An investigation of the properties of vitamin C through a laboratory session

Una investigación sobre las propiedades de la vitamina C a través de una sesión de laboratorio

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Abstract

To increase the cognitive level of attained knowledge about vitamins, the present paper reports on a combined method of literature study, problem solving by experiments, and discussion. Through enquiry-based experiments, pupils were to identify vitamin C among three given substances, examine properties of the "detected" vitamin through reactions with various substances (iodine, silver nitrate, potassium permanganate, copper (II) sulfate and Fehling solution) and on the basis of the in vitro experiment perceive its physiological role. Pupils' achievement was assessed using the results obtained for pre- and post-tests as well as the analysis of worksheets. Obtained results demonstrate that such a method of teaching vitamins to pupils provides for: perceiving vitamins' physical and chemical properties by applying previously attained knowledge about organic and inorganic compounds, developing abilities for problem solving through enquiry-based experiments, developing manual skills, associating teaching contents with everyday life, increasing pupil motivation, and lastly systematizing of teaching contents.

Key words: *vitamin C, properties, physiological role, enquiry-based experiments*

Resumen

Este artículo trata el tema de las vitaminas con ayuda de los métodos de estudios de literatura, resolución de problemas y discusiones para aumentar el nivel cognoscitivo de los estudiantes. A través de los experimentos, los alumnos pudieron identificar la vitamina C entre tres sustancias dadas, examinar las propiedades de la vitamina C por reacciones con varias sustancias (el yodo, el nitrato de plata, permanganato de potasio, el sulfato de cobre (II) y el reactivo de Fehling) y por el experimento *in vitro*, determinar su papel fisiológico. El logro de los alumnos fue controlado utilizando el resultado obtenido en la pre y la posprueba así como en el análisis de proyectos de trabajo. Los resultados obtenidos demuestran que este método de enseñanza permite que los estudiantes perciban las propiedades físicas y químicas de las vitaminas aplicando los conocimientos previos sobre los compuestos orgánicos e inorgánicos, desarrollando habilidades para la resolución de problemas por experimentos creativos. También ellos obtienen, habilidades manuales, asociando al contenido docente con la vida cotidiana, aumentando su motivación y sistematizando el contenido docente del curso.

Palabras clave: *vitamina C, propiedades, papel fisiológico, experimentos creativos.*

INTRODUCTION

Basic knowledge about vitamins represents "chemical literacy". These thirteen small organic molecules take part in a large number of chemical reactions in living organisms. Since they cannot be synthesized by the human body, vitamins must be essential ingredients of man's daily diet. Thus, knowledge about vitamins becomes indispensable for selecting a proper choice of foodstuffs. There are numerous papers which dealt with the vitamins in foods stuffs, particularly vitamin C (KANT & THOMPSON, 1997; ESPEL, 1999; PFEIFER, 1998). Knowledge about vitamins reduces the gap between the science of chemistry and everyday life (GOTT, 1979; SEAY & IRIARTE-GROSS, 2006).

On the basis of the depth of understanding and application of knowledge that the learner exhibits SKEMP (1976) differentiates two types of understanding - instrumental (knowing how) and relational (knowing why). Additionally, BUXTON (1978) distinguishes four different stages from instrumental to relational understanding; rote, observational, insightful and formal. To enhance students' understanding in chemistry three levels of chemical representations (macroscopic, submicroscopic and symbolic, JOHNSTONE, 1982) should be used. In school practice, knowledge about vitamins is most often attained as: division of vitamins, representatives, formulas, diversity of structures, importance for homeostasis maintenance, role of co-enzymes, protection from stress, necessary daily intakes, and foodstuffs containing certain vitamins. The facts thus given are rarely remembered and the overall knowledge of vitamins is mainly reduced to a sentence such as: "Vitamins are very important for functioning of the body, therefore they should be taken." That is why it was assumed that the change in approach to the attainment of the concept of vitamins would lead to that at the understanding and application level, in the sense that pupils utilize previously attained knowledge and discover vitamins' properties by themselves. One of the approaches is that in teaching and learning chemistry, knowledge about vitamins is gained through simple, enquiry-based experiments. These experiments should enable pupils to learn about the properties of substances from their own research (DE ROSE, 1980), namely to enable their independent work. Experiment should be research guided and not given as illustration of some changes (MAUDLIN, 1997, HERMAN, 1998). They should include drawing conclusions on the basis of analysis of data obtained by experimentation. Furthermore other experiments should be chosen (JOHNSTONE & WHAM, 1982).

Through enquiry-based experiments it is possible to: monitor the stability of vitamin C in a water solution and in tablets (WILK, 1976) at a raised temperature, to obtain the evidences of the functional groups and structure of vitamin, to investigate the chemical properties (WRIGHT, 2002; KUHN, 2005), and to simulate and demonstrate their role in chemical reactions in living organisms. Apart from enhancing the functional knowledge about vitamins, this way of allows for systematizing knowledge previously attained through teaching contents of general, organic and inorganic chemistry.

METHODOLOGY

This paper examines the possibility of gaining familiarity of the properties of vitamin C by problem solving through experimental work. The reasons why this vitamin was chosen, apart from being widely used, were as follows:

- the physical properties that do not visually distinguish it from numerous organic and inorganic substances (white crystals, water-soluble etc.), which allows for the setting up of situations where vitamin C is an unknown substance,
- the possibility of setting up various experiments that demand the application of a large number of concepts (pH, hydrolysis, solutions, oxidation-reduction reactions, heterocyclic compounds, cyclic esters, enediols, primary and secondary alcohols, optical isomerism etc) which pupils learned earlier in chemistry school subjects (general chemistry, inorganic and organic chemistry),
- the simple technique of performing various experiments,
- the availability of pure vitamin C in the amounts necessary for conducting the experiment, and
- the availability of reagents that can be used to examine *in vitro* physical and chemical properties of vitamin C.

To learning through problem solving during a class, the following methods were combined: experimental laboratory investigation, demonstration, work with the text, and didactic teaching? Experimental work was carried out through cooperative learning in two-pupil groups (20 pairs). The pedagogic experiment was conducted in a high school in Belgrade (Serbia). The number of pupils involved in the pedagogic experiment was 40 and their age was 18. During the three previous school years pupils learned general, inorganic and organic chemistry. The acquired knowledge provided a solid base for the teaching and learning of biologically important compounds (proteins, carbohydrates, nucleic acids, lipids, vitamins, etc.) in the present school year.

Pieces of information about vitamin C possessed by pupils from their everyday life, as well as from the introduction to teaching them about vitamins, were checked by pre-test. The test was also used to check their knowledge about the structural formula of vitamin C and the functional groups essential to its action.

The text containing basic data about vitamin C (historic facts, molecular structure, functional groups, role in a living organism, daily intake, and manner of its intake) preceded enquiry-based experiments in a laboratory session. Along with the text, pupils were given worksheets with brief

instructions of how to conduct the experiment. Perceptions and conclusions were to be written down in a worksheet.

A laboratory session comprised three enquiry-based experiments. The tasks in the experiments were:

1st experiment: "*Discover*" *vitamin C* among three unknown substances. Apart from vitamin C, pupils were given samples of aluminium sulfate (pH<7, thermally stable) and sodium benzoate (pH=7, thermally unstable). On the basis of a given text about vitamin C, pupils had to decide for themselves how to solve the problem of which substance was the vitamin C by selecting an appropriate approach.

2nd experiment: *Perform and examine the reactions* between the "discovered" vitamin C and various test substances: iodine (in the presence of starch), silver nitrate, potassium permanganate, copper (II) sulfate and Fehling solution. *Note the changes* that occurred during the reactions, *predict* the obtained products, and *make conclusions* concerning the type of reactions.

3rd experiment: *Examine the property* of iron (II) sulfate in the presence and in the absence of vitamin C (simulation of the vitamin C physiological role). Understand *the property* that vitamin C's major role is based upon in a living organism.

The experimental results and the conclusions helped initiate discussion about:

- the disorders in a human body that are caused by the deficiency of vitamin C,
- the role of vitamin C as a hydro-soluble antioxidant, a catcher of free radicals that may cause damages in a body (CIANCAGLINI, 2001; KLIPSTEIN-GROBUSCH, 1999),
- the role of vitamin C in cancer prevention, in regeneration of vitamin E,
- about foodstuffs rich in vitamins, the daily needs for vitamin C and factors that may increase the need for vitamin C (smoking, alcoholism, contraceptive pills) (MATHEWS, 2000),
- the industrial use of vitamin C (for "vitaminizing" fruit juices, preserving product's color and aroma, supplement to greases and oils in the form of ascorbyl palmitate to prevent rancidity…)

After the laboratory session, a post-test was administered comprising of questions referring to the text and laboratory session about vitamin C. Both pre- and post-test contained various types of tasks: alternative choice, multiple choice, enumerations, completions, and analyses of relations. Facts or concepts about vitamin C checked in both tests are presented in tables 1 and 2. In some tasks the same concept was checked, but the level of demand was different. It was assumed that the results would also indicate whether it is possible to apply this method of teaching to similar teaching contents (alkaloids, teaching some foodstuffs…) for systematizing them.

RESULTS AND DISCUSSION

The analysis of the results achieved at pre-test indicated insufficient knowledge about concepts related to vitamin C (mean value 43.4%). The accuracy obtained for each individual question ranged from 0 to 86.5% (Table 1). The best result (86.5%) was achieved for the question related to the pH value of the vitamin C solution. This response was probably due to its use in everyday life. The lowest results were achieved for questions connected with facts: thermal stability (8.1%), the century when it was isolated and the scientist who isolated it (8.1%). There were no correct responses to the question: "Vitamin C in the form of palmitinic acid ester is frequently a supplement to skin creams. Explain why pure vitamin C is not used." The response was to explain the mode of vitamin application. For questions where the explanation of the response was required, incomplete responses were also obtained (average 37.8%).

In the experimental problem solving of vitamin C identification (1st experiment), pupils chose to examine the water-solubility of the offered substances, the pH determination of obtained solutions, and substance thermal stability investigation (Figure 1). These examinations are crucial for a further laboratory session, because it is here that vitamin C "is chosen", which is to be examined in the other two experiments. The analysis of results showed that pupils had examined solubility of all three substances with accuracy ranging from 60 to 100%. All pupils (100%) accurately determined vitamin C solubility, but despite the simple technique, errors were made in determining aluminium sulfate solubility (60% correct responses) and sodium benzoate (95% correct responses). Irrespective of errors in determining the solubility in all obtained mixtures pH was accurately determined. The successful determination of thermal stability fell within the 30-90% range (Figure 1). At first sight the per cent of correct responses for sodium-benzoate is low (30%). However, the analysis of responses demonstrated that thermal stability of sodium benzoate was examined only by 30%. This indicates that the majority of the pupils have immediately rejected the substance whose water solution reaction is not acid, deciding not to examine its behavior at raised temperature. Therefore, results obtained for thermal stability investigations are good. The fact that all pupils discovered which unknown substance was vitamin C indicates their ability of solving problem situations.

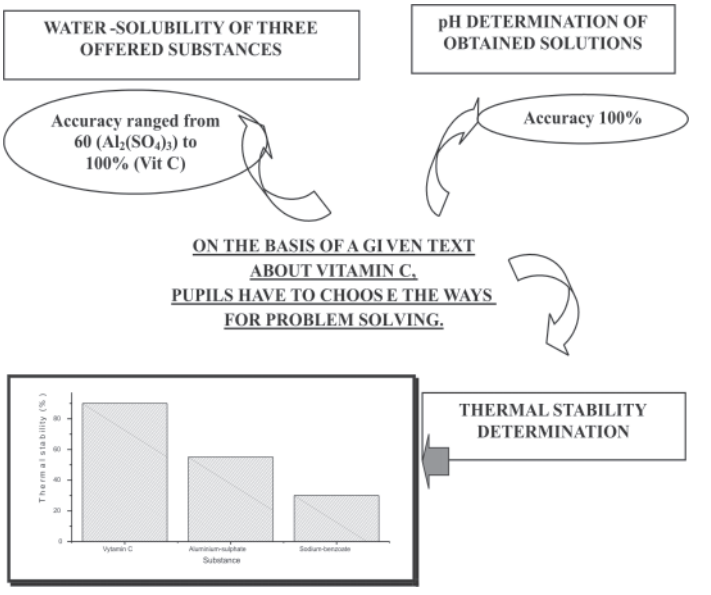

Figure 1. A survey to show the ways chosen to identify vitamin C and the accuracy achieved for its determination.

Table 1

The results obtained at initial testing

Task	Facts or concepts about the vitamin C tested in the tasks	Correct answers (%)	Incorrect answers (%)	Without answers (%)
1.	Solubility	35.1	37.8	27.0
2.	pH value of vitamin solution	86.5	10.8	2.7
3.	Form of which vitamin is used in skin creams	0.0	27	73
4.	Stability at the room temperature	27.0	69.4	8.1
5.	Thermal stability in the solution	8.1	91.9	-
6.	Structural formula and functional groups	47.3	6.8	45.9
7.	Role in a living organism	29.7	62.2	8.1
8.	Deficiency-disease	75.7	5.4	18.9
9.	Application in the prevention of disease	83.8	-	16.2
10.	Daily intake (order of magnitude)	75.7	24.3	-
11.	The historic facts (century and scientist)	8.1	16.2	75.7

To determine the property of vitamin C that enables its major role in a living organism the reactions between vitamin C and various substances (iodine, silver nitrate, potassium permanganate, copper(II) sulfate and Fehling solution) were performed and examined (2nd experiment). In addition, the pH value of the reagents was examined and recorded. On the basis of the experiment results pupils could conclude that vitamin C is a reduction means which manifested this property in both acid and alkaline solution. The results obtained for the description of the reactions and for identifying the resultant products are given in Figure 2. It can be stated that the changes perceived in all reactions (except for the one with copper (II) sulfate) are well described by pupils. A majority of pupils defined elementary silver as a product of the reaction between vitamin C and silver nitrate.

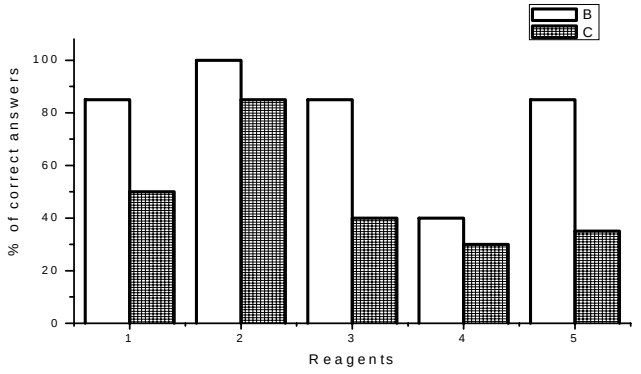

Figure 2. Results obtained for the description of the reactions (B) and for the identification of the products (C) in the reaction of vitamin C with: iodine (1), silver nitrate (2), potassium permanganate (3), copper (II) sulfate (4) and Fehling solution (5).

A large number of pupils (60%) concluded that the reducing properties of vitamin C were identified and confirmed through all the reactions in this experiment. The possibility of using Fehling solution to demonstrate the reduction properties of carbohydrates (accomplished earlier) was stated by 50% of pupils. However, none of the pupils responded correctly to the question as to whether carbohydrates can react with an acid solution of copper (II) sulfate (5% of pupils attempted to respond). The conclusion is that pupils did not realise the importance of the pH of the to enable the reaction to proceed.

The importance of vitamin C reduction power in physiological conditions was determined by 30% of the pupils, although 65% responded correctly about the changes occurring in Fe^{2+} solutions with and without the presence of vitamin C.

The effectiveness of such work was examined by final testing. This post-test was administered during a lesson after the laboratory session (Table 2, mean value is 71.9%). All pupils (100%) know what physical property distinguishes vitamin C from vitamin E. 91.9% of pupils know how to use appropriate doses of vitamin C. A great number of pupils (89.2%) know about the role of vitamin C in the human body, and its relationship with vitamin E. 83.8% of pupils know about the characteristics of the structure of vitamin C. A compound in the form of which vitamin C is used in skin creams, an explanation why pure vitamin C can not be used in cosmetics and the retention of the vitamin's active function in a formed compound, were all accurately described by 86.5%, 35.1% and 67.6% respectively of pupils. 93.3% of pupils know reduction property of vitamin C as well as the reagent by means of which this property can be demonstrated *in vitro*. It is important to highlight the improvement in the knowledge of historical facts on the final test (57% of correct answers) in contrast with the pre test (8.1%). Thus, this applied method of the can lead to an improvement in scientific literacy.

By the comparison of the frequencies of single results (Figure 3) as well as total achievements (mean values 43.4 vs. 71.9%) at initial and final testing statistically significant difference ($p<0.05$) was found. Apart from testing the difference in total achievement, the analysis of achievement for tasks was also done. We selected the tasks that checked the attainment level of the same concept: structure, physical and chemical properties, physiological role, characteristic reactions. Although the same concept was assessed by these tasks, they differed in the level of demand. The results of achievement for those tasks in both tests are given in Fig. 4. It is noticeable that better results were achieved in final testing (the difference is statistically significant at the $p<0.01$ level).

Table 2

The results obtained at final testing

Task	Facts or concepts about the vitamin C tested in the tasks	Correct answers (%)	Incorrect answers (%)	Without answers (%)
1.	Chemical composition and structure	83.8	10.8	5.4
2.	Physical properties of C and E vitamins - differences	100	-	-
3.	Functional groups detemining the acidicity	59.5	24.3	16.2
4.	Necessary of the cumulative application of the C and E vitamins	89.2	10.8	-
5.	The role in pharmaceutical iron's preparations	37.8	27.0	35.2
6.	Reagents for *in vitro* investigations of role in the body (noted of 1 or 2 reagents)	91.9 (37.8; 54.1)	8.1	-
	Role as reduction mean	94.6	5.4	-
7.	Reagent for discrimination of vitamin C and glucose (noted 1 or 2 reagents)	40.5 (37.8; 2.7)	59.5	-
8.	Daily intake	91.9	8.1	-
	Form of which vitamin is used in skin creams	86.5	10.8	2.7
9.	Why?	35.1	10.8	54.1
	Retention of vitamin C properties in esther?	67.6	13.5	18.9
10.	The historic facts (century and scientist)	56.8	13.5	29.7

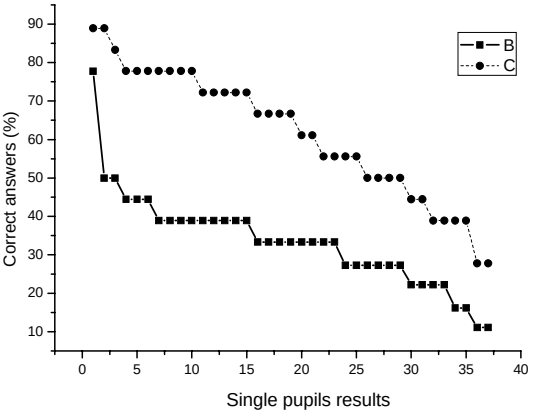

Figure 3. Comparison of the frequencies of single results obtained at initial (B) and final (A) testing.

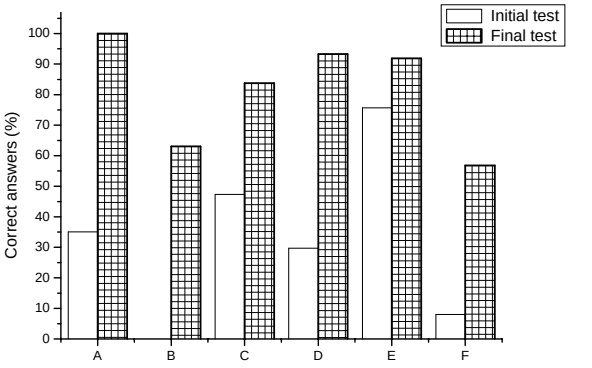

Figure 4. The comparison of the results obtained on tasks at initial (1st number) and final (2nd number) test. Subjects which are tested: A - physical property (1-2); B - Form on which vitamin C is used in skin creams (3-9); C - chemical composition and structure (6-1); D - Role in living organisms (7-6); E - Daily intake (10-8); F - Historic facts (11-10).

Given all the results, it can be concluded that the applied method of work provided for substantial (statistically significant) progress in pupils' knowledge at all three cognitive levels. In addition to the text about vitamin C, well designed and problem-based experiments and resulting achievement was largely contributed to by the discussion about the role of vitamin C in physiological conditions and as a medication in some pathological states. The entire cognitive process and the theme in itself were highly motivational for pupils (they posed a great number of questions).

CONCLUSIONS

The described method of teaching of vitamin C properties required associating instrumental understanding (knowing how) with all three levels of chemical representation (macroscopic, submicroscopic, symbolic), and it makes relational understanding (knowing why) possible. Considering the results achieved at final testing we note that pupils' motivation for experimental work and scientific literacy improved. Also, it has been demonstrated that this type of lesson can be applied for systematizing the contents of teaching general, organic and inorganic chemistry in upper secondary school.

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Small flame tests intense enough for large audiences

Ensayos a la llama en pequeña escala suficientemente intensos para audiencias grandes

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Abstract

The combustion of wood in an oxygen rich atmosphere provides the energy for the emission of light by some elements in a way that is intense enough to resemble fireworks and easily seen by large audiences. The oxygen rich atmosphere is provided by $KClO_3$ decomposition. The reaction can be handled safely because combustible (wood) and oxidant ($KClO_3$) can be kept separate until the moment of the demonstration.

***Key words**: flame test, demonstration, general chemistry, introductory / high school chemistry, teaching / learning aids.*

Resumen

Se presenta un experimento donde algunos elementos emiten luz gracias a la energía recibida por la combustión de madera en una atmósfera rica en oxígeno producido por la descomposición de clorato de potasio. La emisión de luz es lo suficientemente intensa para parecerse a los juegos pirotécnicos y ser vista por grupos grandes. La reacción es segura ya que combustible y comburente pueden mantenerse separados hasta el momento de la demostración.

***Palabras clave**: ensayos a la llama, experimentos demostrativos, química general, ayudas para la enseñanza.*

INTRODUCTION

Flame tests for certain metals involve much of the chemistry involved in the spectacular fireworks frequently seen on special occasions and at celebrations around the world to the laboratory.

Flame colour and fireworks are due to certain metals emitting energy in the form of light, mainly alkalis and alkaline earths; this energy is taken from other strongly exothermic reactions. The characteristic colour of the light emitted by each metal gives the spectators a glimpse of some of the principles of spectroscopy (from the quantum theory of matter) as well as the atomic structure and the application of these principles to analytical chemistry like atomic absorption spectrometry.

Many demonstrations have been reported, (PEARSON, 1985; BOUCHER, 1986; PEYSER, 1988; GOUGE, 1988; AGER, 1988; MATTSON, 1990; BARNES, 1991; THOMAS, 1992; RAGASDALE, 1992; MCRAE, 1994; SMITH, 1995; DALBY, 1996; MCKELVY, 1998; BARE, 1998; DRAGOSLOVIC, 1999; JOHNSON, 2001; SANGER, 2004; SANGER, 2004), each having its own particular advantages and disadvantages. Combustion occurs in most demonstrations in a burner in which the fuel is usually propane gas and the oxidant oxygen from the air; the success of the experiment lies in managing to bring solid or dissolved metal salts to the reaction area in the flame in the most efficient way