnoj domeni.

Parametri rezultata testa za procjenu kognitivnog opterećenja na različitim razinama odgovaraju normalnoj distribuciji. Analiza je pokazala da je procjena kognitivnog opterećenja u skladu s postignućima ostvarenima na testu. Studenti su procijenili da najveće kognitivno opterećenje odgovara submikroskopskoj razini (4,96), što je rezultiralo slabijim postignućima. Rezultati su pokazali da su studenti ocijenili zadatke na navedenoj razini kao teške. Također smo saznali da je procijenjeno kognitivno opterećenje za makroskopsku i simboličku razinu (3,94 i 3,94) u skladu s postignućima. Zadatke na makroskopskoj i simboličkoj razini studenti su svrstali u kategoriju „ni teški ni lagani".

Makroskopski zadaci općenito zahtijevaju uključivanje nižih kognitivnih procesa koji obično odgovaraju nižim kategorijama Bloomove taksonomije, dok za razliku od njih submikroskopski zadaci zahtijevaju aktiviranje viših kognitivnih procesa (Tsaparlis, 2009). Međutim, čak i kada se submikroskopski zadatak definira u istoj kategoriji prema revidiranoj Bloomovoj taksonomiji (Anderson i sur., 2001) kao makroskopski ili simbolički zadatak, subjektivna ocjena kognitivnog opterećenja ukazuje na to da najviše opaženo kognitivno opterećenje odgovara upravo toj razini.

U daljnjem dijelu ovoga rada prikazat ćemo nekoliko primjera zadataka iz testa i istaknuti tipične pogreške.

Na makroskopskoj razini zadatka 3 studenti su trebali znati koji od zadanih kemijskih spojeva (2-propanol i aceton) ima višu točku vrenja. Na submikroskopskoj razini studenti su trebali objasniti razliku u točkama vrenja između alkohola i ketona s istim brojem atoma ugljika. Na simboličkoj razini studenti su trebali prikazati zadane kemijske spojeve strukturnim formulama.

Zadatak je pokazao da su neki studenti stvorili pogrešne pretpostavke o procesu vrenja. Naime, oni smatraju da do pucanja veza unutar molekula dolazi tijekom procesa vrenja i da je zbog prisustva dvostruke veze potrebno više energije za pucanje kemijskih veza unutar molekule acetona. Zbog toga aceton ima višu točku vrenja od 2-propanola. Samo je 5,81 % studenata uspjelo objasniti razlike u točkama vrenja s vodikovim vezama koje se stvaraju između molekula alkohola.

Postoji podudarnost između ocjene kognitivnog opterećenja koju su dali studenti i njihovih postignuća na ovome zadatku.

Na makroskopskoj razini zadatka 5 studenti su trebali rangirati kemijske spojeve po rastućoj kiselosti (imena spojeva bila su dana: octena kiselina, etan, etanol). Na submikroskopskoj razini studenti su trebali objasniti razlike u kiselosti po strukturnim formulama među molekulama zadanih kemijskih spojeva. Na simboličkoj su razini trebali prikazati zadane spojeve strukturnim formulama.

Iako je velik broj studenata uspješno riješio taj zadatak na makroskopskoj razini, vrlo malo njih (3,49 %) uspjelo je objasniti razlike u kiselosti po strukturnim razlikama molekula zadanih spojeva. Većina studenata koji su odgovorili na to pitanje točno na makroskopskoj razini oblikovali su odgovore oslanjajući se na znanje o vrsti kojoj određeni kemijski spoj pripada. Naime, zaključili su da je octena kiselina najkiselija jer pripada vrsti karboksilnih kiselina koje su kiselije od alkohola i alkana. Slično tome, etan je najmanje kiseo jer pripada vrsti kiselina čija je kiselost najmanja – alkanima.

Procjena kognitivnog opterećenja u ovome zadatku je u skladu s postignućima studenata.

Na makroskopskoj razini zadatka 10 studenti su trebali prepoznati vidljivu promjenu koja se događa kada se željezni (II) sulfat doda oksidiranoj otopini kalijeva permanganata. Na submikroskopskoj razini studenti su trebali prepoznati što se dogodilo u reakciji na razini čestica, dok su na simboličkoj razini trebali napisati kemijsku jednadžbu koja opisuje opisanu kemijsku reakciju. Velik postotak studenata (88,37 %) znao je da tijekom reakcije otopina postaje bezbojna, no samo ih je 30,16 % znalo da je spomenuta promjena rezultat smanjenja iona permanganata. Nešto manji postotak studenata (37,21 %) znao je kako točno napisati jednadžbu kemijske reakcije, što upućuje na to da su neki studenti sposobni napisati i uravnotežiti kemijsku jednadžbu koristeći se shemama i algoritmima, no ne razumiju što kemijska jednadžba znači.

Kako je već bilo spomenuto, te kao što je očito iz ovoga primjera, studenti, čak i oni koji su na posljednjoj godini studija, ne posjeduju odgovarajući stupanj znanja o kemijskim pojmovima u submikroskopskoj domeni.

ANOVA analiza

Dobiveni rezultati o postignućima i kognitivnom opterećenju obrađeni su jednosmjernom analizom varijance (ANOVA). ANOVA se koristila da bi se odredilo jesu li razlike u postignućima, kao i razlike u kognitivnom opterećenju između različitih razina značajne. Rezultati ANOVA analize o postignućima i kognitivnom opterećenju prikazani su u Tablici 2. Uvid u rezultate pokazao je da je P-vrijednost F-testa niža od 0,05 i za postignuća i za kognitivno opterećenje. To pokazuje da su razlike među razinama značajne. Stoga se obje nulte hipoteze mogu odbaciti sa stupnjem pouzdanosti od 95 %.

Tablica 2.

Da bi se odredilo koje su vrijednosti značajno drugačije od ostalih, primijenjen je Tukeyev test. Dobiveni rezultati sažeti su u Tablici 3.

Tablica 3.

Može se primijetiti da postoje statistički značajne razlike i u postignućima i u kognitivnom opterećenju između makroskopske i submikroskopske razine, kao i između submikroskopske i simboličke razine, dok ne postoje statistički značajne razlike ni u postignućima ni u kognitivnom opterećenju između makroskopske i simboličke razine.

Rezultati dobiveni u ovom istraživanju u skladu su s prijašnjim rezultatima koji su pokazali da je submikroskopska razina ona uz koju se veže najviši stupanj apstrakcije, te da kemijski sadržaji te domene studentima nisu privlačni. Rezultati su također pokazali da ne postoje velike razlike u prosječnim postignućima studenata na makroskopskoj i simboličkoj razini, što je također u skladu s procijenjenim kognitivnim opterećenjem. Stoga se može zaključiti da su studenti mogli preispitati kognitivne procese i procijeniti težinu zadatka.

Željeli bismo istaknuti važnost stalnog međusobnog djelovanja makroskopske, submikroskopske i simboličke razine u nastavi kemije. Čak iako taj oblik nastave nameće visoke kognitivne zahtjeve učenicima, nastavnici ne bi trebali ignorirati ili favorizirati određene razine, jer te tri domene zajedno vode stvaranju fleksibilnog sustava znanja kemije, što je jedan od glavnih ciljeva obrazovanja u području kemije.

Zaključak

U ovom istraživanju ispitali smo postignuća studenata i procjenu kognitivnog opterećenja na različitim razinama prikaza znanja u području kemije – na makroskopskoj, submikroskopskoj i simboličkoj. U ovom istraživanju korišten je test kao mjerni instrument za procjenu znanja i Likertova skala kao mjerni instrument za procjenu kognitivnog opterećenja. Rezultati su pokazali da postoje statistički značajne razlike u postignućima studenata na makroskopskoj, submikroskopskoj i simboličkoj razini. Nulta hipoteza o statistički nebitnim razlikama odbačena je sa stupnjem pouzdanosti od 95 %. Najveće prosječno postignuće studenata ostvareno je na makroskopskoj razini (49,3 %), a najslabije na submikroskopskoj razini (22,6 %). Prosječno postignuće studenata na simboličkoj razini je 43,2 %.

Nulta hipoteza o statistički nebitnim razlikama u procjeni kognitivnog opterećenja na makroskopskoj, submikroskopskoj i simboličkoj razini odbačena je sa stupnjem pouzdanosti od 95 %. Prema procjenama studenata, najveće kognitivno opterećenje vezano je uz submikroskopsku razinu (4.96), što, prema Likertovoj skali, odgovara procjeni „teško". Studenti su procijenili da i makroskopska i simbolička razina imaju isto kognitivno opterećenje (3.94), što, prema Likertovoj skali, odgovara procjeni „ni teško ni lagano".

Budući da su dobiveni rezultati ponovno pokazali da je submikroskopska razina studentima ujedno i najteža razina, kao i da je ona povezana s najvećim kognitivnim opterećenjem, pitanje je može li se, i kako, kognitivno opterećenje smanjiti. Istraživanja u budućnosti usredotočit će se na submikroskopsku razinu i različite načine prikaza na ovoj razini da bi se odredilo kako određeni načini prikaza utječu na količinu opaženog kognitivnog opterećenja. Nadalje, analiza opaženog kognitivnog opterećenja u konceptualnom i deklarativnom znanju, kao i analiza opaženog kognitivnog opterećenja u funkciji kompleksnosti problema, bit će teme na koje će se buduća istraživanja usredotočiti. K tomu, trebalo bi ispitati kako jezik znanosti korišten u udžbenicima i od strane nastavnika u komunikaciji s učenicima doprinosi stvaranju pogrešnih pretpostavki na submikroskopskoj razini.

Napomena

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