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Integrated knowledge of physics and chemistry: case of Physical Chemistry course

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Abstract: One of the major achievements of the learning process is acquisition of integrated knowledge. This paper presents the first results of the degree of knowledge of the second year chemistry students in subjects relevant to the objects of physical chemistry. Data was collected using questionnaires and tests given out to students of chemistry in the academic year 2010/2011. The first results obtained show a weak and insufficient integration of knowledge in general chemistry, general physics and mathematics required for further subject courses such as physical chemistry. The negative difference in the number of points on the pretest and posttest (the results are lower for 80% of questions on the posttest) was detected, although the test was repeated after the end of the winter semester and completion of Physical chemistry course. This poor performance on tests can be an indicator of a number of difficulties in the learning process, which are identified through this research in attempt to find correct solution for this problem.

INTRODUCTION

Knowledge integration is a complex process starting with a first steps encompassing knowledge accumulation, consolidation and formation of a stable structure. This process subsequently leads to the main issue of long-term quality of acquired knowledge and its use in the process of learning (Taber, 2003b; Taber 2004; Taber 2007). Therefore, the significant role of teachers and the teaching process is to help students to establish a successful transition and the connection to prior knowledge, and to develop different skills that are the result of the new doctrine, which must activate prior learning (Taber, 2007).

One should always keep in mind that the integrated knowledge is characteristic of modern and contemporary approach to world trends that are governed with competitive and collaborative relationships, the exchange of information and culture of support and trust (Ruan et al., 2012). According to the theory of knowledge, „know how“ approach to use the right quantum of integrated knowledge is an imperative especially in the system where knowledge is a key resource for creating competitive advantage (Wang & Farn, 2012). These findings confirm the assumption that it should be the dominant feature of university education and the goal worth striving for.

Integration of physics and chemistry knowledge is expected event not only as a result of historical events but, as many believe, as a logical path since fundamentals of chemistry are the foundations of physics too. Rightly Keith Taber (2003a) points out that the current division of natural science is largely a result of historical accident - it could probably be completely different. Certain boundaries and divisions between these sciences are almost inexistent there - but there are areas of special interest that must be studied as integrated (Hewitt et al., 2007) and in that manner should be implemented in the educational process and in the study of chemistry.

However, some research shows that students generally do not have a habit of taking into account the relevant concepts in physics when learning chemistry (Taber, 2003b). Keith Taber (2008) also showed that if the students are expected to apply knowledge of physics as they study chemistry, they would consider it as unnecessary task. Some studies have shown that the integration of concepts in chemistry and physics is one of the most challenging aspects of learning outcomes (Taber, 2008). The same investigator, in his studies of integrated knowledge of chemistry and physics noted that if the questions are posed in the context of chemistry, physics students often do not know the answer, but if asked to explain it from physicist point of view using the concepts they learned in physics, they will give correct answer. Taber (2008) concludes that it is not surprising that some students are sorting their knowledge grouped into categories according to the of the relevant subject curricula.

Researchers agree that in realization of integrated knowledge in education process teacher has a significant role (Aikenhead, 2003; Taber, 2008). The teacher is the one who decides how and how not students integrate their knowledge of chemistry and physics. On the other hand, some researchers believe that the national tests (as well as international tests that assess knowledge and its integration), mainly containing multiple-choice questions require only a recall of specific information. Thus, instructor has to focus on approach that helps students to memorize facts, without having a chance to develop their critical thinking skills (Liu et al., 2008). Even a teaching stuff face the difficulties in the area of acquisition and integration of conceptual knowledge (Emereole, 2009).

Students often have problems of a conceptual nature (Izatt et al., 1996). One study conducted at the University of Alabama (USA), showed that the engineering students should have better knowledge of mathematics, in order to study chemistry and physics as integrated science. Very common case of learning difficulties is use of SI units (Pitt, 2003), that we also observed when testing our students. The problem of units conversion, the use of mathematical operations with exponents, knowledge of the functional relationship between the physical units are some of the major problems caused by lack of knowledge inherited from early education (Zejnilagić-Hajrić et al., 2010; Nuić et al., 2011).

Students rely heavily on an algorithmic approach in problem solving which involves the use of the memorized set of procedures that is contrary to the conceptual problem solving, which involves understanding the concept and find solutions, without using stored procedures. Algorithmic way of solving problems in chemistry is not in accordance with scientific research and intellectual development of students (Cracolice et al., 2008). Besides using an integrated approach in teaching science increases motivation for learning, but also improves student achievement, as the tests that assess the integration of knowledge, as well as the traditional tests showed (Frampton, 2009).

This paper presents the first results of the degree of knowledge of the second year chemistry students in subjects relevant to the objects of physical chemistry.

RESEARCH METHODOLOGY

Research aim

The effect of prerequisite knowledge courses such as General Chemistry, General Physics and Calculus on success in Physical Chemistry I and II class was examined in this study. The main goal was to determine a level of acquired and integrated knowledge and its subsequent effect on active participation in learning process that ultimately determines student success on final exams.

Participants

Research participants were second year chemistry students (2010/2011). Number of students who participated in research varied from 45 to 35 thus research data are presented in percentages. Seventy percent of students were enrolled in general chemistry major while 30% of them in chemistry education major. Out of total number, 22% of students have repeatedly attended Physical Chemistry I course. Total of 85% of students passed all first year required exams, but 5.5% of them did not pass General Physics exam.

Research questions

Main research question:

Q-1 In what extent second year chemistry students integrate relevant prior chemistry, physics and mathematics knowledge acquired in high school and during the first year of study?

Q-2 What are the learning difficulties that students encounter during lectures and what factors affect the level of integrated knowledge relevant for Physical Chemistry course?

Research instruments

Research instruments designed for this study, were two questionnaires (Q1 and Q2) and Integrated Physics and Chemistry knowledge test. These tests are designed in such way so the pretest (T1) and posttest (T2) results are used to record changes of student knowledge in Physical Chemistry I. Parameters for measuring changes in the achieved knowledge were gain and loss factors.

Q1 and T1 were applied prior to Physical Chemistry I class in the winter semester of the academic 2010/2011, and Q2 and T2 are applied at the end of the winter semester, after completion of Physical Chemistry I teaching, learning and exam taking. The instruments of research are attached.

Test dealing with knowledge integration in mathematics, physics and chemistry consisted of 20 questions with following structure: 8 math questions (3 differential and integral calculus questions, one linear function question and 4 computing questions), 4 questions in chemistry and 8 questions dealing with physics and chemistry together. Each correct answer was worth 1 point (20 points for the entire test). Passing threshold was set to be 55%, or 11 points.

RESULTS

Our results based on the Q1 answers show that students mainly use recommended syllabus literature (49%), lecture notes (41%), and PowerPoint presentations (10%). Physical Chemistry textbook recommended by syllabus was used by 82% of students (67% used a photocopied textbook) while 3% of students did not use any resources for exam preparation. Significant number of students, approximately 33% to 40% uses study materials taken from their senior colleagues for both General Chemistry and Physics courses.

This indicates a passive approach towards preparation and development of study skills.

The largest number of students received grade 8 (C) in General Chemistry I, while in General Chemistry II average grade was 7 (D). In Physics I, Physics II, Calculus I and Calculus II classes, the largest number of students achieved grade 6 (E).

The largest numbers of students quite objectively estimated their own knowledge that is in a good agreement with received grades. Interest in chemistry studies confirmed 40% of students assessing it as high. Over 82% of students have no plans to change their study subject (chemistry) but more than 75% of students, intend to switch from chemistry education major to general chemistry major. An interesting answer is that 80% of students would recommend chemistry studies to their friends or relatives, and even 22% of students stated that they have close family members who already has a degree in chemistry.

The Q2 showed that students rarely behave as an active partner in the teaching process. Only 4% of students had direct contact with the teacher, while in the case of communication between student - teaching assistant results were significantly better (40%), but still unsatisfactory. Students consider the absence of oral exams (according to the Bologna principles study exams are taken mainly in writing, with quizzes and tests) as a reason for lack of direct communication with an instructor. The written form (test) exam are preferred by only 26% of students and more than 50% believe that students should have an oral exam, while 59% of students suggested that a combination of written and oral exams would be the best way of knowledge assessment.

Student questionnaire responses indicate that the deriving and solving mathematical equation in terms of chemical problem explanation was a main source of difficulties in understanding new material. We observed that students have significant difficulty in applying knowledge of differential and integral calculus (the subject of Calculus I and Calculus II courses in the first year of study). According to the data (Figure 1) 51% of students are having difficulties just in the domain of integration of knowledge (explaining, performing logical conclusion, examples of problem solving). At the same time, multiple choice questions were the easiest to answer, but explaining and defending chosen answer was again a weak point for majority of students.

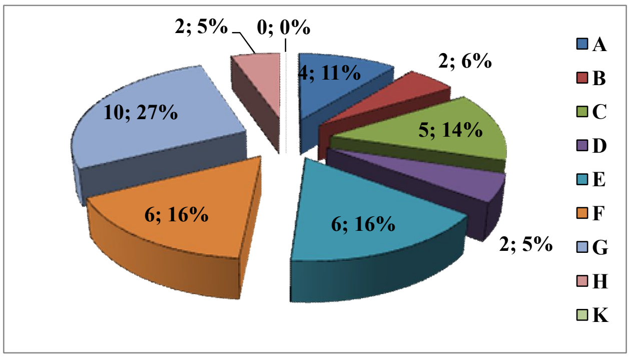

Figure 1. Distribution of student responses according to the type of difficulty encountered in a learning process.
A = Definitions of different terms and values, B = Describing occurrence, C = Explanation, D = Comparison, E = Problem solving, F = Giving a new example, G = Deriving an equation, H = Giving logical conclusion, and K = Multiple-choice questions

In response to one of the questions dealing with the content of courses by complexity, the students cited three concepts: chemical potential, state functions in physics and partial molar volumes. Such responses are not surprising since previous knowledge, especially in mathematics, is necessary for understanding these complex concepts.

The results of the T1 and T2 are presented in Figure 2.

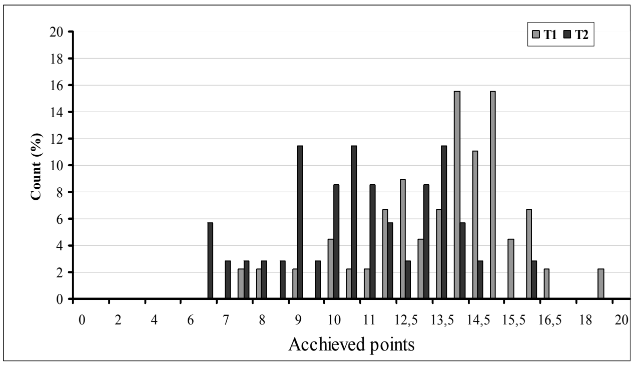

Figure 2. Distribution of number of students according to achieved results in tests (T1 i T2).
T1 = Pretest , T2 = Posttest

The average number of points per student is 12.8 points on the pretest, and 9.5 points on the posttest.Gain and loss factors that represent difference between a number of points achieved on test 2 when compared to test 1 are represented in Table 1. It is obvious that the gain factor was achieved only for four questions out of twenty. Statistical data of T1 and T2 results are presented in Table 2.

Table 1. Gain/loss factor distributed according to question number of T1 and T2.

Question	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
gain									2			8			32		2			
loss	66	26	32	15	9	30	24	40		8	10		3	16		6		23	20	56

Table 2. Statistical analysis results for T1 and T2.

Test	N	Mean	Median	Mod	Max	Min	Variance	St.dev.	Total points	Total points (%)
T1	45	13.5	14	15	19	7.5	5.1	2.3	608.5	67.6
T2	35	11	11	11	16	6.5	5.9	2.4	385.5	55.1

With the passing threshold set as 11 points, the average number of points on the pretest was greater than the passing threshold, and on posttest the average number of points was equal to the number of required points for the pass which was unexpected for us.

On the pretest the difference between the minimum and maximum number of points was 11.5, and 9.5 on posttest. Total sum of points at T1 was 67.5% while on T2 was 50.1%. According to the number of obtained points students can be divided into three groups: (a) Group I consists out of students who achieved a score of 0-10 points; (b) Group II consists out of students who achieved a score of 11-15 points.; (c) Group III consists out of students who achieved the score of 16-20 points.

The largest number of students on both tests is in Group II. When T2 was analyzed, a decrease in Group II and Group III was observed, while a significant increase in Group I was observed (Figure 3).

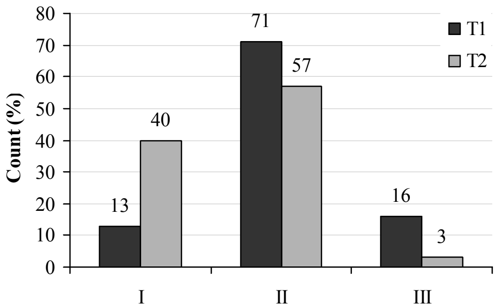

Figure 3. Students' test score distribution per group.
T1 = Pretest, T2 = Posttest

On the pretest, a total of 87% of students have had scores above the passing threshold, and on the posttest that number dropped to 60% of students, showing the negative factor of achievement (Figure 4).

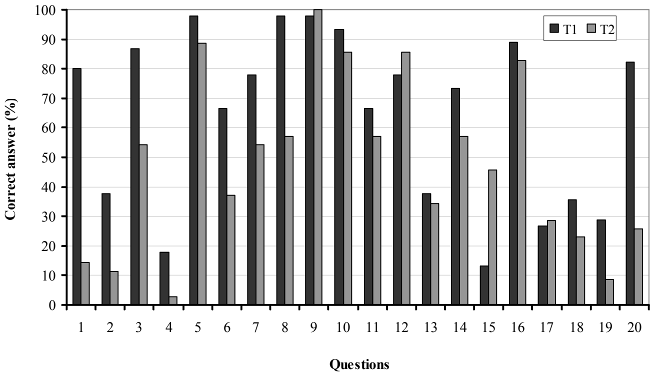

Figure 4. Correct answers distribution for T1 questions 1 to 20.
T1 = Pretest, T2 = Posttest

The lowest score questions were those relating to the fundamental concepts and prior knowledge such as knowledge of basic mathematical functions, knowledge of the SI units of measurement and the procedure for conversion of larger to smaller units and *vice versa*, as well as explanations of the chemical concept problems.

DISCUSSION

A large number of independent variables in the questionnaires and the first data collected during the study have helped to gain insight into the many reasons why students showed poor results, not only on T2 but also on the exams (Physical chemistry I and II). Some of the reasons are different programs of secondary education. Most students had completed high school (50%), followed by nursing school (30%) and various technical schools (20%). Four years of chemistry through high school have had 75% of students. The number of years having physics and mathematics as a subject in high school education is less encouraging, 40% of students did not have physics subject in all grades of high school, while in the case of mathematics this percentage is higher (45%). Applications and implementation of curricula of the three basic subjects' matters (mathematics, physics and chemistry) relevant for chemistry study are different in different types of secondary schools and in different parts of the country. Such circumstances may arise as a significant cause for both low prior and actual (university) level knowledge of chemistry students. As an indication of lack of preparedness of students for the chemistry study can be considered lack of elementary knowledge in mathematics and physics, such as use of SI units and conversion factors (the problem of understanding the small and large numbers and decimal exponents in the SI system of units). In addition, a large number of class and contact hours plus five hours of weekly help sessions, open email communications with a teaching stuff should have helped in achieving better scores.

At the University of Sarajevo, additional two weeks help classes were officially introduced as a mean of additional help, for all students who failed to pass the final exam. In the case of Physical Chemistry I and II course, students showed no interest in additional help lectures although they stated in surveys that they have difficulty solving computational problems or understanding particular concepts.

Additionally, poor teaching conditions including insufficient or outdated lab equipment, large number of students in class, lab or quiz sessions (not compatible with the Bologna principles of organization of teaching) show how numerous are factors that cause the poor efficiency of the teaching/learning process in the case of the analyzed test group of students. Lack of basic textbooks, insufficient number or no copies of textbooks in the library, poor Internet connections and not enough places for internet communication, the obsolescence of existing computer equipment, overloaded teachers and assistants are all additional, but not less important factors that affect the quality of teaching and the outcomes of teaching and learning.

When all these factors are put together, it is obvious that a number of changes in accordance with current education trends have to be implemented in education process if the higher quality learning outcomes are to be expected.

CONCLUSIONS

(1) The data obtained in this study showed that the integration of mathematics, chemistry and physics acquired, necessary for further studies especially in cases of physical chemistry, is poor.

(2) Some factors such as uncoordinated curricula and poor teaching conditions, student -instructor ratio, students' lack of motivation, poor secondary education quality, and insufficiently rigorous enrollment selection, could be reasons for such results.

It is evident that the results of longitudinal studies can help to evaluate the curricula subjects and find new solutions tailored to the active role of students, which is outlined in the documents of the Bologna process.

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Appendix 1

QUESTIONNAIRE 1

1. Your major is:
General Chemistry Chemistry Education
2. Type of high school you completed is:
a) High school b) Technical school ________________________ c) Nursing school
d) Other ________________________
3. Number of high school years in which you had Mathematics class:
a) zero b) one c) two d) three e) four
4. Number of high school years you had Physics class:
a) zero b) one c) two d) three e) four
5. Number of high school years I have had chemistry class:
a) zero b) one c) two d) three e) four
6. I am taking Physical Chemistry I class:
a) first time
b) second time
c) third time
d) I am enrolled in first academic year for a second time, but I am taking Physical Chemistry second year course
7. Estimate your interest in Chemistry studies:
a) no interested at all b) weakly interested c) satisfactory interested d) very interested e) extremely interested
8. I completed the first year of a study with:
a) Passed all exams
b) Failed on one exam (course name ____________________________________)
c) Failed on two exams (courses name ________________, ________________)
d) Failed on more than two exams (courses name: _______________________
____)
9. My achieved grades in following courses are:
a) General Chemistry I grade: A(10); B (9); C(8); D(7); E (6), F(fail)
b) General Chemistry II grade: A(10); B (9); C(8); D(7); E (6), F(fail)
c) General Physics I grade: A(10); B (9); C(8); D(7); E (6), F(fail)
d) General Physics II grade: A(10); B (9); C(8); D(7); E (6), F(fail)
e) Calculus I grade: A(10); B (9); C (8); D(7); E (6), F(fail)
f) Calculus II grade: A(10); B (9); C(8); D(7); E (6), F(fail)
10. During the first year of my study, I was using the most:
a) lecture notes b) recommended textbooks c) materials found on internet
d) Other sources (which ones:____)
11. Are you planning to change the major: yes no maybe
12. Among your close family members, who has a degree in chemistry?
a) one of my parents b) both parents c) siblings ____ d) close relatives: ____ e) no one
14. Would you recommend the chemistry study at the Department of Chemistry to your family members or friends?
yes no

In the following questions (15-17), circle the number corresponding to the meanings below:
1 - very dissatisfied; 2 - somewhat satisfied;
3 - no opinion; 4 - satisfied; 5 - very satisfied

15. What is the level of your satisfaction with acquired knowledge in General Chemistry?
1 2 3 4 5
16. What is the level of your satisfaction with acquired knowledge in General Physics?
1 2 3 4 5
17. What is the level of your satisfaction with acquired knowledge in Mathematics?
1 2 3 4 5

Appendix 2

QUESTIONNAIRE 2

1. How often during one semester you use consultation offered by your teacher?
a) never b) 1-2 times c) rarely d) often e) very often

2. How often during one semester you use consultation offered by your teacher's assistant?
a) never b) 1-2 times c) rarely d) often e) very often

3. For study and exam preparation in Physical Chemistry I, you used the following sources:
a) your own, recommended by the teacher textbook, problem solving workbook
b) photocopied, recommended by the teacher textbook, problem solving workbook
c) recommended by the teacher textbook, problem solving workbook borrowed from your school library
d) recommended by the teacher textbook, problem solving workbook borrowed from National University Library
e) books borrowed from your colleagues
f) books borrowed from your teacher's assistant
g) books borrowed from your teacher
h) none of the above
i) other ____

4. The exam taking method you prefer is:
a) Written only b) Oral only c) Both, written and oral
Explain your answer:
____
____
____

5. Type of my difficulty encountered in a learning process is mostly:
a) Definitions of different terms and values,
b) Describing occurrences,
c) Explanation,
d) Comparison,
e) Problem solving,
f) Giving a new example,
g) Deriving an equation,
h) Giving logical conclusion,
k) Multiple-choice questions.

6. Your intent to continue your study in Chemistry is:

yes no undecided

7. If your answer to question six was NOT or UNDECIDED, can you, please, list at least two reasons why, and what would be your alternative field of study (in case you would continue undergraduate study at all)

1. ____

2. ____

3. ____

8. Please write down your suggestions for improvement in acquiring better knowledge in Physical Chemistry I and II

Appendix 3

TEST OF KNOWLEDGE INTEGRATION IN MATHEMATICS, PHYSICS AND CHEMISTRY

Problems

1. Calculate: $\int xdx$ =
2. Calculate: $\int \frac{dx}{x^2}$ =
3. Write down first derivative of the function: $y = 2x^4 + x^2 + 5$
4. How are determined parameters a and b of the function: $y = ax + b$?
5. Calculate: 2 + 2 : 2 =
6. What is the logarithm of 10^{-14} to base 10?
7. Calculate square root of $3.6x10^{-11}$.
8. Round off the following numbers to two decimal places according to the rounding rules:
   1.258 __________, 1.253 __________, 1.255 __________
9. Write the chemical eqilibrium equation for the following reaction: $N_2 + 3H_2 = 2\ NH_3$
10. What volume, under standard conditions, occupies 1 mol of some gas?
11. Convert: 1 mol dm^{-3} = _______ mol cm^{-3}
12. Convert: _________ mg cm^{-3} = 2 g dm^{-3}
13. Write the value of gas constant and Avogadro's number using SI units
    R = N_A =
14. Where will water boil sooner, On Mount Everest or mountain of Bjelašnica and why?
15. Explain the difference between one molal and one molar solutions?
16. If a dissolution process of a salt is exothermic process, what change of temperature is expected to be seen in calorimeter?
17. Explain the effect of catalyst on the rate of chemical reaction.
18. Gas is expanding isobarically at 105280 Pa. If the gas volume change was 0,5 dm^3, the value of work done by gas is:
    a) 52.64 b) 52.6 J c) 52.6 W d) 52.64 J
    Round off numbers!
19. When will hydrogen atom emit violet light?
20. What is a photon?

Summary/Sažetak

U procesu učenja jedno od važnijih postignuća su integrirana znanja. U ovom radu su predstavljeni prvi rezultati analize stupnja integriranih znanja studenata druge godine hemije iz predmeta relevantnih za oblast fizikalne hemije. Set podataka je prikupljen na osnovu upitnika i testova koje su studenti hemije rješavali u akademskoj 2010/2011. godini. Prvi dobijeni rezultati pokazuju slabo i nedovoljno integriranje znanja iz opće hemije, opće fizike i matematike, potrebnih za oblast fizikalne hemije. Negativna razlika u broju postignutih bodova na ulaznom i ponovljenom testu (dobijeni rezultati su slabiji za 80% pitanja na ponovljenom testu), iako je ponovljeni test realiziran nakon nastave održane u zimskom semestru iz fizikalne hemije. Ovako slabi rezultati studenata mogu biti pokazatelj određenih poteškoća u procesu učenja, koje su kroz ovo istraživanje identificirane s ciljem da se traže rješenja za njihovo ublažavanje.