A CONTRIBUTION TO SCIENCE FOR ALL: LEARNING ABOUT POLYMERS

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Abstract

The 21st century is already marked as the century of synthetic polymer materials and their presence in our daily lives makes them unavoidable in chemistry education. The theme of Synthetic polymers is rather extensive, therefore only contents necessary to any student (individual) should be chosen.
In the present paper, synthetic polymers are considered as a necessity in everyday life, in technology and economy of the contemporary world, as well as potential pollutants of the environment. Knowledge about basic procedures for polymer synthesis, their physical and chemical properties, ways of degradation, all this makes possible for every individual to properly choose and utilize various synthetic materials in diverse areas where they are used. This way provides the perception of the interactive relation between science and society.
The teaching of the theme Polymers enabled students to use knowledge of chemistry from various fields in a situation different from the one where it had been acquired and to link the concepts into a single system. The teaching of the theme proceeded through the discussion and enquiry-based experiments in work with small groups during two teaching hours (1.5 h). The investigation was carried out with a group of high school students (85). Statistically significant difference ($p<0.001$) in the achieved results at final testing (73.4%) compared to initial testing (32.6%), especially in tasks related to comprehension and application of chemistry concepts, indicates that the tested method of work is applicable in school practice.
Key words: *inclusive science, synthetic polymers, enquiry-based experiments, learning/teaching chemistry, high school, secondary-level education.*

Introduction

The demands facing teaching/learning all sciences, hence natural sciences too, are numerous in the 21st century. Science must be available to anyone, which means that at school science must be inclusive but not exclusive (Fensham, 1985, 1987 & 1988). It is necessary to develop comprehensive thinking i.e. critical and creative thinking through the teaching/learning process. Teaching/learning of natural sciences should proceed through practical work, because student scientific-research activities are developed in this way (Lamanauskas, 2008). In the contemporary education, science, technology and society should be linked up. This fact is supported by numerous programs designed within the STS project (Science, Technology, Society Project), which are used worldwide. Environmental education (EE) of students of all ages is indispensable and compulsory (Mayer, 1990). One of the imperatives in teaching natural sciences is that it should motivate students for lifelong knowledge acquisition (Mammino, 2005; Nakhleh, 1992). To embrace all mentioned, careful selection of teaching contents, teaching methods and forms of work should be performed for all school subjects and age of students. Education in a certain science must reflect methodologically the science it is related to i.e. it should bring closer to the student its area and research methods (Faust, 1989). Teaching contents of every science must show (define) its place in exploring the world around us and its connection to other sciences in solving problems that emerge in everyday life and economy. It is evident from the above mentioned that chemistry, being a central natural science (Brown, 1997), is facing numerous tasks. It is through teaching/learning chemistry that very many contents related to everyday life situations can be considered. These are: human health, food and hunger in the world, dangerous substances, energy sources, drinking water, environment protection, mineral resources, environment impact on the endangerment and extinction of plant and animal species… The enumerated examples also show that fixed borderlines cannot be drawn between sciences.

When it comes to new materials, synthetic polymers are the top materials. In the 20th century it was evident that the 21st century would be the era of synthetic polymers (Jovanovic, 2004). The presence of synthetic polymers in our daily lives makes them unavoidable in chemistry education, but also indicates that their place and method of teaching them must be changed in chemistry curricula at all educational levels. Today, in Serbia, synthetic polymers are mainly taught as products of one type of reactions entered into by some classes of organic compounds, mainly alkenes and alkadienes, with presenting a single concrete example and its application. Modern times – the era of polymers – require knowledge about the properties and changes of those substances (Gilbert, 2001). The current curricula are impeding the possibility of associating polymers structure with their application, nor are they pointing to contemporary trends in polymer industry. Starting from the above mentioned (as well as from the slogan *Science for All*), the aim of the present work was to choose the contents related to synthetic polymers that will make possible for students to understand the necessity for their broad application in diverse areas of technology, economy and in everyday life but, at the same time, the consequences of their improper utilization. In addition, it was needed to choose appropriate methods to present the chosen contents and to test student achievement accomplished by applying those methods.

Starting Points for the Choice of Contents

In setting up this investigation, we started from the following questions:

– What should a secondary school student know about synthetic polymer materials from abundant data on polymers? Is it important to know how people got an idea to make macromolecules? Should one know that substances belonging to various classes of compounds are used as monomers? Is classification of polymers important? What group of polymers would students arrange nitrocellulose into?

– How can we use previously acquired knowledge of general, organic and inorganic chemistry to teach synthetic polymers? When is the most suitable time during the teaching process to talk about synthetic polymers? What is the structure of polymers? How do physical and chemical properties of polymers depend on their composition and structure? How does the use of polymers depend on their composition and structure? How complex is the technological procedure of polymer production? Where is polymer production industry put up? Does polymer production endanger human health and environment? What determines the cost of polymer production? Is there a polymer paradox related to environment protection?

The answers to all posed questions indicate that they are involving science, technology, economy and society all the time. The possibility of associating science, society, economy and technology through synthetic polymers is shown in Figure 1.

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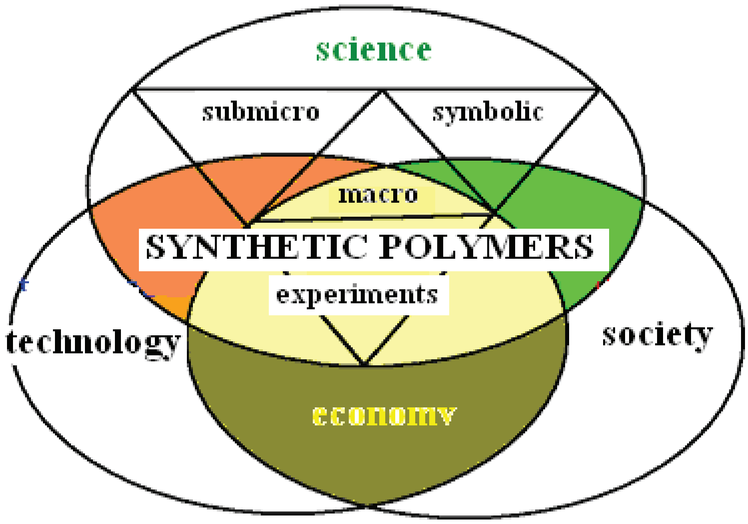


Figure 1. Associating science, society, economy and technology through synthetic polymers.

What can each of the presented segments (science, technology, economy and society) tell us about polymers?

The science of polymers deals with their structure, how they are synthesized, their physical and chemical properties and permanent research on new monomers and polymers whose characteristics are adapted to a certain application. This indicates that chemistry is a basic science of polymers and that it considers each substance that can be a monomer or will become a polymer at macro-, submicro- and symbolic level (Johnstone, 1982; Gabel, 1999). The macro level considers substances used to produce synthetic polymers, choice of monomers, sources of monomers, conditions of polymerization reaction (polymerization according to the type of free radicals, polycondensation, polyaddition), properties of the obtained product (thermoplasts, elastomers and thermohardening polymers). The submicro level deals with molecular structure of polymers i.e. types of chemical bonds in monomers, additives and polymers. The symbolic level is concerned with names and identification codes of polymers. Many codes are found on products used in everyday life and consumers of these products should be acquainted with their meaning.

The knowledge of **polymer production technology** can be useful for students in very many ways. The story of the **history of polymer production procedures** is an appropriate material for discussion where critical and creative thinking are developed. Historic data provide for the perception of how the idea of discoveries develops and how long the road that one discovery goes by is. Questions related to polymer production technology are numerous: Why it was only around 1850 that people started to work on chemical changes of natural rubber even though the knowledge of polymers dated back to the 16th century? Why did the abrupt development of polymer technology begin as late as in the early decades of the 20th century (1930)? How is it possible that industrial production of polymers had started before the knowledge about their molecular structure emerged? How is it explained that the “golden period” of polymer materials is the 1930-1960 period? What is the nature of relation between petrochemistry and polymer production? Why did the number of new monomers decline after 1960 even though the total production of polymers was increased? What type of polymer materials are produced the most and why? Why are the production and consumption of polymer materials so high compared to the production of other materials? Can polymers be used as raw materials to obtain energy and thereby substitute oil and gas? Is polymer production technology that what is called “dirty chemistry”? Does polymer production technology demand a highly skilled producer?

The role of polymers in **economy** of the contemporary world is a sphere that students should be also familiar with. They should understand why economy is a demanding consumer of polymers. What directs the economy of some country to polymer materials production? Are large-scale producers of polymer materials their biggest consumers at the same time? Why do regions differ in polymer materials consumption per capita? Is consumption of polymer materials per capita rising or declining across the world? What are the reasons for rising/declining of polymer materials consumption? What is the argumentation of one country's economy to increase or decrease polymer materials production? What is the attitude of economy towards polymer waste recycling?

Society, still greedy polymer consumer, must have citizens who understand the advantages and disadvantages of polymer materials. To achieve this, each individual should possess basic knowledge of polymers. It is only in this way that he/she will be able to choose, utilize, process or destroy them properly. In everyday life we more often talk about environment pollution by synthetic polymers than about their wide use, for example, in medicine, protection of paintings and objects. Synthetic polymers are commonly associated with their use in textile industry, sports equipment, car and aircraft industry, construction but more commonly with various packaging materials. It is little known and talked about how much energy is saved if polystyrene is used as an insulating material in construction, how much fuel is saved in transportation if polymers are used as packaging material. Students should understand that polymer materials possess energy of raw materials that they are produced from and that they can be used as fuel. It must be spoken much more about how much polymers influence the development of other technologies, for example, microelectronics. It is often the case that inappropriate attitude of people towards synthetic polymer materials leads to a negative image that is created about them when it comes to environment protection.

Consideration of mentioned and other similar questions makes possible for students to perceive the relation science ↔ technology ↔ society. Historic approach connects natural and social sciences and shows their mutual influence. At the same time, students learn how to advance hypotheses, collect arguments from various areas to confirm them. In this way, they are preparing for future responsible problem-solving in daily life. It is through this form of teaching / learning that conditions are provided for developing critical attitude and creative thinking.

It results from all mentioned reasons that during chemistry hours the polymers should be presented in a way that will provide for students to accept these compounds as a necessary material that one should know how to handle properly. Since understanding and application of the concept of synthetic polymers call for knowledge from diverse areas of chemistry, students are in a position to apply that knowledge, differing from the situation where it was separately acquired. The concepts are thus linked into a system and knowledge becomes operational.

Methodology of Research

The selection of contents and methods

In the teaching process the presentation of synthetic polymers followed learning of general, organic and inorganic chemistry. That enabled students to draw conclusions about polymers to a great extent independently.

At the beginning of the pedagogical experiment through a test comprising 10 tasks knowledge check was done (from those areas) needed for understanding of how polymers are obtained, their properties and polymer application in particular. The test also contained questions related to the application of synthetic polymers in everyday life. Test results were guidelines for teachers to prepare additional text about polymers.

To achieve the above mentioned aim i.e. understanding of the necessity of wide use of polymers in everyday life as well as of the consequences of their improper use, a choice was made of:

• Contents representing the relation: polymer structure ↔ properties ↔ application. Data given in Table 1 were used for the purpose.

• Demonstration experiments and experiments for a laboratory exercise. Laboratory-experimental method of work was chosen because it makes possible for the student to independently arrive at the perception of the mentioned relation by applying the principle of first-hand obviousness (Gilbert, 2008), and thereafter at understanding and application of acquired knowledge. In the experiments for a laboratory exercise the polymers (PS, PE, PVC, PET, PMMA, PTFE, PIP) were used as basic chemicals i.e. samples of various materials and objects (polystyrene, a bag, a window frame, a plastic bottle, glass for sunglasses, a pan coating) that students come across every day. The teaching of the theme proceeded through a discussion and enquiry-based experiments in work in small groups.

Table 1. Materials and objects from the environment, polymers they are produced from, and properties that their application is based on in everyday life.

Object	Polymer	Code	Property	Application in everyday life
nylon tights	nylon 6, 6	PA 6	heat (non) conductivity, elasticity, insolubility in water	items of clothing, greenhouses
PVC window, cables	polyvinylchloride	PVC	Heat, electricity and sound (non)conductivity, hardness, insolubility in water	structural carpentry, sacks for vegetables, bottles for vegetable oils
plastic bottle	polyethylene-terephthalate	PET	state of matter, smell, density, brittleness, chemical inertness	packaging materials for carbonated drinks
polystyrene board	polystyrene	PS	insolubility in water, relative density against water, nonreactivity, heat nonconductivity, light-weight, relative density against water	structural insulating materials, buoys, packaging materials
plastic bag	polyethylene	PE	biodegradability,behavior in heating and burning, chemical reactivity, insolubility in water	packaging material, toys, bottles for detergents, foils, energy source
transparent board	polymethacrylate	PMMA	hardness, brittleness, transparency	substitute for glass, (construction, car and aircraft industry, sunglasses)
condom	polyisopropene	PIP	elasticity,solubility in organic solvents, insolubility in water	protective rubber

bullet-proof vest	kevlar	/	toughness, nonelasticity, mechanical and heat resistance	ultra strong fibers (bullet-proof vests, ironing boards, diving and space suits)
rubber glove	polypropene	PP	elasticity, insolubility in water, nonreactivity with acids and bases	packaging materials for margarine and yogurt, cookware for microwave ovens, protection at work and in household cleaning

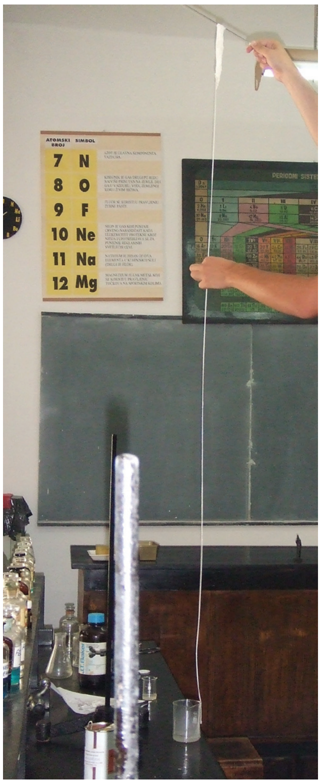
In the classroom

Table 2 presents the sequence of steps in realizing the chosen contents about polymers, with pointed out objectives. Polymers were taught for two teaching hours (90 min.). At the beginning of the first hour an enquiry-based demonstration experiment was performed – nylon synthesis from adipoyl-dichloride (in non-polar solvent) and 1, 6-diamynohexane (in water) (Figure 2). During the experiment (10 min) students presented their perceptions and wrote them down on a worksheet. After the demonstration, there followed the discussion guided by teacher's questions (what was the state of the starting substances, but what state produces the reactions; why were two layers formed; how is the reaction between two substances solved in two not intermixed solvents possible; why did one substance evaporate during the reaction; what substance is it; why did organic solvent evaporate but not water; what is the thermal effect of the reaction; what type of reaction is it). An 18-min discussion ended in writing the equation of nylon synthesis. All mentioned made possible for students to do the following task: writing the equation of PUR-foam synthesis from toluene-diisocyanate. Thereafter, an illustrative-demonstration experiment (2 min) of PUR-foam synthesis was performed by directly mixing diisocyanate reactants and diol (without solvent presence) and the results of the experiment were discussed (15 min).

During the second teaching hour a laboratory exercise was done in groups of three students each (20 min). The first task was writing of the equation for polystyrene synthesis. Testing of its physical (smell, state of matter, hardness, elasticity, toughness / brittleness, (un)solubility in water, acetone, chloroform, relative density against water and metals – aluminium, copper) and chemical properties (reactions with acids, bases, salts, potassium permanganate) was carried out. After that, a representative of each group presented their perceptions on polystyrene properties and explained them by relating them to molecular structure. On the basis of each property, students enumerated the applications of polystyrene in everyday life. The discussion was extended to examples of other polymers and their application founded on the above mentioned properties (20 min). The objective was thus achieved – an understanding of the relation structure ↔ property ↔ polymer application.

At the end of the hour one student performed an enquiry-based demonstration experiment – heating of the ends of a metal plate and Plexiglas in a flame. The discussion (5 min) on the cause of perceived difference in the behavior of the two materials at raised temperature, i.e. polymer structure and metal chemical bond, resulted in understanding of polymer application as an insulator and metal as a conductor.

Table 2. The sequence of steps and methods applied to realize the contents about polymers.

1. Demonstration experiments Objective: *Getting acquainted with methods of polymer production* Nylon synthesis *polycondensation in base medium* (adipoil-dichloride, hexamethylendiamine) Pur foam synthesis *polyaddition* (diisocyanate, diol) **2. Discussion and drawing of conclusions:** **- defining and relation between the concepts of macromolecule and polymer** **- writing of synthesis equations for mentioned polymers from monomers** **3. Experiments for a laboratory exercise** Objective: *To link polymers properties to their structure* *To link polymers properties to their application and ecological problem of bionondegradability* Testing of polymer physical properties: State of matter, smell, hardness, elasticity, brittleness, solubility (water, acetone, chloroform), density (compared to water and metals – aluminum, iron, and copper) Testing of polymer chemical properties: Polymer reactivity with acids (HCl), bases (NaOH) and oxidizing substances ($KMnO_4$) **4. Demonstration experiment** Objective: *To link polymers properties to their structure* *To link polymers properties to their application and ecological problem of bionondegradability* Testing of polymer properties (polymethylmetacrylate) when heated **5. Discussion and drawing of conclusions:** **- perception of relation between structure, properties and polymer application** **- writing of synthesis equations for polymers (PS, PE, PVC, PET, PMMA, PTFE) that polystyrene, a bag, a window frame, a plastic bottle, glass for sunglasses, pan coating were all produced from corresponding monomers.**	 **Figure 2. Nylon synthesis during a chemistry hour**

Homework assignment involved writing of polymer formula (and their monomers), from which objects of everyday life are made (PVC window, a pan Teflon, sunglasses, a plastic bag, a plastic bottle, condom, bullet-proof vest).

The investigation was carried out using a sample of 85 high school students of vocational education in natural sciences (age 17–18).

Evaluation of successfulness level of the applied method of work was performed through final testing. The results obtained for different tasks and level of demand (reproduction level, understanding and application level) were expressed as the means ± standard deviation (SD). The statistical analysis was performed by the Student’s t-test and non-parametric Mann–Whitney *U*-test.

Results and Discussion

Mean value for student achievement in final test (73.4%) is statistically significantly higher ($p<0.001$) compared to the mean obtained for initial test (32.6%). A more detailed analysis of the results per demand (Tables 3 & 4) reflects student progress much better.

The analysis of results obtained for the tasks at reproduction level

Table 3 shows the results achieved in initial and final tests for the tasks at reproduction level. From the achieved results it is evident that the least progress (2–6%) was made for demands related to defining the concepts of macromolecule, polymer, polymerization, and for enumerating the examples of polymers (mean values in initial and final test: 49±6.3% and 52.5±5.9%).

The recognition of objects (Q-PACK packaging material, PET bottle, polystyrene boards, PVC frames, tights, tires and condoms) produced from polymers was checked through a multiple-choice task. Students were very successful in choosing the objects at both initial and final tests. However, the achievement in final test (94.1±3.5%) is statistically significantly higher ($p<0.05$) compared to obtained for initial test (85.1±7.1%).

A low number of students (1-4%) gave incorrect answers, choosing ceramic washbasin, concrete, coins and glass bottle as objects/materials produced from polymers. It should be pointed out that at initial testing 32.0% of students chose aluminum foil as a polymer material (most likely due to its widespread use as a foil). However, at final testing aluminum foil was also classified into polymer materials by 9.0% of students. The reason for such result, in addition to the mentioned, is in the fact that after initial testing, aluminum foil was not considered in the teaching of polymers.

The highest progress (from 31.4±26.2% to 66.6±21.8, $p<0.05$) in the group of tasks at reproduction level was achieved for knowledge about the application of certain polymers (polystyrene, polyethylene bags, nylon, PVC), what was one of the main goals of this approach.

At initial testing right away, a high per cent of students (65%) assumed that synthetic polymers are toxic and that polymer production process is always harmful to the environment (62%). At final test that per cent is always lower (below 20%), explaining that human factor is always responsible for how synthetic polymers are produced and utilized, therefore it depends on humans whether polymers i.e. their monomers will be pollutants or not.

Table 3. Results achieved in initial and final test for demands at reproduction level.

Demands in tasks	Students' answers	Per cent of answers		Progress (%)
		Initial test	Final test	
Defining the concept of macromolecule		56	58	2
Defining the concept of polymer		48	49	1
Defining the concept of polymerization		41	46	5
Giving examples of 3 synthetic polymers		51	57	6
	Mean ± SD	49±6.3	52.5±5.9	

Recognition of objects produced from polymers	PET bottle	88	97	9
	Polystyrene boards	72	98	26
	Q-PACK packaging material	86	93	7
	Condoms	90	96	6
	Tights	81	89	8
	Tire	94	96	2
	PVC frames	85	90	5
	Mean ± SD	85.1±7.1	94.1±3.5[a]	
	Aluminum foil *	32	9	23
	Ceramic washbasin*	1	0	1
	Concrete *	1	1	0
	Coins *	3	3	0
	Glass bottle *	4	2	2
The application of certain polymers	Polystyrene	48	84	36
	Polyethene	22	75	53
	Nylon	16	61	45
	PVC	68	82	14
	Polyisoprene	3	31	28
	Mean ± SD	31.4±26.2	66.6±21.8[a]	
Are polymers pollutants?	Yes*	36	13	23
	Yes, if they are not used properly	29	68	39
	No*	22	11	11
	I do not know	13	8	5
Is polymer production process harmful to the environment?	Yes*	62	18	44
	Yes, if prescribed production conditions are not controlled	20	58	38
	No*	6	12	-6
	I do not know	12	12	0

* incorrect answers; [a] $p<0.05$ compared with the initial test

The analysis of results obtained for the tasks at understanding and application level

Student achievement in tasks for cognitive levels of understanding and application was considerably increased in final compared to initial testing (Table 4).

Chemistry literacy was checked through a number of tasks. The difference between the total achievements in final (42.2 ± 4.6 %) and initial test (4.7 ± 1.6 %) is very significant ($p<0.001$, $t=18.74$, critical value $t_6=3.71$). In initial test, the results for writing synthesis equations of various polymers are unexpectedly very low as the polymerization reaction was presented in alkenes. After teaching polymers in the way presented above, the equations of polyethene, polystyrene and nylon synthesis were much more successfully written (progress by 36.0%, 29.0% and 46.0% respectively). Similar results were obtained for the demand of writing the polymer structural formulas. In initial test the per cent of correct answers was only about 5.0% and in final over 40.0%.

For the group of questions with which the relation between structure and properties of polymers were tested, the results obtained in final test (51.8±15.6%) are also significantly ($p<0.01$, using t-test: $t=5.15$, critical value $t_4=4.60$; and $p<0.05$ using the Mann–Whitney *U*-test) higher compared to the initial test (9±5.7 %). By discussing the results of demonstration experiments, students revised and systematized knowledge about functional groups of organic compounds. Experiments and practical examples from everyday life contributed to students' utilization of knowledge about chemical structure, especially about properties of functional groups, and symbols, and perception of their application to better understand everyday life. The contribution of laboratory exercise to the perception and understanding of relation between polymer structure and physical properties (solubility, electrical and heat conductivity) is evidenced by the achievement results in both tests. The impact of structure on solubility of various polymers was explained by 9.0% of students in initial test and 40.0% of students in final test, and on electrical conductivity 16.0% and 42.0% respectively. Even though all students knew from everyday life that plastics soften when heated, the structure impact on polymer behavior at temperature rise (melting, boiling) was explained only by 2.0% of students in initial test. In final test the achievement was 74%.

A great progress (from 21.6±13.8% of corect answers in inital test to 57.9±19.6% in final test, $p<0.01$, using t-test: $t=4.01$, critical value $t_{10}=3.17$; and $p<0.05$ using the Mann–Whitney *U*-test) was made in explaining the application of polymers as light-weight materials (24→78%), as insulators (29 → 70%), in packaging materials (non)resistant to a certain chemical (acids, 21 → 52%; oxidizing substance, 17 → 40%; acetone, 15 → 48%; water, 45 → 84%), as a material for cookware coating (0 → 33%). The explanation that polymers are hard-biodegradable materials but can be recycled was given by only 8% of students at initial test and 43% at final test. After the laboratory exercise, demonstration experiments and discussion on experiment results had been all done, the knowledge of organic chemistry became applicable.

Table 4. Results achieved in initial and final test for demands at understanding and application level.

Demands in tasks	Students' answers		% of answers		Progress (%)
			Initial test	Final test	
Writing of synthesis equations of:	Polyethene		7	43	36
	Polystyrene		5	34	29
	Nylon		2	48	46
Writing of polymer structural formulas from assigned monomers	Polyvinylchloride		5	43	38
	Polypropene		4	41	37
	Polyglycol		5	44	39
Mean ± SD			4.7±1.6	42.2±4.6[a]	
Perception of functional groups in a polymer molecule			9	51	42
Impact of structure on polymer physical properties:	polymer solubility	Explanation	9	40	31
	electrical conductivity	Explanation	16	42	26
	polymer behavior when heated	Explanation	2	74	72

Mean ± SD			9±5.7	51.8±15.6[b,c]	
Application of polymers as:	light-weight materials	Explanation	24	78	54
	Insulators	Explanation	29	70	41
	acid-resistant packaging material	Explanation	21	52	31
	packaging material resistant to oxidizing substance	Explanation	17	40	23
	water-resistant materials	Explanation	45	84	39
	cookware-coating material (teflon)	Explanation	0	33	33
Is condom wetted with acetone functional?	Explanation		15	48	33
Mean ± SD			21.6±13.8	57.9±19.6[b,c]	
Are polymers pollutants?	Explanation		8	43	35

incorrect answers; [a] $p<0.001$; [b] $p<0.01$ (t-test), [c] $p<0.05$ (Mann–Whitney U-test) compared with the initial test

Instead of the Conclusion

The 21st century requires from each individual the mastery of basic knowledge about synthetic polymers concerning their wide use in everyday life. Of natural sciences, chemistry, being a science about substances, their properties and changes should make possible for students to understand the role and place of polymers in technology, economy and society. As for teaching contents, the polymers can no longer be taught as a product of polymerization reaction of unsaturated carbon hydrides, because such approach contributes only partially to chemistry literacy. In the era of polymers more extended knowledge is needed about the relation between the structure and properties of various polymers that their application, keeping and disposal is based on. It is also needed to view polymers as substances having positive ecological balance, "keeping" the energy of raw materials they are produced from, thereby providing for possibility to be used as fuel.

To research the appropriate and find out optimal strategies of teaching/learning that make possible to acquire such knowledge is a basic task of methodic of school subjects. Methods of teaching polymers, presented in this work, enable students to acquire mentioned knowledge that, at the same time, provides for positive attitude towards this type of compounds, science of polymers, polymer technology and necessity for polymer application.

Concerning the achieved results, it can be considered that student motivation for learning chemistry is also largely increased by using such approach, compared to traditional method of teaching those compounds. This assumption is also underpinned by student activity: asking questions, appropriate distribution of experimental tasks performance in a group, attitude towards work and work place, interest in extra work, desire to try new reactions, whereby the atmosphere of a real exploratory chemistry laboratory at school was achieved.

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