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The Development of Research in the Field of Chemistry Education at the University of Novi Sad since the Breakup of the Socialist Federal Republic of Yugoslavia

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☞ The first PhD thesis in the field of Chemistry Education at the Faculty of Sciences, University of Novi Sad, was defended in 1992. This can be regarded as the symbolic dawn of Chemistry Education as a scientific discipline in this region. After the official breakup of the Socialist Federal Republic of Yugoslavia, research that had started in the 1980s, and which was focused on the development of tools for assessing the quality and flexibility of student knowledge, was continued through the 1990s. This research included the application of computers to chemistry teaching, as well as the development of appropriate chemistry learning programmes. In the following period, research focused on the analysis of chemical teaching programmes in the Republic of Serbia, with a special emphasis on the possibility of including eco-chemical content in curricula. Accordingly, potentially efficient models were suggested. The most recent research has been focused on the investigation of the effectiveness of instructional strategies based on a systemic approach and a triplet model of content representation, using combined measures of students' performance and mental effort. In this regard, tools for the efficient assessment of knowledge (systemic synthesis questions, context-based questions) have been developed along with tools for the efficient assessment of students' misconceptions (multi-tier tests). Furthermore, in order to make teaching more effective, procedures for assessing the cognitive complexity of chemical problems have recently been developed and subsequently validated both statistically and by applying Knowledge Space Theory.

Keywords: research in chemical education, directions of research, chair of chemistry education

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Razvoj raziskovanja na področju kemijskega izobraževanja na Univerzi v Novem Sadu po razpadu Socialistične federativne republike Jugoslavije

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Prvi zagovor doktorata znanosti na področju kemijskega izobraževanja na Fakulteti za naravoslovje Univerze v Novem Sadu je bil leta 1992. To lahko štejeemo za simbolni začetek kemijskega izobraževanja kot znanstvene discipline v tej regiji. Po uradnem razpadu Socialistične federativne republike Jugoslavije se je raziskovanje, začeto v 80. letih prejšnjega stoletja ter osredinjeno na razvoj orodij za ocenjevanje kakovosti in fleksibilnosti znanja študentov, nadaljevalo tudi v 90. letih prejšnjega stoletja. V raziskavo smo vključili uporabo računalnikov v poučevanje kemije pa tudi razvoj primernih programov za učenje kemije. V naslednjem obdobju se je raziskovanje osredinjalo na analizo programov za poučevanje kemije v Republiki Srbiji, s posebnim poudarkom na možnosti vključevanja ekokemijskih vsebin v kurikulum. Skladno s tem so bili predlagani potencialno učinkoviti modeli poučevanja kemije. Najnovejše raziskave se osredinjajo na preučevanje učinkovitosti učnih strategij, ki temeljijo na sistemskem pristopu in trojnem modelu predstavljanja vsebine z uporabo preverjanja uspešnosti učencev in njihovih miselnih naporov pri tem. S tem namenom so bila razvita orodja za učinkovito ocenjevanje znanja (sistemska sintezna vprašanja, kontekstualna vprašanja), skupaj z orodji za učinkovito ocenjevanje napačnih razumevanj študentov (večdelne naloge v preizkusih znanja). Poleg tega so bili za izboljšanje poučevanja pred kratkim razviti postopki za ocenjevanje kognitivne kompleksnosti kemijskih problemov, ki so bili potrjeni statistično in tudi z uporabo teorije prostorskega znanja (KST – Knowledge Space Theory).

Ključne besede: raziskovanje v kemijskem izobraževanju, smeri raziskovanja, katedra za kemijsko izobraževanje

The Beginning of Research at the Chair of Chemistry Education

The beginning of scientific research in the field of chemical education at the University of Novi Sad is related to the establishment of the Chair of Chemistry Education (CCE) in 1974. As early as in 1975, specialist and masters programmes in chemistry education were established, and in 1992 the first PhD dissertation in the field of chemical education was defended.

At the beginning of the breakup of the Socialist Federal Republic of Yugoslavia (SFRY), the focus of the research group formed around the CCE was the application of tests in chemistry teaching. To this end, knowledge tests were designed as instruments for identifying the factors of creativity and success in chemistry teaching and learning, for assessing students' achievements in chemistry teaching and their ability to learn chemistry, and for evaluating the flexibility of chemical knowledge. The construction of instruments was based on the application of Bloom's taxonomy. Therefore, the possibility of specifying and operationalising educational goals and tasks in some teaching areas was analysed (Segedinac & Halaši, 1998). The factors of creativity in chemistry teaching and of success in learning chemistry were identified by the means of factor analysis. In secondary school chemistry, three factors of creativity were identified: (i) the factor of flexibility of thinking, (ii) the general reasoning factor, and (iii) the factor of originality and fluency (Segedinac, Konjović, & Dukić, 1994).

An important part of research within the CCE pertained to chemistry teaching content in primary and secondary education. Particular attention was paid to the possibilities of updating teaching content in the field of chemical production. It was found that, in the period after 1975, a large quantity of outdated content regarding chemical production and applied chemistry had been excluded from the primary school chemistry programme, but new content had not subsequently been included. Accordingly, a model for curriculum extension was proposed with the content of modern chemical production and applied chemistry (Cvjetičanin, Segedinac, & Letić, 2008, 2009). In addition, significant attention was devoted to the development of functional chemistry programmes for the needs of secondary vocational education (Segedinac, Adamov, & Halaši, 2007).

The Evolution of Research at the Chair of Chemistry Education

Research on the Use of ICT in Chemistry Teaching

In education, different countries follow different innovations regarding information and communication technology (ICT). ICT plays an important role in education in general and in chemical education in particular by providing better opportunities for visualisations, simulations and modelling of content, and by supporting laboratory instructions (cited in Krause, Pietzner, Dori, & Eilks, 2017).

Research on the application of educational technology in chemistry teaching commenced within the CCE in 1995, when the possibilities of applying computers to the individualisation of chemistry teaching were examined (Halaši, Segedinac, Konjović, & Halaši, 1995).

Later, the use of computers in the teaching practice of chemistry teachers in primary and secondary schools in our country (Adamov & Segedinac, 2006a) and in neighbouring countries (Halaši, 2004) was examined. It was shown that although in the last decades, in line with education reforms and harmonisation with European standards, teachers were aware of the need to use information and communication technology (ICT), and although computers were quite accessible to teachers, the level of their application was lower than expected. In cases of greater use of ICT, it was shown that such use only covered a narrow range of applications, while the use of computers by students during class time was not recorded. Teachers considered that they needed wider support and training to increase the use of ICT in teaching.

Further studies also included research on the characteristics and possibilities of using a virtual classroom in modern teaching practice (Adamov & Segedinac, 2006b), explaining the advantages and disadvantages of computer-assisted education and examining the prejudices that e-learning designers encounter during dissemination. The state of e-education in our country was investigated and described, and the importance of the role of ICT in defining and evaluating interaction in online learning was emphasised (Adamov & Segedinac, 2007). Different roles and forms of interaction between students, between teachers and in student-teacher relations were discussed in the light of designing e-learning models, while the difficulties that educators inexperienced in the field of electronic learning and design of electronic courses encounter during implementation were also pointed out. The conditions and necessary prerequisites for the development and organisation of an electronic teaching course as an integral part of formal education, as well as various forms of non-formal education, were examined (Adamov & Segedinac, 2006c).

Eco-Chemical Education as a Research Focus

Environmental chemistry is a very important part of chemistry education. It is aimed at raising awareness of the effects, both negative and positive, of using chemical products and processes in our environment (Aram & Manah, 1995). Research in the field of eco-chemical education within the CCE started with the aim of developing models for the eco-chemical education of employees in some branches of chemical production. Since 2014, CCE members have been dealing with ecological and eco-chemical teaching content in current chemistry and chemistry-related curricula in secondary vocational schools (Maravić, Ivković, Segedinac, & Adamov, 2014). Problems and barriers that the existing education system imposed on the development of ecological awareness among students were described and, due to insufficient representation of this content, proposals for curriculum extension were developed with content relevant to certain educational profiles (Maravić, Ivković, Adamov, & Segedinac, 2014).

As part of the study on ecocompetences, the awareness of employees in the chemical industry regarding knowledge of the ecological impact of the substances they encounter in their professional work was examined and, on the basis of the results obtained, a model for their permanent eco-chemical education was proposed (Cvjeticanin, Segedinac, & Adamov, 2010). The ecopedagogical competences of primary school teachers (class teachers and subject teachers of different fields of science) are assessed on the basis of examining their ecological literacy, expressed through attitudes, behaviour and knowledge of ecological and eco-chemical content.

Analysis of Factors Influencing Student Achievement in Chemistry

One of the recent directions of research within the CCE relates to investigation of the motivation of pupils and students to learn chemistry, their learning styles and the approaches to learning (deep, superficial or strategic) that they apply while learning chemistry, as well as the correlation of these factors and student achievements in chemistry.

Researchers who have noted the important role of motivation in learning science often mention its complex and multidimensional nature (Salta & Koulougliotis, 2015). The development of instruments for measuring student motivation has therefore received growing interest (Glynn & Koballa, 2006; Salta & Koulougliotis, 2015; Tuan, Chin, & Shyang, 2005). At the University of Novi Sad in the Republic of Serbia, a suitable questionnaire with five subscales was adapted to examine student motivation for learning chemistry content, and its psychometric characteristics were validated on a sample of 750 grammar school students. It was shown that the indicators of reliability and

representativeness of the questionnaire were satisfactory for its application in further research (Olić, Ninković, & Adamov, 2016). Using this questionnaire, the distribution of five different elements of motivation in the sample of grammar school students was examined. It was shown that students were mostly oriented towards learning, followed by the application of strategies of active learning and an orientation towards achievement, while the least developed was the feeling of self-efficacy and understanding the importance of chemistry as a science. Motivation for learning was shown to be a significant predictor of student achievement (Olić, Adamov, & Babić-Kekez, 2014).

Another group of research within the CCE included learning styles. The theoretical background for this research was Kolb's experimental learning theory (Kolb & Kolb, 2005), as one of the most influential theories in the field of learning styles. An earlier study conducted by Kidanemariam, Atagana and Engida (2014) showed that learning styles had little effect on the adoption of fundamental chemical concepts. However, the authors concluded that further research was needed to examine the relationship between different students' learning styles and their achievement in chemistry. Therefore, by examining differences in achievement in chemistry between students who prefer different learning styles, researchers within the CCE showed that students who prefer a convergent learning style achieve better performance, while teachers most often apply teaching strategies that suit students with assimilating and convergent learning styles (Olić & Adamov, 2016, 2018a). Teaching strategies that correspond to a convergent learning style proved to be the most powerful predictor of achievement (Olić & Adamov, 2017). A similar study conducted on a sample of students from the Department of Chemistry of the Faculty of Sciences in Novi Sad showed that individuals with high perceived learning efficiency had higher achievements, and that student motivation is a constant predictor of academic success (Olić, Adamov, & Babić-Kekez, 2017). On a sample of chemistry students, it was shown that there was a positive correlation between student success and the presence of a deep approach to learning chemistry, although the students with the highest grades preferred a strategic approach to learning (Olić & Adamov, 2018b).

Research on Gifted Students in Chemistry

Within the CCE, research on gifted students commenced in parallel with research about learning styles. It was noticed decades ago that students can differ in terms of different learning styles and expressions of giftedness, which have different manifestations (Passow, 1981). In the initial studies about the characteristics of gifted students and their recognition, as well as teaching

strategies for such students, the knowledge of class and subject teachers was examined (Adamov, Olić, & Segedinac, 2014). In order to help teachers work with such students, proposals for an individualised curriculum for teaching chemistry in primary and secondary schools were prepared (Adamov & Olić, 2014).

Chemical Experiments and Mini Projects

Research within the CCE was also focused on chemical experiments and the application of projects at all educational levels. The influence of independent student laboratory experiments on the acquisition of chemical knowledge in the population of Roma students was specifically examined, and it was found that such experiments significantly increase the students' motivation for learning chemistry and facilitate their progress (Adamov, Segedinac, Ković, Olić, & Horvat, 2012). The importance and possibility of applying experiments in the integrated teaching of natural sciences to different teaching topics were examined (Cvjetičanin, Segedinac, Adamov, & Branković, 2008a; Cvjetičanin, Segedinac, & Halaši, 2010), as well as the importance of applying a heuristic approach to the formation of the knowledge of second-grade students about the influence of heat on living beings and materials (Cvjetičanin, Segedinac, Adamov, & Branković, 2008b).

In addition, content for mini projects for including chemical and multidisciplinary topics in the integrated teaching of natural sciences within the teaching subject Nature and Society were proposed (Adamov, Olić, & Halaši, 2014; Adamov & Segedinac, 2011). It is well known that project teaching as an instructional strategy puts the student in the position of researcher, and that the student's work on projects with other students is followed by an increment in intrinsic motivation (Blumenfeld et al., 1991; Lam, Cheng, & Choy, 2010).

Models for a New Chemistry Curriculum

After publishing the official educational standards for the end of compulsory education, their realisation on a sample of over one thousand students was examined. It was shown that, in the case of chemistry, these standards had not been achieved for either the basic or the intermediate level, and that there is no correlation between students' knowledge and their grades in chemistry at the end of compulsory education (Adamov & Olić, 2015). The results obtained were the reason for carrying out research on the attitudes of teachers and students on the need for the introduction of chemistry in the sixth grade of primary school (Adamov, Radanov, Olić, & Segedinac, 2012). The opinions of teachers and students obtained in this research indicated the need for chemistry curriculum reform in order to arrange a three-disciplinary chemistry programme in three

years of learning (sixth, seventh and eighth grade). Additionally, a proposal for a sixth grade curriculum is provided.

Research Related to Scientific Literacy

Part of the research within the CCE is dedicated to studies of scientific literacy (Adamov, Marković, & Olić, 2012). The key component of scientific literacy is chemical literacy, which is very important because it represents the capability to understand key chemistry concepts (Shwartz, Ben-Zvi, & Hofstein, 2006).

The results of research on the scientific literacy of an adult non-chemical population in Vojvodina gave a generally positive impression. The lowest achievement of respondents was recorded in the category that refers to the knowledge of concepts in the field of health, which is a significant determinant of adult health behaviour (Adamov, Olić, Segedinac, Ninković, & Kovačević, 2013). The data obtained indicated the need to develop a systemic approach to meeting the requirements for the scientific literacy of adults. This would contribute significantly not only to the professional mobility of adults, but also to an improvement in the productivity of the national economy.

The Effectiveness of Using Concept Maps

Concept maps were introduced in the early 1970s as tools that show how new concepts are integrated into the learner's cognitive structure (Novak, 2010). Thus, they are hierarchical representations of the learner's organisation of their own cognitive structures (Novak & Govin, 1984). Such maps have been used in science education and have not been overlooked in chemistry (Johnstone & Otis, 2006; Pendley, Bretz, & Novak, 1994; Regis, Albertazzi, & Roletto, 1996).

In chemical education, concept maps have been widely investigated, as they can help in building connections between abstract concepts. Regarding the strategies of learning and teaching chemistry, the possibility of using concept maps as tools for diagnosing the acquisition and retention of knowledge in the field of biochemistry in secondary schools was examined within the CCE (Adamov, Segedinac, Cvjeticanin, & Bakoš, 2009). The findings suggested using concept maps in determining the level of acquired knowledge and in determining students' ability and efforts in learning biochemical content, as well as using them as an indicator of knowledge retention and for assessing the effectiveness of the applied teaching method and the performance of teachers.

The Latest Research within the Chair of Chemistry Education

The latest research within the CCE is being undertaken in two parallel directions: (i) the development and evaluation of effective instructional models; and (ii) the construction and validation of tools for assessing the quality of student cognitive structures.

Examination of the Effectiveness of Instructional Strategies

The examination of the effectiveness of instructional strategies is based on combined measures of performance and invested mental effort. In addition to the classic approach to measuring mental effort, which is based on the application of subjective measurement scales, a methodology for assessing the cognitive complexity of items has been elaborated, which, in addition to the assessment of objective item difficulty, takes into account the interactivity of elements. A combination of measurement of students' achievement, mental effort and cognitive complexity has provided valid and a reliable assessment method and upgraded tools for assessment of task and test quality (Knaus, Murphy, Blecking, & Holme, 2011; Raker, Trate, Holme, & Murphy, 2013).

Within the CCE, research in this domain began with the teaching area of stoichiometry. The Table for the Assessment of the Difficulty of Concepts Present in Stoichiometric Problems was developed (Horvat, Segedinac, Milenković, & Hrin, 2016). Each stoichiometric concept was evaluated according to its difficulty as easy, medium or difficult. By summing the obtained values of concept difficulties and adding the value of their interactivity, a numerical rating of the cognitive complexity of a problem can be calculated. For the validation of this procedure, linear regression analysis was used, correlating student achievement and applied mental effort as dependent variables with the numerical rating of the cognitive complexity of the problem as an independent variable. In addition to the statistical procedure for validating the method for assessing the cognitive complexity of stoichiometric tasks, this method was further validated by applying Knowledge Space Theory (Segedinac, Horvat, Rodić, Rončević, & Savić, 2018). Knowledge Space Theory enabled the fine differentiation of concepts and the identification of differences between the expected knowledge space, which was constructed based on the numerical rating of cognitive complexity, and the real knowledge space, which was constructed based on the students' achievements. The differences between the knowledge spaces were determined as the graphs' differences. The continuation of the research involved the development of procedures for the assessment of the cognitive complexity of tasks in the field

of chemical production and the calculation of the hydrogen exponent (Horvat, Rodić, Rončević, & Segedinac, 2019; Horvat, Rodić, Segedinac, & Rončević, 2017).

Regarding the research related to the assessment of efficiency, the efficiency of two instructional models was examined: Model 1, which is based on the application of the chemistry triplet, and Model 2, which is based on the application of the systemic approach to chemistry teaching and learning. Model 1 is based on an early idea of Johnstone (1991, 1993), who highlighted the notion that chemical knowledge can be represented at three levels: *macroscopic*, which includes perceptible properties of chemical substances and processes that can be experienced with the senses; *submicroscopic*, which refers to the structure of atoms, molecules and ions; and *symbolic*, which includes chemical symbols, formulas and equations. The research was conducted in the form of a pedagogical experiment with parallel groups (experimental and control). The experimental group was trained through instruction based on the idea of a triplet model, where each experiment and new concepts were studied through the constant interplay between macroscopic, submicroscopic and symbolic levels, while the control group was trained in a traditional way. The study applied a pretest-posttest design, and differences in respondents' performance, as well as differences in perceived mental effort, were compared statistically. In addition, the aforementioned variables were also used in the assessment of instructional efficiency. The results of this study have shown that a strategy that relies on the application of a chemistry triplet model had a positive impact on the performance of the respondents, and that it had an equally positive effect on the performance of both male and female respondents. It was also shown that this kind of instruction had a positive effect on the amount of invested mental effort by both male and female students, which eventually resulted in greater efficiency of students in the experimental group in solving the majority of problems (Milenković, Segedinac, & Hrin, 2014). It should also be noted that the applied instruction had a significant influence on the elimination of students' misconceptions (Milenković, Hrin, Segedinac, & Horvat, 2016a).

Linking the Cognitive Load Theory and Constructivist Theory of meaningful learning, Hrin, Fahmy, Segedinac and Milenković (2016a) have developed Model 2, which emphasises the potential use of the systemic approach, or more precisely systemic synthesis questions [SSynQs], as efficient instructional tools in secondary school organic chemistry teaching and learning. The systemic approach to teaching and learning chemistry was designed, presented, implemented and evaluated for the first time by Fahmy and Lagowski (2003). Examining the structure of concept maps, these authors designed systemic

diagrams and systemic assessment questions as an interacting system of arranged concepts in which all relations between the set of concepts are clearly stated (Fahmy & Lagowski, 2003). There are several different types of systemic assessment questions. One example of a systemic synthesis question [SSynQ] designed for the teaching and learning of hydrocarbons is presented in Figure 1. Besides higher performances in the final testing, secondary school students from one high school from Novi Sad, Republic of Serbia, who were exposed to [SSynQs] in organic chemistry classes invested lower levels of mental effort in comparison to students who were subjected to the traditional instructional method (i.e., teacher lecturing, discussion sections, solving conventional problems). The correlation between the students' performances and invested mental effort allowed the researchers to analyse the real instructional efficiency of both applied instructional methods: [SSynQs] and traditional. A value of high, positive instructional efficiency was calculated for the applied instructional method in the experimental group, whereas a low, negative value of instructional efficiency was calculated for the traditional instructional method applied in the control group. It was emphasised that the application of [SSynQs] was more suited to female students than male students. As possible reasons for this, the characteristics of [SSynQs] as teaching and learning tools as well as learning style differences between genders, were noted. In addition to being characterised as efficient instructional tools focused on helping students to overcome difficulties in learning organic chemistry content (Hrin et al., 2016a; Hrin, Milenković, & Segedinac, 2016b), after conducting an exploratory factor analysis of the obtained data, [SSynQs] were characterised as highly effective, valid and reliable tools for assessing students' meaningful understanding (Hrin et al., 2016b).

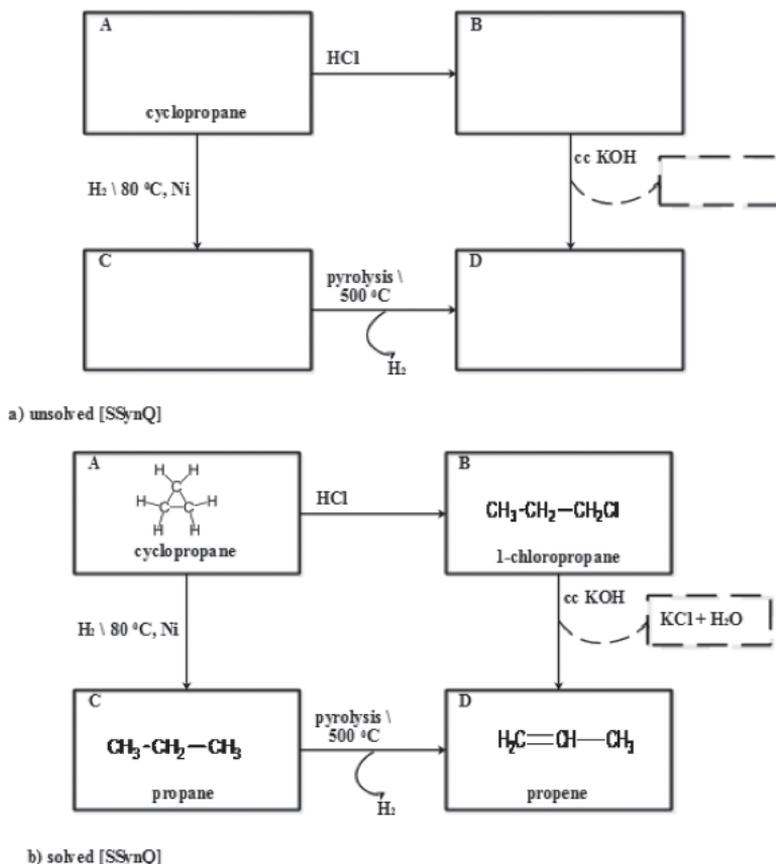


Figure 1. Example of an [SSynQ] designed for the teaching and learning of hydrocarbons

Construction and Validation of Assessment Tools

The second direction of research relates to the development and validation of teaching tools for (i) determining students' misconceptions, (ii) evaluating the conceptual understanding of chemistry content, (iii) system thinking assessment, and (iv) examining students' capacity to understand and reflect on written texts.

Two-tier and three-tier multiple-choice tests have been constructed to identify student misconceptions. Taking into account directions from the previous studies, test tasks were constructed in such a way that the first-tier contains a content problem, the second-tier contains a reasonable explanation of the first-tier question, and the third-tier is called a confidence tier, where students indicate whether they are sure of their answers and confident that they

understand the content of the task (Chandrasegaran, Treagust, & Mocerino, 2007; Cetin-Dindar & Geban, 2011). Contrary to common multiple-choice items, multi-tier items reduce the ability to guess the correct answers and enable more accurate identification of students' misconceptions. Within the CCE, the designed two-tier and three-tier instruments were validated and, on the basis of the results, a large number of misconceptions in the field of inorganic chemistry was identified among secondary school students (Milenković, Segedinac, Hrin, & Horvat, 2016), as well as in the field of biochemistry among students of pharmacy (Milenković et al., 2016a). An example of one three-tier multiple-choice item included in the research is presented below.

1. Circle the letter of the correct answer. Which of the following compounds **does not give** a red coloured product by reaction with Fehling's solution?

- a. Lactose
- b. Mannose
- c. Sucrose
- d. Fructose

The reason for your answer is:

- a. Sugars whose molecules contain an aldehyde group cannot be oxidised by weak oxidising agents.
- b. Sugars whose molecules contain a keto group cannot be oxidised by weak oxidising agents.
- c. Disaccharides whose molecules do not contain a free hemiacetal group cannot be oxidised by weak oxidising agents.
- d. Disaccharides whose molecules contain a free hemiacetal group cannot be oxidised by weak oxidising agents.

Are you sure of your answers?

- a. Yes
- b. No

In addition, misconceptions that occur among students who are gifted for chemistry, i.e., students involved in national chemistry competitions, have also been analysed (Milenković, Hrin, Segedinac, & Horvat, 2016b).

In order to examine and compare the quality of the cognitive structures of secondary school students and pre-service chemistry teachers (who were in their final (fourth) year of study towards a bachelor's chemistry degree) in the organic chemistry domain, a new form of [SSynQs] were applied in a study by Hrin, Milenković, and Segedinac (2018). In our previous studies (Hrin et al., 2016a, 2016b; Hrin, Milenković, Segedinac, & Horvat, 2016c, 2017), [SSynQs] had a more constrained format in which students should have recognised defined relations or some initial concepts that were missing (i.e., filling empty fields in the provided diagrammatic form, as shown in Figure 1). In the new study, however, our intention was to analyse the students' and pre-service chemistry teachers' thoughts about organic chemistry compounds using so-called student-generated [SSynQs] (Hrin et al., 2018). This type of [SSynQ] is an individual visual representation of the closed framework of the provided concepts, in which, within the organic chemistry domain, the participant should establish proper relations between organic chemistry compounds using labelled lines with reagents and/or reaction conditions. Using the described student-generated [SSynQs], the overall quality of the cognitive structures, the size (extent) and strength (complexity) of the conceptual structures, were analysed. Observing the written responses of our participants, the results showed that both high school students and pre-service chemistry teachers had a relatively good familiarity with IUPAC naming and the chemical structures of a wide range of organic chemistry compounds except for ethers, which have a substantial quantity of conceptual structures. On the other hand, the strength of the conceptual structures (i.e., inter-correlations between organic chemistry concepts) was evaluated as weak for high school students, and medium for pre-service chemistry teachers. In addition, it was important that we were able to identify the main learning difficulties, accompanied by a lack of understanding (potential misconceptions) with regard to the chemical properties and relations of organic compounds in both high school students and pre-service chemistry teachers.

Taking into account the fact that, within the traditional instructional method, teachers usually pass on facts to students that are not properly linked to other facts, but are fragmented or chunked, two studies were conducted by the same team of researchers (Hrin et al., 2016c, 2017) in order to work on the development and assessment of one of the higher-order thinking skills: systems thinking, defined as the ability to more deeply understand and interpret the characteristics of complex systems (Evagorou, Korfiatis, Nicolaou, & Constantinou, 2009). The importance of such understanding has recently been recognised in chemical education. Firstly, secondary school students' difficulties

in dealing with complex organic chemistry systems were considered in both studies (Hrin et al., 2016c, 2017). Then, two parallel groups were formed, each of which was subjected to different learning environments. This enabled us to examine the benefit of [SSynQs] as instructional tools that may help students in developing systems thinking skills, comparing them with traditional instruction. In the first study (Hrin et al., 2016c), three different types of systems thinking were analysed in both groups: structural systems thinking, level I of procedural systems thinking, and level II of procedural systems thinking. The students exposed to the [SSynQs] achieved higher performance scores in all of the aforementioned types of systems thinking, with the greatest difference between the groups being found in the most complex type: in level II of procedural systems thinking. In our second study (Hrin et al., 2017), the scoring rubric was developed to evaluate students' responses to [SSynQs]. Four levels of systems thinking were defined, and the findings showed that differences between the two groups' abilities to think systemically grow linearly with the complexity of these levels. The students subjected to [SSynQs] made meaningful progress, reaching the highest levels of systems thinking. Observing gender as an independent variable, it was found that the female students in the experimental group outperformed the male students, demonstrating a better aptitude for dynamic and cyclic systems thinking. In this part, the study was linked with our previous results (Hrin et al., 2016a), highlighting the need to discuss this issue in more detail in our future research.

Finally, tools to examine students' capacity to understand written texts, i.e., to examine the influence of the context of the task on student achievement and invested mental effort, have been developed (Milenković, Segedinac, Hrin, & Gajić, 2015). In this research, tasks were constructed in three levels of context complexity (tasks without context, and tasks with moderate and rich context). Within each task, there was a seven-point Likert type scale. The results of the research showed that students were most successful in solving tasks without context (they achieved high performances while investing small amounts of mental effort), while their efficiency in solving tasks with a moderate and rich context was considerably weaker. These results indicated the problem of the functional reading of respondents involved in this research, that is, problems that include finding, selecting, interpreting and evaluating information from a broad textual context.

Dissemination of the Results and Implications for Further Research

The results of our latest research were disseminated among chemistry teachers within the three-year accredited CPD programme Contemporary Forms of Evaluation in Teaching Chemistry. To date, the CPD programme has been executed three times, with a total of 64 primary and secondary school chemistry teachers taking part in the first year of implementation. It should be emphasised that the innovations in knowledge evaluation were very well accepted by chemistry teachers, who evaluated the programme with a very high grade (3.78 out of 4.00).

Future research will be oriented towards the construction of new rubrics for the assessment of cognitive complexity for various teaching topics; the development of four-tier diagnostic instruments as the most reliable tools for the identification of students' misconceptions; the application of eye-tracking methodology to examine the quality of student cognitive structures; and, last but not least, textbook analysis as a possible source of students' misconceptions and misunderstandings, with a special focus on textbook illustrations.

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