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Implementation of Active Learning and Assessment for Chemistry Courses

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Abstract: In this paper we consider active learning approach with focus on project-based learning implemented into the teaching practice for training Bachelor and Master students of Chemistry Department at the Buketov Karaganda State University. Project study allows acquiring knowledge and skills needed to deal with real-life situations and developing teamwork and communication skills. We gave examples of using project studies in the classroom and discuss the effectiveness of active learning strategies for promoting deeper understanding of courses material. Learning in Chemistry classes was evaluated using various types of assessment. Bloom's taxonomy was applied to identify critical thinking skills (comprehension, application, analysis, synthesis, evaluation) that can be connected with specific assessment methods such as Venn diagrams, open-ended questions, image analysis, and concept maps. Assessment criteria for Bachelor and Master students' activities were elaborated. We revealed the positive role of both active learning approach and formative& summative assessment for the progress of chemistry students, their positive attitude toward the subjects as well as the trainees' motivation for further study and developing creative thinking skills.

Keywords: Active learning, Project based learning, Assessment

Introduction

Our society today needs flexible, creative and active young people, who can solve problems, make decisions, think critically, communicate ideas effectively and work efficiently within teams and groups. The knowledge is no longer enough to succeed in the world which we live in. It is now widely accepted that young people need to have opportunities to develop personal capabilities and effective thinking skills as part of their education. The revised curriculum and active learning approach used at the Buketov Karaganda State University aim to empower young people to develop their potential as individuals and to make informed and responsible decisions for living and working in the 21st century.

To enhance training process for Bachelor and Master students the teachers of Chemistry Department introduce and implement active learning technologies. Shift from a teaching-centric approach to a learning-centric one resulted in modernization of courses structure, elaborating other types of assignments, changing forms of students' assessment, and getting feedback. Such modernization of the modules had a positive effect on students' motivation to study chemical disciplines which in turn affects the formation of professional competencies among students.

Active learning instructional strategies include a wide range of activities that share the common element of "involving students in doing things and thinking about the things they are doing" (Bonwell & Eison, 1991).

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Active learning instructional strategies can be created and used to engage students into thinking critically or creatively, speaking with a partner, in a small group, or with the entire class, expressing ideas through writing, exploring personal attitude and values, giving and receiving feedback, and reflecting upon the learning process.

Active learning involves discussion, problem-solving, presentations, group work such as buzz groups, role playing, brainstorming, debates – anything that gets students interacting with each other and engaging with the material delivered by a teacher (Revell, & Wainwright, 2009). Active learning types include collaborative learning, case studies, peer learning, enquiry based learning, problem based learning, project based learning, etc. (Prince, 2004).

This paper describes learning activities and assessment methods that may be adopted in chemistry courses taught in English, Kazakh, and Russian to encourage conceptual understanding rather than rote memorization of facts. We assume the reader has no prior experience in active learning methods and provide directions for implementing these techniques in the classroom. We discuss project based learning and give the examples used successfully in the teaching& learning practice at the Chemistry Department, Buketov Karaganda State University. We also focus on the assessment methods for active learning activities. Criteria for evaluation of Bachelor and Master students' projects were elaborated and applied in training process. Pedagogical experiments and our experience also show the effectiveness of using active learning in general, and project based learning in particularly.

Method

Project-Based Learning (PBL)

Project method popularized by W.H. Kilpatrick was revived in the 21st century as problem based learning. There are many definitions of this pedagogical approach. According to Buck Institute for Education PBL is "a systematic teaching method that engages students in learning knowledge and skills through an extended inquiry process structured around complex, authentic questions and carefully designed products and tasks (Markham, Larmer& Ravitz, 2003).

PBL in its initial form was a highly structured approach and as Howard Barrows says "Problem-based learning has become a popular term in education and is now often applied to educational methods and innovations that do not resemble what many of us working in the area of problem-based learning research and development would recognize as problem-based learning." (Barrows& Wee Keng Neo, 2007).

The essential features of PBL include: a central project; a constructivist focus on important knowledge and skills; a driving activity in the form of a complex question, problem, or challenge; a learner-driven investigation guided by the teacher; a real-world project that is authentic to the learner (Barron& Darling-Hammond, 2008; Thomas, 2000).

One important aspect of PBL is the changed role of the teacher. Rather than having the traditional role of the holder of the knowledge whose task is to transmit it to the learners, the role becomes more of a facilitator or coach whose main responsibility is to listen to the learners so that he/ she can guide them in their enquiries. This requires a major reorientation for staff who have been accustomed to a traditional didactic approach and can be a significant obstacle in the adoption of this methodology. Nevertheless there is a tendency for teachers to adapt PBL to preexisting systems of practice (Pecore, 2012).

Despite the number of positive benefits some educators found some barriers to successful implementation of PBL. Among them one can note length for in-depth exploration, adherence to district curriculum guidelines, use of technology as a cognitive tool, and design of authentic assessment to measure student understanding (Marx, Blumenfeld, Krajcik& Soloway, 1997).

Assessment techniques and measurement tools used to assess effectively student work within the context of active teaching and learning are different from traditional techniques of assessment. Traditional techniques of assessment are often inappropriate because of the nature of active-learning experiences. Exams cannot assess reliably the acquisition of skills and processes that are often the desired learning objectives of active learning and teaching (Major, 1999; Major, & Palmer, 2001). Assessment techniques for active learning in general and project based learning in particular tend to be linked to student performance and analyzed according to a set of clear criteria to determine if the student has achieved the learning objectives.

For assessment of students' activities we elaborated set of general criteria which are presented in the Table 1.

Table 1. Evaluation of the project

Criterion	Score
Manifestation of personal and interpersonal competencies obtained during the project	5
Integrity and rationality of the study carried out	5
Visibility and accessibility of presentation	5
Quality of speech during the presentation	5
Final score	**20**

Each criterion was subdivided into five positions, each of them characterizes the requirements for successful realization of project method in training process (Tables 2-5).

Table 2. Manifestation of personal and interpersonal competencies

Criterion	Score
Fully mastered all the necessary skills	5
Mastered all the necessary skills to a greater extent	4
In general mastered all the necessary skills	3
Not fully mastered all the necessary skills	2
Not quite mastered all the necessary skill	1

Table 3. Integrity and the feasibility of the study carried out

Criterion	Score
Comparative chemical study was carried out correctly	5
Comparative chemical study t was carried out with some inaccuracy	4
Comparative chemical study not carried out properly and there are a few mistakes	3
Comparative chemical study not carried out correctly and there are a lot of mistakes	2
Comparative chemical study was not carried out	1

Table 4. Visibility and accessibility of presentation

Criterion	Score
Material is compiled and presented accurately and correctly. The presentation is easy to understand	5
Material is compiled and presented with minor errors	4
Material is generally processed competently, but the presentation is not quite clear	3
Material is made partly correct, but the presentation is not quite clear	2
Serious mistakes in presenting the material were made and the presentation was unstructured	1

Table 5. Quality of speech during the presentation

Criterion	Score
A student builds his/her judgment properly, responds to any additional questions quickly and clearly	5
A student builds his/her judgment in correctly but he/she can answer not all questions clearly and properly	4
A student knows the answers to most questions and has general understanding of the topic	3
A student makes 1-2 gross errors in judgment, give answers to at least half of the questions, there is a gap in understanding topics	2
A student makes logical fallacies in arguments, can not find the answer to the question superficially	1

The criteria elaborated were used for assessment of Bachelor and Master students projects executed during for 2016-17 and 2017-18 academic years. These sets of criteria can be applied by teachers and students for self- and peer-assessment as well.

Results and Discussion

Having many years of experience in teaching chemistry disciplines in English, Kazakh and Russian the teachers of Chemistry Department note the positive role of application of active learning approach into the practice since students' understanding of the subjects is improved, students are interested in learning these disciplines. In order to assess the effectiveness of implementing project based learning into the teaching practice we considered a broad range of learning outcomes. We rely on the indicators of the current and final performance of students in chemistry disciplines, and throughout the entire course of the study, on the results of interviews and questioning of students, on the effectiveness of programs of academic mobility, internship and employment.

Project studies for Master and Bachelor programs

We designed a careful study with two groups of Master students in 2016-17. Project based learning was implemented for discipline "Step-Growth Polymerization" for 7 Master students studying on specialty 6M011200 "Chemistry" this group was control one; main types of academic activity were lecturing, seminars, and labs. Master students studying on specialty 6M07200 "Chemical Engineering of Inorganic Compounds" represented experimental group. Types of activity were interactive lecturing and educational projects. Both the experimental and control groups had an average GPA 3.28. Master students were also given pre-tests to evaluate their understanding of the basic concepts. They were given posttests on acquisition of knowledge and were also asked to write comments and answer questions at the interviews about their perceptions of the course procedures in both groups.

Among many types and kinds of projects we decide to choose individual long-term projects. Topics for Master students' Projects in 2016-17 were "Linear Unsaturated Polyesters vs Linear Saturated Polyesters", "Nylon 6,6: Diacid vs Diacyl Chloride", "Terylene: Commercial Synthesis vs Laboratory Synthesis", "Synthesis of Nylon 6,6 from Benzene", "Polyurethanes: Chain Extenders vs Cross-Linkers".

Example of Elaborating Project
Here is the example of developing Master student project. Steps of executing educational project includes setting the problem; forming the hypothesis; planning; execution of operations planned; analysis of results obtained; defense of the project.

Topic: Synthesis of Nylon 6.6 from Benzene
Master Student`s surname: Charushina Ye.
Motto: «Everything will turn out if you try»

Table 6. Synthesis of Nylon 6.6 from Benzene

Purpose	Subsequent synthesis of adipic acid and hexamethylenediamine from benzene for Nylon-6.6 production	Check-points
Planning	Analysis of literature data	12.02.17
	Synthesis of adipic acid from benzene	05.03.17
	Synthesis of hexamethylene-diamine from adipic acid via adiponitrile	12.03.17
	Step-growth polymerization of adipic acid and hexa-methylenediamine to produce nylon 6,6	19.03.17
Execution	Analysis of literature data	12.02.17
	Synthesis of adipic acid from benzene	05.03.17
	Synthesis of adipic acid from cyclohexane	12.03.17
	Synthesis of hexamethylenediamine by hydrogenation of adiponitrile	19.03.17
	Step-growth polymerization of adipic acid and hexamethylenediamine to produce nylon 6,6	02.04.17
Presentation	Presentation	16.04.17
Evaluation		16.04.17

According to the results of the 2016-2017 academic year average score of post-tests on acquisition of knowledge of the experimental group (Master Program) was 15% higher compared to the average score of the control group (Master Program) whereas the average results of pre-tests in both groups were almost the same.

Laboratory courses provide opportunities for using project based learning at studying chemistry. Bachelor students of Chemistry Department execute educational short-term group projects. For example, topics of students' projects were Optimal Method for Sulfanilic Acid Synthesis, Synthesis of Phenolics: Novolak and Resol, Determination of Casein Quantity in Milk, Study of Content of Ascorbic Acid in Citrus Fruits, and Synthesis of Plexiglas. Figure 1 shows some snapshots of students' final presentations on accomplishment of short-term group projects delivered in Kazakh. Students' benefits of project-based learning include improved attendance, advanced self-reliance, enhanced attitudes toward learning, better academic gains, improvement of complex skills.

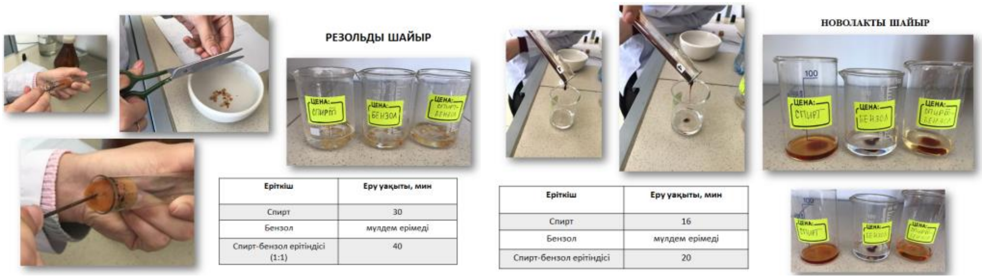


Figure 1. Snapshots of students' presentations on accomplishment of short-term group projects

Master and Bachelor students evaluations and interviews were also used to assess our experiment effectively. The majority of Master students' comments were positive. During the interview Master students of the experimental group also noted that the use of PBL approach enabled better understanding the basic concepts of the discipline as they were actively involved in educational activities, and they were not passive listeners. At the same time the students of the control group noted a low acquisition of the material with simple following instructions given by a teacher. When the experimental and control group switched their roles the situation was vice versa.

Assessment methods

Assessment is a key component of education and plays a critical role in students learning. Implementation of different assessment methods that promote collaborative, active learning helps to encourage in-class learning during lecture periods. In our practice we use various assessment techniques including Venn diagrams, image analysis, concept maps and open-ended questions. For these methods of assessment to be effective, we find questions to ask that will engage students and provide answers that can be used to signal understanding or confusion. Furthermore, we link these assessment tools to different learning skills to nurture cognitive development.

Venn diagrams are a graphical method for comparing and contrasting features or phenomena. Such diagrams represent an opportunity for students to identify the characteristics of classification systems or to analyze the key components (McConnell, D.A. et. al, 2003). For example, students may be asked to compare and contrast benzene and naphthalene using a Venn diagram (Figure 2). The use of Venn diagrams may involve knowledge, comprehension, application, and analysis levels of Bloom's taxonomy. Venn diagrams are used extensively in application areas.

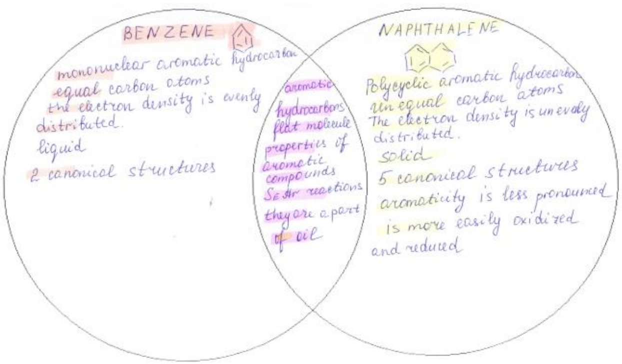


Figure 2. An example of Venn diagram compiled by chemistry students

Open-ended or divergent questions do not necessarily have a specific correct answer. Such questions can be written by the instructor to involve almost all levels of Bloom's taxonomy (Freedman, 1994). A form of open-ended question known as a minute paper is one of the most commonly utilized assessment methods in large classes. A minute paper is a short informal writing assignment that requires little time to complete and can be assessed easily (Angelo and Cross, 1993; Macdonald and Korinek, 1995; Murck, 1999). Students may be given literally one minute or a few minutes longer to complete the writing assignments. Minute papers can be used to determine whether students have grasped the key ideas presented during lecture. For examples, students are asked to write down structures of the organic compounds, chemical reactions or mechanisms of the reactions studied.

Image analysis is a form of slide observation (Reynolds and Peacock, 1998) where students are shown a photograph, map, or diagram and asked to make observations and interpretations. These types of exercises are an excellent way to begin a class as they immediately engage the student in the topic at hand. Image analysis involves knowledge, comprehension, application, and analysis levels of Bloom's taxonomy. Under certain circumstances exercises may also require students to synthesize and evaluate information. Figure 3 shows an example of an image that we use in Chemistry class. Students are asked to complete the scheme.

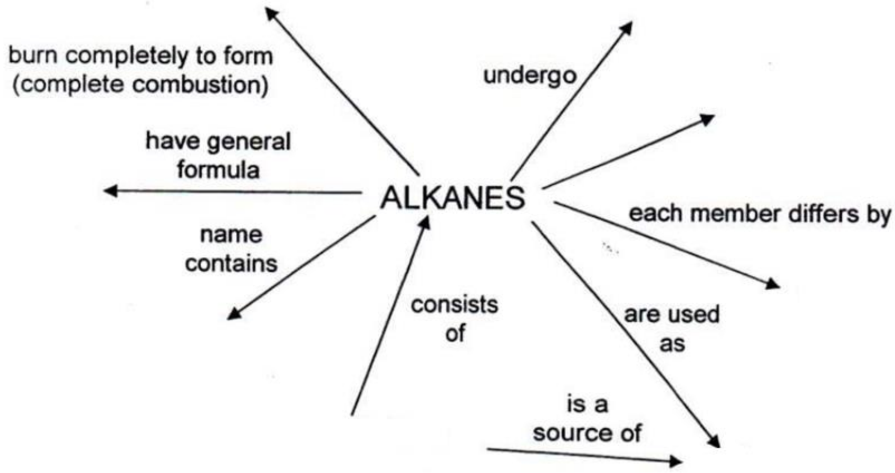
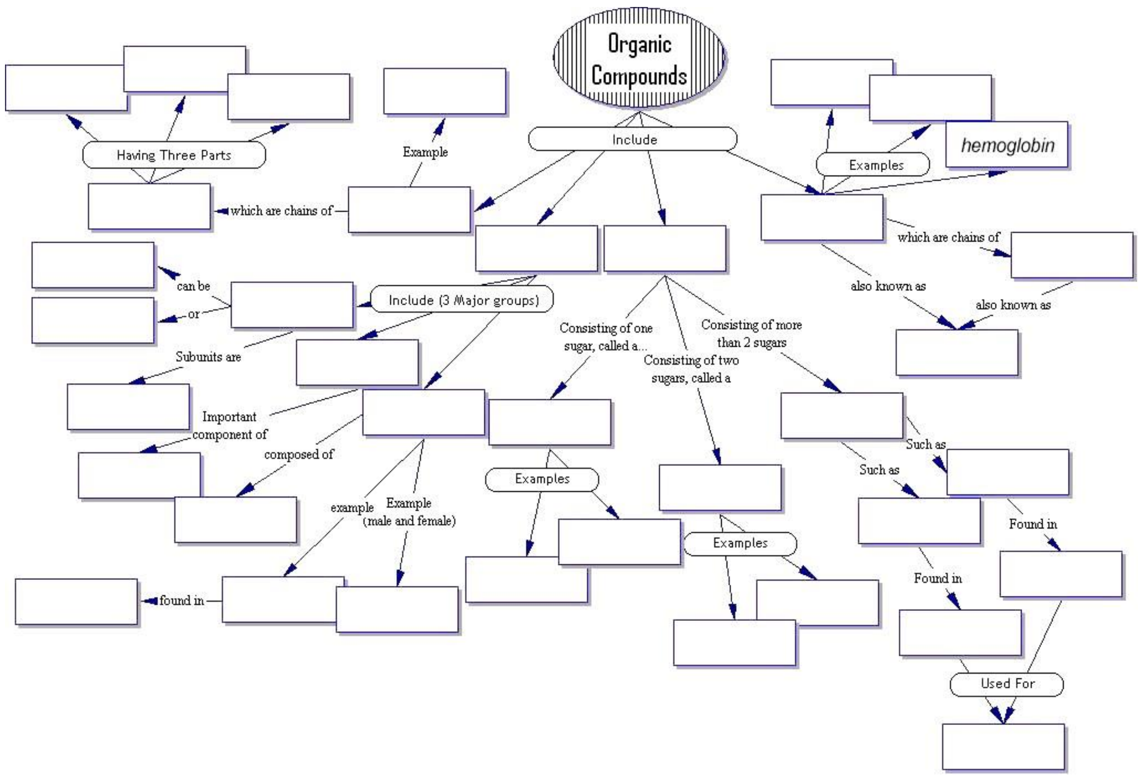


Figure 3. The task for image analysis assessment method

A concept map is a graphical representation of a student's knowledge about a topic (Zeilik et al., 1997). Concept maps are pictorial essays, a method of illustrating the principal concepts of a lesson, and include supporting information that indicates how a student has organized ideas. Concept maps present a "big picture" view of student's understanding of a topic. Good concept maps force their creators to challenge their own understanding and to build a strong foundation for information that follows. A poorly constructed map allows a reviewer to quickly identify gaps in logic or comprehension. Concept maps will vary from person to person, no two are alike. They allow for creative thinking in their construction. Concept maps have two principal components: 1.Terms or concepts - often presented in boxes; 2. Directional links (arrows) and linking phrases (prepositions) - that connect the terms. Concept maps identify the relationships between components and therefore correspond to synthesis in Bloom's taxonomy. The number of levels in a concept map can be readily counted. The terms are joined by logical linking phrases appropriate for the topic. The maps can be readily evaluated as good, average, or poor to speed assessment. Figure 4 shows an example of a concept map that we often use during lecturing.



Word bank
Amino acids, animals, Carbohydrates, Cell membrane, Cholesterol, DNA, Disaccharide, Egg yolk, Energy storage, Enzymes, Fats, Fatty acid, Fructose, Glucose, Glycogen, Hemoglobin, Hormones, Insulin, Lactose, Lipids, Monosaccharide, Nitrogen Base, Nucleotide, Nucleic Acids, Phosphate Group, Phospholipid, Plants, Polypeptides, Polysaccharides, Proteins, Saturated, Starch, Steroids, Sucrose, Unsaturated, 4 rings of carbon, 5 carbon sugar

Figure 4. A concept map “Organic Compounds”

Implementation of assessment methods considered aimed at recognizing and correcting misconceptions during lecture and laboratory classes. Such learning tools can be assigned as in-class exercises or used by students outside of class in preparation for exams. The assessment methods described are keyed to Bloom’s taxonomy. Our experience suggests that application of active learning and the PBL approach for teaching chemistry allow gaining greater knowledge than the older methods and may affect student learning in different ways. Students acquire skills and competencies necessary for future career. We revealed positive Bachelor and Master students learning outcomes in the areas of content knowledge, engagement into learning process, motivation for learning, critical thinking, problem-solving skills and collaborating skills.

Conclusion

A variety of learning strategies were incorporated into chemistry classes at the Buketov Karaganda State University taught in English, Russian and Kazakh languages. A traditional course was converted into an active learning environment through the incorporation of PBL and other formative assessment methods matched to different levels of cognitive development. Such a conversion can be readily accomplished through a combination of short lecture segments and group assessment exercises. Improvements in student achievement on exams and logical thinking skills were established. A majority of students viewed the PBL approach and other active learning methods positively.

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