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The effects of problem-based learning on students' achievements in primary school chemistry

Zejnilagić-Hajrić, M.*, Šabeta, A., Nuić, I.

University of Sarajevo, Faculty of Science, Department of Chemistry, Zmaja od Bosne 33-35, 71000 Sarajevo, Bosnia and Herzegovina

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***Corresponding author:**
E-mail: mzejnilagic@pmf.unsa.ba
Phone: 00-387-33-279864
Fax: 00-387-33-649359

Abstract: Specific applications of cognitive and constructivist theories in problem-based learning (PBL) include connecting prior knowledge and skills with new information. This prominent instructional method is widely accepted in higher education around the world, but it also shows good results when applied in primary education of various disciplines. This paper presents effects of PBL application in 8th grade primary school chemistry when learning about chemical compounds, using questionnaires and tests of knowledge in pretest-posttest study with control (CG) and experimental (EG) groups. Students in CG were taught in usual way with teacher-centered approach, while in EG the PBL materials designed for the purpose of this study were applied. Results showed (1) significant improvement of students' achievements in EG, (2) these students are not used to this teaching method so they encountered certain difficulties, (3) overall interest and engagement in chemistry lessons has increased.

INTRODUCTION

Many authors agree that teaching methods which allow active participation of students in the teaching process result in better achievements and overall learning results. One of those methods is problem-based learning (PBL).
Problem-based learning (PBL) is an instructional method aimed at preparing students for real-world settings. By requiring students to solve problems, PBL enhances students' learning outcomes by promoting their abilities and skills in applying knowledge, solving problems, practicing higher order thinking, and self-directing their own learning (Jonassen and Hung, 2012). PBL was implemented in medical school programmes in the 1950s for the first time, in response to students' unsatisfactory performances due to the emphasis on memorization of fragmented biomedical knowledge (Barrows and Tamblyn, 1980). Since then, it has been modified and applied in various professional areas (Yoon, Woo, Treagust, *et al.*, 2014), among them in science (Duch, Groh and Allen, 2001) and education (Peterson and Treagust, 1998).

PBL implies learning during problem solving – students focus on a simple or complex problem which does not have only one correct answer readily available from textbook (Hmelo-Silver, 2004). Students can learn individually or divided in groups. Accent is set on "what" to learn to successfully solve the problem (Artino, 2008).
Application of PBL in science courses can be more efficient if it includes some components of scientific processes and science concepts (Gallagher *et al.*, 1995). Gallagher *et al.* (1995) suggested four essential elements for PBL in science:

(a) problems should focus on significant science concepts,
(b) there should be opportunities to test students' ideas through experiment or fieldwork,
(c) students should manage their own data,
(d) and the presentation of their solutions.

PBL is conceptually based upon the cognitive and constructivist theories. Their specific applications in PBL include connecting new information with prior knowledge, elaboration and construction of information learned and collaborative learning. Students' learning is initiated by a need to solve an authentic problem. In PBL, students are no longer receiving the learning content from the instructor in a "textbook" logical sequence (Jonassen and Hung, 2012).

Problem solving promotes learners' higher-level thinking skills, and consequently, results in deeper understanding and better application of the knowledge in the future. It is challenging and motivating. This intrinsic motivational component helps increase students' desire to learn and sustains their interest throughout the course of the learning.

Traditional instruction usually presents content information with context-free problems. The main shortage of traditional methods is the lack of connection between knowledge learned and real-life practice. As stated in US National Science Education Standards (1996, p. 173), "for students to develop the abilities that characterize science as inquiry, they must actively participate in scientific investigations, and they must actually use the cognitive and manipulative skills associated with the formulation of scientific explanations". Students tend to develop algorithmic rather than cognitive skills, which leaves student with no choice but memorizing algorithms if they want to survive chemistry course (Cracolice, Deming and Ehlert, 2008).

Many empirical studies were testing the effectiveness of PBL in various contexts and the general conclusion is that PBL enhances students' problem solving, higher order thinking, self-directed learning skills, and motivation to learn. Also, PBL students consistently outperformed traditional students on long-term retention assessments (Jonassen and Hung, 2012).

PBL can be effectively applied in chemistry education, especially in laboratory part of courses. The laboratory is an important component of science education that can foster positive attitudes and interest towards science. Students can learn not only scientific concepts, but also scientific thinking abilities, and experimental skills (Yoon, Woo, Treagust, *et al*., 2014). PBL is an alternative to typical laboratory instructional methods because as it can resolve its several shortcomings (Arnold, 2003; Hicks and Bevsek, 2012; Kelly and Finlayson, 2007; Ram, 1999).

RESEARCH METHODOLOGY

This pretest-posttest study was conducted during April and May 2012. It included control (CG) and experimental (EG) groups, questionnaires and tests of knowledge as instruments for collecting data. Participants were 8th grade primary school students (n=51) from one school in Sarajevo, divided in two groups equal by their knowledge of chemistry at the beginning of this study.

Study included four major teaching units in primary school chemistry: Oxides, Acids, Bases, and Salts.

Students in CG were taught in usual way with teacher-centered approach with demonstration when applicable, while in EG the PBL materials designed for the purpose of this study were applied. EG students were working in groups and teacher served as facilitator of the learning process.

For topic Oxides students were asked to propose and to perform an experiment to prove that people exhale carbon dioxide using glass, plastic straw and water solution of calcium hydroxide. After defining oxides as group of chemical compounds, teacher demonstrated burning of magnesium strip and students were asked to divide oxides into groups.

Acids – based on PowerPoint presentation on acid rain, students needed to conclude how the rain becomes acidic, which chemical processes happen in the atmosphere? After group experiment on the properties of indicator in acidic solutions, students defined acids and their properties, acid dissociation and its examples.

Knowledge test T1 is used in order to establish prior knowledge, and final test of knowledge identified students' achievements. Both test were the same for both groups and made using textbooks for primary school and were comprised out of tasks and questions corresponding to the age of participants.

Questionnaires were used to identify students' most common difficulties in learning chemistry, to get insight into frequency of PBL application in teaching chemistry and (for EG), opinion on PBL method applied in their classes.

Research hypotheses

Based on research of relevant literature on problem-based learning, the main hypothesis set was:

H: PBL is more effective in teaching chemistry at primary school than usual teaching methods based on teacher-centered approach.

Sub-hypotheses were also set in order to verify and support main hypotheses:

SH1: Students perceive learning chemistry as more difficult and demanding than other teaching subjects

SH2: Students are more interested in PBL than usual teaching methods

SH3: Students have certain difficulties in finding solution to the problem

SH4: Students have considerable experience in PBL during their education – considering that their primary education lasts for nine years.

SH5: PBL supports students' engagement in teaching chemistry

Instruments for collecting data

Test of knowledge T1 was used to explore students' knowledge on fundamental chemical concepts relevant for learning and understanding selected teaching section involving four topics. Moreover, it was needed to establish whether these two groups were equal by their knowledge on the beginning of the study.

Test of knowledge T2 was used to explore students' knowledge on the topics that were taught using PBL in EG and using usual teacher centered approach in CG.

Questionnaires for students of experimental (QS_{EG}) and control (QS_{CG}) group containing questions about students' perceptions on chemistry as science, teaching and learning chemistry and problem-based learning.

RESULTS AND DISCUSSION

Students' achievements on entry knowledge test (T1) with no statistically significant difference (M_{CG}=2.72, SD_{CG}=0.64; M_{EG}=2.80, SD_{EG}=0.63) indicated that our participants have comparable knowledge on fundamental chemical concepts important for this study. This fact is also obvious in Figure 1. showing marks of these students they earned on this test of knowledge.

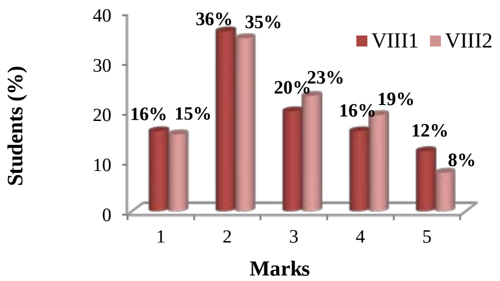

Figure 1. Students' achievements on T1

After teaching all four topics, results of a knowledge test (T2) showed statistically significant difference in students' achievements in EG compared to CG (M_{CG}=2,84, SD_{CG}=0,64; M_{EG}=3,84, SD_{EG}=0,72). Students' marks are shown on Figure 2.

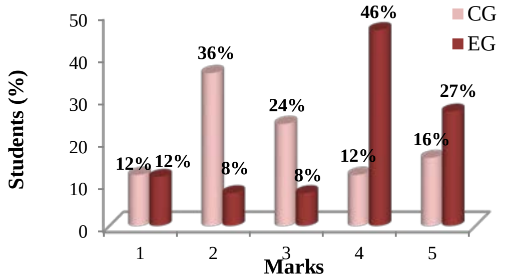

Figure 2. Students' achievements on T2

As shown on Figure 2, greatest differences are noted when considering mark 2: 36% of CG students and only 8% of EG students were awarded with mark 2. When considering marks 4 and 5, only 28% of CG student earned these marks, but 73% of EG student for marks 4 and 5 show promising effects of PBL application when teaching these concepts in primary school. It should be noted that results of a questionnaire showed that this was the first time that these students encountered with PBL, so better results could be expected with continuous application of PBL.

In order to illustrate the headway of EG student, we have shown the comparison of EG students' results on T1 and T2.

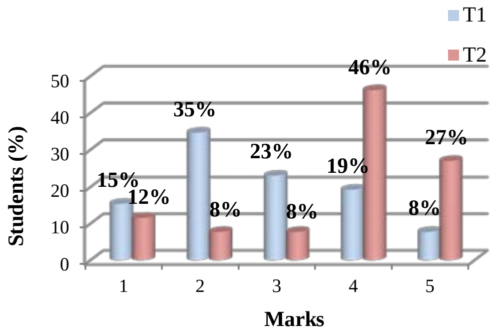

Figure 3. Comparison of EG students' achievements on T1 and T2

There is obvious difference between students' achievements before and after teaching using PBL method. We have tested different concepts with these two tests – we have compared them because marks are much higher when PBL was applied, disregarding the teaching content.

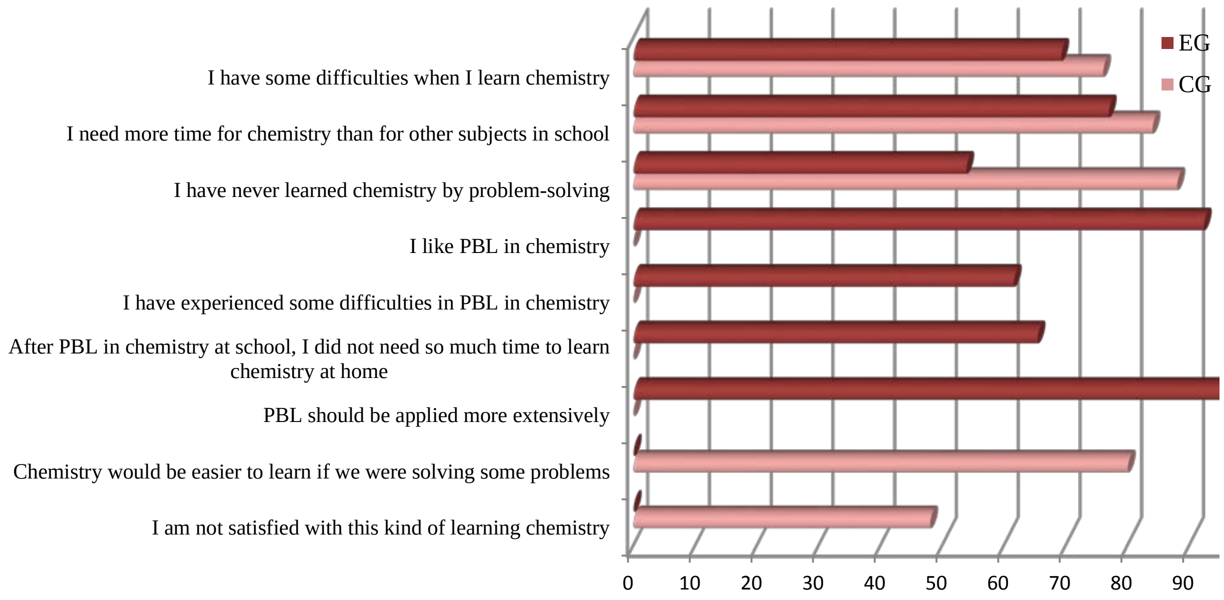

Figure 4: Selected data from questionnaire

Overall results of a questionnaire showed that students are interested in PBL method, but they do encounter certain difficulties when finding a solution to problem.

Items in questionnaire were designed in order to test sub-hypotheses.

SH1 was confirmed because a majority of students perceive chemistry as a difficult subject (CG: 76%, EG 69.2%), that they need more time to learn for than some other subjects in school (CG:84%, EG: 76,9%).

SH2 was also confirmed since majority of EG students liked PBL application during teaching sequence (100%), and consider that PBL should be applied more extensively (100%). CG students were not familiar with PBL but they were not satisfied with the current way of teaching and learning chemistry (88%).

EG student were also asked if they are familiar with PBL in other subjects. Even though curricula for primary school went through modernization few years ago, from 8-year to 9-year long primary school, PBL is not instructional method that is extensively applied during primary school. Therefore, 61.5% of EG students experienced some problems in finding solution to problem in PBL, which confirmed SH3.

As stated above, it was expected for “new” curriculum to be changed not only in themes and subjects, but also in new teaching methods that were not represented before. This is in accordance with Bodner (1992), who suggested that changing the curriculum may not be enough, proposing that the methods of curriculum delivery must also be changed. These teaching methods are not new, but they were not used sufficiently. This sub-hypothesis (SH4) therefore was not confirmed since 88% of CG students said that they never solve problems during learning chemistry, and 92% that they never (or rarely) do that when learning other subjects; EG students’ responses were similar: 92.3% do not (or rarely do) learn chemistry by solving problems, and 88.5% on other subjects in school.

Last sub-hypothesis was also confirmed since the teacher noticed overall greater engagement and involvement of her student in learning chemistry, but also their statements from questionnaire: 52% of CG student are not involved into the teaching process, 80% of EG students believe that chemistry would be easier to learn if problem solving was represented, while 65.4% needed less time for learning chemistry at home after PBL application.

CONCLUSION

Results of this study, comparable to findings of foreign authors, showed the benefits of problem-based learning as teaching method in primary school chemistry. The main hypothesis, that a problem-based learning is more efficient than conventional teaching methods in chemistry (based on teacher-centered approach) is confirmed. Also, we have encountered some difficulties in using this method, primarily due to its rare application in primary school teaching generally. We believe that if teachers applied this method more extensively, these problems would be minimized, while both students and their teachers would benefit from it.

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Summary/Sažetak

Specifične primjene kognitivne i konstruktivističke teorije u problemskom učenju (engl. Problem-based learning, PBL) uključuju povezivanje prethodno stečenog znanja i vještina s novim informacijama. Ova istaknuta nastavna metoda je široko prihvaćena u visokom obrazovanju širom svijeta, a također pokazuje dobre rezultate i kada se primjenjuje u osnovnoj školi u različitim nastavnim predmetima. U ovom radu prikazani su efekti primjene problemske nastave u nastavi hemije u osnovnoj školi prilikom poučavanja hemijskih spojeva u osmom razredu osnovne škole, upotrebnom anketnih upitnika i testova znanja u predtest-posttest istraživanju koje je uključivalo kontrolnu (CG) i eksperimentalnu (EG) grupu. Učenici kontrolne grupe poučavani su uobičajenim načinom, frontalnim oblikom rada, dok su učenici eksperimentalne grupe bili poučavani problemskim pristupom, primjenom nastavnih materijala dizajniranih za potrebe ovog istraživanja. Rezultati su pokazali (1) značajno poboljšanje postignuća učenika u EG, (2) učenici nisu navikli na primjenu ove nastavne metode te su se susretali s određenim poteškoćama, (3) opći interes i zalaganje u nastavi hemije su porasli.