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Physical Chemistry for Undergraduate Students: Sources of Students' Difficulties and Potential Solutions

Gojak-Salimović, S.*, Korać, F., Zejnilagić-Hajrić, M., Nuić, I.

Department of Chemistry, Faculty of Science, University of Sarajevo, Zmaja od Bosne 33-35, 71000 Sarajevo, B&H

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***Corresponding author:**
Gojak-Salimović Sabina
E-mail: sgojak@pmf.unsa.ba
Phone: +387 33 297 907

Abstract: Traditionally, university students struggle with physical chemistry courses at Faculty of Science. This is particularly evident in the mutual integration of knowledge in general chemistry, physics, and mathematics that are considered as fundamental to physical chemistry. This paper presents the results of research conducted with the 2nd year chemistry students at the Faculty of Science University of Sarajevo, with the main aim to find solutions to these difficulties that could lead to greater learning efficiency, and a successful continuation of their chemistry studies. The results indicated that students' knowledge of concepts relevant to physical chemistry is not at a satisfactory level. This is in line with the rather low students' grades in general chemistry, general physics and mathematics during the first year of the study. Students reported their most common difficulties: the lack of time for learning, the lack of literature recommended by the syllabus, and certain mathematical concepts they do not understand. To overcome them, it is important to direct students to use the available resources more efficiently, and to emphasize the significance of knowledge integration.

INTRODUCTION

Education in the 21st century is mainly oriented towards gaining good, solid, and permanent knowledge that will serve as a fundament for lifelong learning (LLL). Science educators give priority to the quality of knowledge over its quantity, to the knowledge that can be used for solving problems. In order to prepare for active participation in EHEA (European Higher Education Area), teachers at University of Sarajevo, Bosnia and Herzegovina (B&H), are in a process of modernization of their teaching practices.

Chemistry students make up about 20% of total enrolled students at the Faculty of Science, University of Sarajevo. They generally believe that chemistry professionals have a perspective: some of them have their interest in this study thanks to the ability to find their place as future experts in chemical, pharmaceutical, and food industry.

The world around us integrates science. To understand the world and nature, we need to look at the world in an integrated way (Hewitt, Lyons, Suchocki, *et al*., 2007). Knowledge integration is a way to utilize knowledge and a core competency (Wang and Farn, 2012). It is defined as a process of "adding, distinguishing, evaluating, and sorting out phenomena, situations, and abstractions in science" (Linn, Davis, and Bell, 2004), as cited in Liu, Lee, Hofstetter, and Linn (2008). This presumes that knowledge integration needs to be one of the characteristics of university courses.

Traditionally, integration within science courses (physics and chemistry) at the freshman level is not very common, in spite of their fundamental similarities. Students encounter many, often confusing and conflicting ideas when they learn science (Linn, Lee, Tinker, *et al*., 2006). One of the consequences is that students have difficulties with concepts that cannot be classified as purely physical, chemical or mathematical (Izatt, Harrell, and Nikles, 1996). Izatt *et al*. (1996) attempted to develop an integrated curriculum of physics and chemistry for freshmen students. They believe they have created a positive learning experience for their students. Curriculum integration leads to standardized notation and the elimination of duplication of teaching content.

One of the important interdisciplinary fields of science is physical chemistry. It is based on mathematical, chemical and physical principles and is of a vital significance in medicine, pharmacy, agriculture, development and application of new materials, in monitoring and protection of a healthy environment. Physical chemistry spreads its boundaries and overlaps with other fundamental and applied sciences (Zielinski and Schwenz, 2004; Peric, 2009).

The importance of knowledge integration is highlighted in many research studies (Izatt *et al*., 1996; Linn *et al*., 2006, Liu *et al*., 2008). It relies on a constructivist theory of learning that assumes that existing knowledge is the basis for a new, meaningful learning (Taber, 2008). However, Taber also pointed out that some students believe that teachers' expectations for the integrating chemical knowledge with the existing basis from physics are unreasonable to demand (Taber, 1998).

Preliminary research results, mostly diagnostic, pointed to many conceptual difficulties (Gojak, Galijašević, Hadžibegović, *et al*., 2012), but also the lack of procedural knowledge originating in middle and high school. Insufficient integration of knowledge from chemistry, physics, and mathematics was observed, as well as the insufficient use of recommended literature, a low degree of permanent knowledge, mostly regarding general courses on the first year of study (Zejnilagić-Hajrić, Hadžibegović, Galijašević, *et al*., 2010a). Students have problems that come from their earlier education: operating with units of measurement, SI units (also reported in Pitt, 2003; Ford and Gilbert, 2013), mathematical operations involving exponents, as well as knowledge of functional relationships between physical values (Zejnilagić-Hajrić, Hadžibegović, Galijašević, *et al*., 2010b; Nuić, Zejnilagić-Hajrić, Hadžibegović, *et al*., 2011).

Physical chemistry has been taught continuously at several faculties within the University of Sarajevo since the Chair of Physical Chemistry at the Department of Chemistry has been established in 1954. Traditionally, courses within this scientific discipline have been demanding and difficult for students.

According to the pre-Bologna curriculum, the domain of *Physical chemistry* was represented by four two-semester courses (Physical Chemistry I, Physical Chemistry II, Corrosion and Corrosion Protection, and Kinetics and Catalysis). They were taught during 2nd and 3rd year of a 4-year study programs *Chemistry* and *Chemistry Education*. The introduction of the Bologna model of study in 2005 resulted in transforming former Physical Chemistry I into two one-semester courses: Physical Chemistry I (PC I) and Physical Chemistry II (PC II), in 3rd and 4th semester, respectively. Teaching content was slightly changed, and the number of hours of lectures and exercises per week was reduced. Accordingly, Physical Chemistry II transformed into Physical Chemistry III (PC III) and Physical Chemistry IV (PC IV), both in 3rd year. The present model of study contains seven compulsory and three elective courses with a total of 48 ECTS points for the domain *Physical chemistry* during the first cycle (total 240 ECTS). After the first cycle, students can enroll the second cycle (60 ECTS) and choose *Physical chemistry* as their major and earn total 20 ECTS for elective courses.

General Physics courses during 1st year of study comprise topics of mechanics, thermodynamics, electricity, and magnetism (1st semester), optics and quantum mechanics (2nd semester). Mathematics curriculum includes linear equations, matrices, operations with vectors (1st semester) derivation and integral calculus (2nd semester).

Course PC I consists mainly of chemical thermodynamics, while PC II includes chemical equilibrium, phase equilibrium, and chemical kinetics. The programs of the PC I and PC II courses assume that students have certain knowledge in general chemistry, physics and mathematics in order to learn new concepts by integrating previous and new knowledge. In the end, it facilitates passing the final exam, as one of the most important students' goals.

Laboratory and calculation exercises make a substantial part of the courses PC I and PC II. Students, supervised by teaching assistants and technicians, usually perform laboratory exercises in pairs. After measuring, collecting and analyzing data, students present their results to the teaching assistants for verification. Verification of the entire set of laboratory exercises is one of the prerequisites for taking the final exam.

METHODOLOGY

Research problem

In recent years, the number of students who had passed the final exam or the continuous partial exams during the semester was fairly low. The fact is that students experience difficulties in applying the appropriate learning techniques. The main aim of this research was to explore the sources for the observed low passing rate and potential ways for improving students' understanding of physical chemistry concepts.

Participants and research instruments

The research described in this paper has been conducted at the Faculty of Science, Department of Chemistry, with 2nd year chemistry students in two subsequent academic years.

Research instruments included a test of knowledge (Gojak *et al*., 2012) used as a pretest and posttest. Additionally, the initial questionnaire Q_I aimed to explore students' grades in relevant courses, their satisfaction with the knowledge they acquired, and certain general characteristics of the learning process. Final questionnaire Q_F aimed to explore students' perceptions on courses PC I and PC II, and most common difficulties they encountered during learning.

Test of knowledge contained 17 items, including basic mathematical calculations and their application into chemistry and physics, therefore all relevant to physical chemistry. Each item was given one point if true, 0 point if it is false. The data was confidential and had no impact on students' grades. The criterion for passing the test of knowledge was set to 55%, according to Bologna's model of study at the University of Sarajevo.

The analysis of the internal consistency of the test of knowledge resulted in lower values of Cronbach's alpha for the pretests and higher for the posttests (Table 1), indicating that teaching process affected the participants' knowledge regarding test items.

Table 1. Analysis of internal consistency for the test of knowledge

	Pretest		**Posttest**	
Group	I	II	I	II
N	47	55	26	19
Alpha	0.652	0.385	0.831	0.853

RESULTS

Students' knowledge on concepts relevant for Physical chemistry

Table 2 represents the descriptive statistics for the test of knowledge aimed to explore students' knowledge of mathematical, chemical and physical concepts relevant to physical chemistry courses. It was administered as a pretest and as a posttest for two generations of students.

Table 2. Descriptive statistics for the test of knowledge

Group	**Pretest**						
	N	**M**	**SD**	**SE**	**X_{Min}**	**X_{Max}**	**Mode**
I	47	9.61	2.67	0.39	4.0	14.5	7.0[a]
II	55	9.29	1.90	0.26	6.0	14.0	8.5
Group	**Posttest**						
	N	**M**	**SD**	**SE**	**X_{Min}**	**X_{Max}**	**Mode**
I	26	10.81	3.57	0.70	2.5	16.0	13.0
II	19	8.07	2.68	0.61	4.0	12.0	9.0[a]

Legend: N - number of participants; M - arithmetic mean; SD - standard deviation; SE - standard error of the mean; X_{Min} - lowest score on the test; X_{Max} - highest score on the test; Mode - value that appears most often; [a] - multiple modes exist, the smallest value is shown

The maximum score that could be earned was set to 17. Means indicate that average students' achievements were around 50% of the maximum score, which is rather low for university students and this type of the test of knowledge addressing their previous knowledge relevant to physical chemistry.

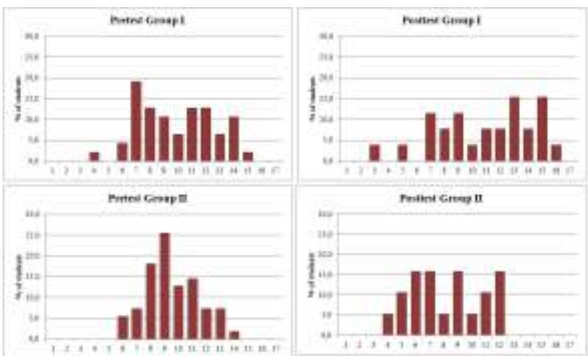

Figure 1. Frequency distributions of students' total scores on tests of knowledge

Visual representation of students' total scores on tests of knowledge indicates that Group I progressed from pre- to posttest, but that was not the case for Group II students.

Table 3 represents students' average grades (with standard deviations in parentheses) in *General Chemistry* (Ch), *General Physics* (Ph) and *Calculus/Mathematics* (M) courses during the first year of study, and their own grades that they believe they deserved, both on scale 6-10. The non-parametric Wilcoxon signed-rank test was performed to compare them.

Table 3. Students' grades and perceptions on the acquired knowledge

	Group I			**Group II**		
	Ch	**Ph**	**M**	**Ch**	**Ph**	**M**
Average grades	7.30 (0.72)	7.04 (0.65)	6.53 (0.72)	6.86 (0.67)	6.95 (0.75)	6.40 (0.56)
Assessment of acquired knowledge	7.85 (0.88)	7.15 (0.93)	7.00 (0.91)	7.64 (1.19)	7.15 (0.89)	7.14 (0.92)
Z	-3.556	-0.767	-3.429	-4.910	-1.592	-5.019
Asymp. Sig.	0.000	0.443	0.001	0.000	0.111	0.000

It is evident that students from both groups tend to evaluate their knowledge in *General Chemistry* and *Mathematics* with higher grades than their teachers, while in the case of *General Physics* the difference was not statistically significant.

Students' perceptions on the first year of the study

Initial questionnaire Q_I covered various topics such as students' assessment of the courses, and aspects considering preparation for exams.

Table 4. Students' satisfaction with the acquired knowledge

	Group I			**Group II**		
	Ch	**Ph**	**M**	**Ch**	**Ph**	**M**
M	3.32	3.11	3.06	3.69	3.34	3.29
SD	0.96	1.05	1.03	0.68	0.98	1.02
MR	2.17	2.02	1.81	2.25	1.86	1.89
χ^2		**4.672**			**8.792**	
p		**0.097**			**0.012**	

Legend: M - arithmetic mean; SD - standard deviation; MR - mean rank; χ^2 - chi-square value (Friedman's test); *p* - significance level

Table 4 represents the data on students' assessment of the acquired knowledge in general chemistry, general physics and mathematics on scale 1-5. Means indicate that students are generally more satisfied with acquired knowledge in *General Chemistry*. The difference between students' assessment among courses was examined using Friedman's test which indicated statistically significant difference in case of Group II students (p = 0.012). Wilcoxon signed-rank test[1] pointed to the difference between students' assessment of knowledge in favor of *General Chemistry* compared to both *General Physics* (p = 0.008) and *Mathematics* (p = 0.006).

Table 5. Selected data from the initial questionnaire Q_I

Statement	**Group I (%)**	**Group II (%)**
I am motivated for continuing the study	21.3	20.3

[1] The Bonferroni correction was applied resulting in a significance level set at p < 0.017

I plan to change the field of the study	19.1	18.6
I would recommend my friends to enroll Chemistry	63.8	71.2
I am able to integrate acquired knowledge	74.5	81.3
I own a laptop/computer at home	85.1	96.6
I have unlimited access to the Internet	63.8	74.6
I have the prerequisites for online communication with the teacher	87.2	93.2
My knowledge of English is at a satisfactory level	87.2	88.1
I use the recommended literature for preparing the exams	74.5	54.2

The data in Table 5 reflects interesting findings: only about 20% of students are motivated to continuethe study, but they do not plan to change it and recommend it to their friends. Additionally, they believe they are able to integrate knowledge, but this is not consistent with the results of the knowledge tests. Analyzing the necessary prerequisites for learning and preparing for exams, students mostly have good conditions: a laptop or a computer, Internet access, while their knowledge of English is quite good. It is interesting that Group II students do not use the recommended literature for exams to the extent as the Group I students. Group II students rely on their lecture notes and PowerPoint presentations provided by teachers. The fact is that our libraries do not follow the modern trends and have deficiencies in the recommended literature due to financial obstacles, but useful sources can be found online from safe and trusted websites (universities, academic associations, free e-books, and scientific papers). This requires knowing foreign languages (mostly English) which apparently is not a problem for most students

These data suggest that online communication and English language skills with students can be used to a greater extent.

Students' perceptions on the second year of the study

The final questionnaire covered various topics related to the teaching process at the PC I and PC II courses.

The results revealed students' difficulties regarding some mathematical concepts required for PC I and PC II, such as deriving equations, differential, and integral calculus. These concepts make part of the syllabi of the courses Calculus I and Calculus II. Students experience difficulties in integrating knowledge, explaining, deriving a logical conclusion, solving problems.

Students' perceptions of supplementary classes in Physics and PC I are generally positive. They see benefits in clarifying some ambiguities and emphasizing the most important topics by the teacher but also pointing to the importance of previous learning activities.

One item in Q_F asked students for specific themes within PC I and PC II they found to be most difficult. The most common answer was thermodynamics, a broad area that requires solid previous knowledge, especially in mathematics.

Table 6. Selected data from the final questionnaire Q_F

Statement	Group I (%)	Group II (%)
I have attended the supplementary classes in Physics	63.0	9.1
I have attended the supplementary classes in PC I	7.4	59.1
I have consulted the teacher regarding some topics in PC I	22.2	45.5
I have consulted the teaching assistant regarding some topics in PC I	85.2	40.9
I combine recommended literature with my notes in learning PC I	40.7	27.3
I am aware of the rules of taking exams and evaluation process in PC I	81.5	86.4
I find the oral exam in PC I to be transparent	48.1	50.0

Students' exam results

According to the syllabus of the PC I course, students' achievements are evaluated as follows: Attending lectures and engagement (5%); Physical chemistry calculation exercises (5%), Laboratory exercises (10%), two written exams during the course and combined (written and oral) final exam (80%).

In order to pass the course, a student needs a minimum of 55%. In case they fail, there are the possibilities to repeat the final exam at the end of the particular semester and at the end of the academic year (September). These facts are regulated by the Law of higher education at the University of Sarajevo.

Physical chemistry teacher's records show that 44.4% of Group I students passed the exam with average grade 7.43[2]. Group II students pass rate was higher (76.2%), but the average grade was only slightly higher (7.66).

DISCUSSION

Inadequate and insufficient previous knowledge of students could originate from various sources, such as secondary school education, inadequate curricula, the lack of motivation, etc. Students do not exploit resources provided by the institution, such as consultation with teachers and teaching assistants to resolve doubts and ambiguities they encountered during learning. Those students, who come for consultations, usually ask help regarding the lack of mathematical skills needed for required calculations.

Even though students were encouraged to talk about their conceptual difficulties, these consultations were more instructive and focused mainly on some specific

[2] Scale is defined according to the Law of Higher Education in Canton Sarajevo - Scale 6-10, grade 6 (E) being the lowest passing grade.

task rather than a discussion about some problem regarding the overall understanding of the concept.

The students showed a self-critical opinion regarding their individual work and stated some difficulties they struggle with: the lack of time for learning and preparing for exams, the lack of literature recommended by the syllabus, certain mathematical concepts they do not understand and difficulties when working on numerical assignments. Exam items requiring explaining and reasoning of given answer or problem solving were reported as too demanding. Definitely, *Chemistry* is a demanding study program and requires commitment not only in the exam period but during the entire semester. The mandatory, as well as most of the recommended literature are available at the library of the Faculty as well as at the National and University Library of Bosnia and Herzegovina.

From the teachers' perspective, a large number of students attending lectures (approx. 60) reduces the opportunity for a single student to approach the teacher, or for the teacher to treat students individually. This can be solved by consultations with the teacher, which students generally do not usually use.

We should also emphasize that, due to financial difficulties, our laboratory equipment is rather old and insufficient. Increased number of students in laboratory groups (up to 16, while labs are initially planned for a maximum 10 students) affects the quality of laboratory exercises. They are planned for individual students' engagement in order to take the responsibility (or even consequences) of the results obtained.

From students' exam results we got the impression that students learn only as much as they think it is enough to pass, and not to acquire permanent, integrated and usable knowledge.We need to emphasize to students that their main interest is to learn for their future, and the grades they receive are not as important. There is no use in forcing students to learn information they will remember during the exam period, but later they could not even remember them. After all, in our own research or teaching, we do not simply rely on our memory for even the simplest formula, but we check it in the appropriate textbook. The responsibility for students' results in learning and integrating knowledge is on students, their parents, but also on their teachers (Cooper, 2012).

CONCLUSIONS

In order to properly understand physical chemistry concepts, it is clear that students need proper assistance with learning, mostly due to integration of previous knowledge. We need to motivate our students to solve the problems they have in their learning process through different ways of assistance they have the right under our law and regulations (to consult their teachers more frequently, to attend the lectures within additional teaching). The difficulties reported by students relate to the lack of certain resources. Although we admit that the situation is inconvenient to a certain extent, some assistance might help in resolving them. The main goal is for students to find adequate techniques of learning in order to make their achievements higher and the learning process more efficient. We need to direct our students not to differentiate their knowledge by course programs but to integrate it among courses, levels of education, and with previous knowledge. In order to accomplish this, students need to increase their active participation.

Certain limitations of the study need to be acknowledged. The data collected did not affect students' grades in any way, but we cannot be sure whether students therefore put an effort in answering the test items or simply superficially choose certain options. The data gathered using questionnaires resulted in a certain number of (mostly open-ended) items without answer. We cannot be sure whether students considered the questionnaires in their full context or how truthful they were since some items required self-critical evaluation of their own learning process. For a complete image of students' knowledge and attitudes towards their study, these results need to be seen as a reflection of the current socio-economic situation in our country. There is a certain number of students who enroll „any" study program in order to be eligible for financial support[3]. Additionally, Bosnia and Herzegovina's chemical industry had been seriously damaged during the war and still has not recuperated, which limits the potential employment for graduate students.

Since this study is a part of a longitudinal research, these results point to the fact that student's difficulties observed in our earlier research are common among our students and are not related to a single generation. We have explored their potential sources and we will try to address them during the teaching process in the following period, but we do expect students to take active role in this process. After all, we have the same goal – acquiring solid, applicable knowledge for future chemists.

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[3] Students who come from families of disabled war veterans or fallen soldiers have right to financial support as long as they are full-time students.

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Summary/Sažetak

Tradicionalno, predmeti iz oblasti fizikalne hemije predstavljaju određene poteškoće za studente u postizanju dobrih rezultata učenja i polaganja ispita. Ovo je posebno uočljivo kroz nedovoljnu integraciju stečenog znanja u fizici, hemiji i matematici, za koje se smatra da su temeljni za fizikalnu hemiju. U ovom radu prikazani su rezultati istraživanja provedenog sa studentima druge godine studija hemije na Prirodno-matematičkom fakultetu Univerziteta u Sarajevu, s glavnom svrhom pronalaženja mogućih rješenja za navedene teškoće, koja bi mogla dovesti do veće učinkovitosti učenja i uspješnije nastavljanje studija hemije. Prema dobivenim rezultatima, možemo zaključiti da znanje studenata o pojmovima relevantnim za fizikalnu hemiju nije na zadovoljavajućoj razini. To je u skladu s relativno niskim ocjenama iz predmeta iz oblasti opće hemije, opće fizike i matematike tokom prve godine studija. Najčešći problemi koje su studenti naveli su nedostatak vremena za učenje, nedostatak literature preporučene silabusom, te određeni matematički pojmovi koje ne razumiju. Kako bi ih prevazišli, važno je usmjeriti studente kako bi efikasnije koristili pružene resurse, kao i istaknuti važnost integriranja znanja.