

Higher-Order Thinking Development through Adaptive Problem-based Learning

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Abstract

In this paper we propose an approach to organizing Adaptive Problem-Based Learning (PBL) leading to the development of Higher-Order Thinking (HOT) skills and collaborative skills in students. Adaptability of PBL is expressed by changes in fixed instructor assessments caused by the dynamics of developing HOT skills needed for problem solving, flexible choice of control tests and problems for students, and adaptive formation of HOT skills within heterogeneous collaborative groups. It induces the students to develop HOT skills and collaborative skills through a combination of personalized and collaborative PBL. Adaptability of PBL is realized by taking into account values of the proposed coefficient of HOT skills development. The two-stage process of adaptive PBL allows guided development of HOT skills in students during study of a subject. Attention in the first stage is devoted to development of analytical HOT skills in students through personalized PBL. The main attention on the second stage is devoted to the development of creative HOT skills and collaborative skills in students through collaborative PBL. The proposed approach provides effective development of HOT skills and collaborative skills in students owing to: availability of a two-stage adaptive PBL process, complex and adaptive assessment of HOT skills, dynamic choice of control tests and problems for students, adaptive formation of HOT skills heterogeneous collaborative groups, and management of HOT skills development of students.

Keywords: higher-order thinking, adaptive learning, problem-based collaborative learning

1. Introduction

Development of Higher-order Thinking (HOT) skills of students is a complicated multidimensional challenge of education. The most significant HOT skills of students are the skills needed for problem solving. The favorable environment for development of such skills can be created through the use of the Problem-based Learning (PBL) model (Duch, Groh, Allen, 2001; Amador, Miles, Peters, 2006; Barell, 2006; Barret & Moore, 2010). Such an environment should be: HOT skills-centered (an instructor must focus on HOT skills development of students); student-centered (an instructor should encourage student interest in critical thinking and problem solving); assessment centered (an instructor should monitor student performance, and provide a high quantity and quality of assessment while stimulating students for HOT skills development); computer-supported to promote students' HOT skills development and decrease an extra-heavy workload for an instructor (Hannafin & Land, 1997; Jonassen, 1998; Bransford, Brown, and Cocking, 1999; Baden & Major, 2004; Pettigrew & Scholter, 2010).

There are two distinct types of HOT skills needed for problem solving: analytical and creative thinking skills. Analytical or logical thinking skills allow critical thinking and help select the best alternative. The analytical thinking skills are: ordering, comparing, contrasting, evaluating, and selecting. Creative thinking skills are also needed for problem solving. The creative thinking skills are problem finding (identifying the problem), efficiency (producing many ideas), flexibility (producing a broad range of ideas that characterizes flexible understanding), originality (producing uncommon ideas), and elaboration (developing ideas) (Hmelo-Silver, 2004; Bednarz, 2011; Cottrell, 2011; Cottrell, 2013).

The goal of the proposed approach is the development of HOT skills and collaborative skills in students through adaptive problem-based learning. Adaptability of PBL is expressed by changes in fixed instructor assessments caused by dynamics of HOT skills development, flexible choice of control tests and problems for students, and adaptive formation of HOT skills heterogeneous collaborative groups. It should induce the students to develop HOT skills and collaborative skills through PBL. Adaptability of PBL is aimed at personalization of learning.

According to the proposed approach, development of HOT skills in students during study of a subject by the class is realized through a two-stage process of adaptive PBL. The course knowledge is acquired during the first stage, and is devoted to the development of analytical HOT skills in students. Fixed initial assessments of analytical HOT skills are set. After this stage, analytical HOT skills of every student are examined by the personal control questions based on course material. It allows assessment of development of the analytical skills. Next, adaptive collaborative group formation takes into account the assessment results of individual students.

The second stage of adaptive PBL is fulfilled by the collaborative groups through a problem-solving process based on course material. The main attention on this stage is devoted to development of creative HOT skills and collaborative skills of students. After the second stage, developing HOT skills and collaborative skills of individual students are examined. The choice of control questions for examination of analytical HOT skills development is triggered by the assessments of the skills after the first stage. Development of creative HOT skills of a particular student is examined by control problems.

2. Related Research

The proposed approach is directed towards developing HOT skills and collaborative skills of students through the realization of adaptive PBL. The approaches, methods, and tools reviewed here are examined relative to various aspects of this process.

Savery (2006) affirms that the goals of PBL are knowledge building and adoption of a problem-solving process. Barrows & Kelson (1995) and Hmelo-Silver (2004) determine the goals of PBL, including flexible knowledge; effective problem-solving skills; self-directed, lifelong learning skills; effective collaboration skills; and intrinsic motivation. According to Hmelo-Silver (2004), "Intrinsic motivation occurs when learners work on a task motivated by their own interests, challenges, or sense of satisfaction." Students are induced to collaborate through their reflection and through the interdependence of learning within the group. Zimmerman (2002) specifies self-directed, lifelong learning skills enabling autonomous learning.

Schmidt & Moust (2000) emphasize the particular importance of collaboration because it affects intrinsic motivation and learning outcomes. Mennin (2007) explores a PBL group as a complex adaptive system (CAS). CAS is characterized by diverse agents interacting with each other capable of changing by self-organizing. A small student group is complex. It is adaptive in that the participants individually and in a group are altered. Burgos, Tattersall & Koper (2006) propose different types of adaptive learning support including problem-solving support, information filtering, collaborative grouping of students, adaptive testing, and real-time course modifications by the instructor to meet the specific needs of learners. Brusilovsky & Peylo (2003) consider adaptive group formation using knowledge about collaborating peers, and adaptive collaboration support providing an interactive support of a collaboration process assisting an individual student in solving a problem.

Knight (2000) pointed to the need for a systematic approach in the assessment of students' learning that provides reliability, validity, and usability. Moallem (2007) considers the process of evaluation relative to the following stages: initial assessment, progress assessment, and product assessment. Lovie-Kitchin (2001) rightly claims assessment methods should be congruent with the PBL process. Macdonald and Savin-Baden (2004) stressed the need for specific assessment methods for PBL. The authors note assessment should reflect the practical orientation of PBL. Brookhart (2010) asserts that holding students accountable for HOT through assessment increases student motivation and improves the results of learning. Student assessment is realized through reflection on built knowledge.

Papanastasiou (2014) defined adaptive assessment as a type of assessment that is set for each student taking into account an assessment of his (her) previous performance. This allows an assessment to be more accurate in terms of individual ability. Tilchin & Raiyn (2015) introduce an innovative approach to complex, adaptive, and computer-mediated assessment of HOT skills development of students. The complexity of assessment is expressed by forming the combined assessments of HOT skills of different types. Adaptation of assessment to the process of HOT skills development is expressed by changes in an instructor's fixed assessments by crossing from one phase of PBL to another. Assessment adaptation is provided for individual students as for a study group. Computer mediation of assessment is provided by a Computer Assessment Tool which promotes students' HOT skills development and facilitates the assessment process for an instructor.

The analysis of publications above shows that no approach exists for organization of adaptive PBL directed towards development of HOT skills and collaborative skills of students. The proposed approach will promote productive HOT skills development of students due to: complex and adaptive assessment, dynamic choice of control tests and problems for students, adaptive formation of HOT skills heterogeneous collaborative groups, and management of HOT skills development.

3. Organizing Adaptive Problem-Based Learning for Thinking Development

Organizing adaptive PBL leading to development of HOT skills and collaborative skills of students is realized by the following steps:

- A. Preparation of the needed instructional materials for a course
- B. Assessment of developing analytical skills of the students after the first stage of PBL
- C. Building HOT skills heterogeneous collaborative groups of students
- D. Formation of fixed assessments of HOT skills for the second stage of PBL
- E. Assessment of HOT skills development of students after the second stage of PBL
- F. Assessment of collaborative skills of students

A. Preparation of the needed instructional materials for a course

Preparation of the needed instructional materials for a course includes:

- The forming of a list of course topics
- Formulation of course requirements from a student with regard to development of HOT skills. After studying a course, a student should have developed HOT skills and collaborative skills. Thereby, he (she) should be able to apply effectively acquired knowledge through taking creative solutions during solving of the proposed instructional problems, and explain cause-and-effect relationships.
- The forming of a list instructional problems covering all learning outcomes and HOT skills
- Setting fixed initial assessments of analytical HOT skills. The difference of the fixed initial assessments of the skills expresses the preference of an instructor in the development of certain skills during the first phase of Adaptive PBL. An example of setting the fixed initial assessments is represented by Table 1. The “Evaluating” skill has the greatest need for development since it provides critical thinking. Consequently, the maximum fixed initial assessment is set for this skill.
- The forming of control questions and instructional problems for the examination of HOT skills of students. The instructor composes: a list of control questions which should examine analytical HOT skills of students after the first phase of Adaptive PBL; a list of control questions and problems for examination of analytical and creative HOT skills of students after the second phase.

Table 1. Fixed assessments of analytical HOT skills

The type of thinking skills	Skills name	The fixed initial assessments (%)
Analytical (40%)	Evaluating	14
	Selecting	10
	Contrasting	7
	Comparing	5
	Ordering	4

B. Assessment of developing analytical skills of students after the first stage of PBL

A student’s analytical HOT skills are assessed (by an instructor) through the answers given by a student to control questions from the individual list. An instructor assessment of a student answer to a question varies from zero to the fixed initial assessment of an analytical skill corresponding to a question. If a student cannot answer a question, or an answer is incorrect, then an instructor assessment is equal to zero. If a student answers a question corresponding to a certain skill correctly, an instructor assessment is equal to a fixed initial assessment of the corresponding skill. It means he or she has developed this skill. If a student answer is not full, an instructor sets a suitable assessment. As a result, an assessment of a student is made. Assessments of other students from a study group are set analogously. An example of assessment of the analytical skills of students is represented by Table 2. Formative assessments of analytical skills in student s_1 , s_3 , and s_5 are 34, 19, and 14, accordingly.

Table 2. Assessment of analytical skills after the first stage of PBL

The questions	Skills names		S1	S2	S3	S4	S5	S6
q_{11}^a	Evaluating	7%	7	2	3	5	2	4
q_{12}^a	Evaluating	7%	7	2	2	4	0	3
q_{21}^a	Selecting	5%	4	3	5	3	0	5
q_{22}^a	Selecting	5%	4	2	5	4	0	5
q_{31}^a	Contrasting	7%	7	4	2	7	3	4
q_{41}^a	Comparing	5%	3	5	2	4	5	2
q_{51}^a	Ordering	4%	2	0	0	0	4	0
Formative assessment of analytical skills			34	18	19	27	14	23

The obtained assessments allow an instructor to assess developing analytical skills of students through comparison of received assessments with fixed initial assessments by using a formula:

$$\delta(k_i) = (g^f(k_i) - g(k_i)) / g(k_i), \quad -1 < \delta(k_i) \leq 0 \quad (1)$$

where

$\delta(k_i)$ is a coefficient of development of skill k_i in students of the study group;

$g^f(k_i)$ is a total formative assessment of skill k_i for the study group. It is the equal sum of formative assessments of skill k_i of study group students;

$g(k_i)$ is a total fixed assessment of skill k_i . It is determined by multiplication of the fixed assessment of the skill k_i on the number of students in the study group.

Example1:

There are six students s_1, s_2, \dots, s_6 in the study group. The formative assessments of the “Evaluating” skill for these students are 14, 4, 5, 9, 2, 7, accordingly (Table 2). Hence, a total formative assessment of this skill for the study group is equal to 41. Fixed assessment of this skill is equal to 14 (Table 1). Consequently, a total fixed assessment of the skill for the study group comprising six students equals 84. Then, the value of the coefficient of development of the “Evaluating” skill in the study group, according to formula (1) is $\delta(k_i) = -0.51$. Analogously, the values of the coefficient of development of “Selecting”, “Contrasting”, “Comparing”, and “Ordering” skills are -0.33 , -0.36 , -0.3 , and -0.75 , accordingly.

C. Building HOT skill heterogeneous collaborative groups of students

Effective PBL is created by the following conditions for building a collaborative group:

- All the students studying a course should have all analytical HOT skills. Students develop needed HOT skills as a result of collaboration with other students in a study group.
- Maximum mutual supplementation of skills of students inside a collaborative group. This condition provides facilitation of developing skills of the students of the collaborative group through interactions compensating for the lack of personal skills.
- Taking into account individual characteristics of students during the formation of collaborative groups. This condition allows removal of limitations of collaboration.

The students will get an opportunity to develop HOT skills through collaboration owing to: intra-group interactions among students if cumulative skills of students in a collaborative group equal the required analytical HOT skills; inter-group interactions among students if cumulative skills of students in a collaborative group are less than the required analytical HOT skills.

Example2:

Guided by the stated conditions of building collaborative group and based on the assessments of analytical skills of students (Table 2), two collaborative groups are formed. The first collaborative group g_1 includes the students s_1, s_3 , and s_5 . The second collaborative group g_2 includes the students s_2, s_4 , and s_6 . Further development of analytical HOT skills of the students in the group g_1 can be provided by intra-group interactions among students because the group has all needed skills. All students of the group g_2 received assessment of the skill “Ordering” equal to zero. It means that the students of the group did not develop this skill. Hence, development of this skill in the students of the group g_2 can be provided through inter-group interactions with the students from the group g_1 .

D. Formation of fixed assessments of HOT skills for the second stage of PBL

Analytical skills development occurs during the first phase of PBL. Consequently, fixed assessment of this skill type is decreased for the second stage of PBL. Furthermore, analysis of assessments of analytical HOT skills reveals a lack or inadequate development of certain skills in a study group. It stipulates the need for adaptation of a study group’s analytical skills assessments in the process of developing these skills. Adaptation of assessments is realized by changing fixed analytical HOT skills assessments, and if examination results reveal a lack of a certain skill development for the study group, then fixed assessment of this skill is modified by an instructor.

Example 3:

Fixed assessment of the analytical skill type is set equal to 20% for the second stage of PBL. Analysis of the determined values of the coefficient of analytical skills development (Example1) reveals inadequate development of some analytical skills in the study group. Owing to that, fixed assessments of “Comparing”, “Selecting”, “Contrasting”, “Evaluating”, and “Ordering” are set equal to 2, 3, 4, 5, and 6, accordingly. The fixed assessment is set for the skill “Ordering” because this skill has the weakest assessment for the study group after the first phase of PBL.

An assessment of collaborative skills must be introduced for the stimulation of interactions among students during collaborative problem solving. This assessment is set equal to 20%. Fixed assessments of creative skills are set on the

basis of preferences of an instructor. Adaptive assessments should provide stimulation and facilitation of acquisition of HOT skills and collaborative skills.

An example of setting fixed assessments of HOT skills for the second stage of PBL is represented by Table 3.

Table 3. Fixed assessments of HOT skills for second stage of PBL

The type of thinking skills	Skills name	The fixed assessments
Analytical (20%)	Evaluating	5
	Selecting	3
	Contrasting	4
	Comparing	2
	Ordering	6
Creative (60%)	Originality	15
	Efficiency	12
	Flexibility	11
	Problem finding	9
	Elaboration	13

E. Assessment of HOT skills development of students after the second stage of PBL

The instructor composes individual lists of control questions on the basis of the complete list for examination of analytical skills development. An individual list can contain some questions for examination of a certain analytical skill. The individual questions are formed on the basis of skill assessments of a student after the first stage of PBL. It provides adaptive personalized learning. Next, the instructor composes individual lists of control problems based on the complete list. Development of the creative skills of a student is assessed by the instructor as a result of solving the problems from the individual list. The aggregate of control questions and problems from the individual lists should provide examination of all analytical and creative skills. An example of assessment of HOT skills of students after the second stage of PBL is represented by Table 4.

Table 4. Assessments of HOT skills after second stage of PBL

The questions	Skills names		S1	S2	S3	S4	S5	S6
q ^a ₁₁	Comparing	2%	1	2	1	2	2	1
q ^a ₂₁	Selecting	3%	3	2	3	2	1	3
q ^a ₃₁	Contrasting	4%	4	3	3	4	3	4
q ^a ₄₁	Evaluating	5%	5	4	4	5	3	4
q ^a ₅₁	Ordering	3%	2	2	3	3	3	3
q ^a ₅₂	Ordering	3%	3	2	3	1	3	2
	Assessments of analytical skills		18	15	17	17	15	17
q ^c ₁₁	Problem finding	9%	5	3	6	2	4	2
q ^c ₂₁	Flexibility	11%	7	6	5	5	8	9
q ^c ₃₁	Efficiency	12%	8	7	9	8	10	6
q ^c ₄₁	Elaboration	13%	9	7	8	4	9	10
q ^c ₅₁	Originality	15%	10	8	12	7	14	9
	Assessments of creative skills		39	31	40	26	45	36

Assessment of HOT skills development is realized by comparison of the values of the coefficient of skill development after the second stage of PBL with the corresponding values of the coefficient of skill development after the first phase of PBL. The values of the coefficient of developing skills in the study group are determined by formula (1).

Example 4:

The values of the coefficient of skill development $\delta(k_i)$ after the first phase of PBL(Example 1) are

“Comparing” - 0.3; “Selecting” – 0.33; “Contrasting” - 0.36; “Evaluating” - 0.51; and “Ordering” – 0.75 .

The values of the development coefficient $\delta(k_i)$ of these skills based on assessments of HOT skills after the second phase of PBL(Table 4) are:

“Comparing” - 0.25; “Selecting” – 0.22; “Contrasting” - 0.13; “Evaluating” - 0.17; and “Ordering” – 0.16.

Comparison of the specified values of the coefficient of skill development in the study group shows significant development of analytical HOT skills due to the second stage of PBL. Particular development of “Evaluating” and “Ordering” skills confirms effectiveness of adaptive formation of fixed assessments of HOT skills and collaborative PBL.

Combined assessments of HOT skills of the students are determined as a result of summation of corresponding assessments of analytical and creative skills. The combined assessments based on data from Table 4 are presented in Table 5.

Table 5. Combined assessments of the student HOT skills

	S1	S2	S3	S4	S5	S6
The assessments of analytical skills	18	15	17	17	15	17
The assessments of creative skills	39	31	40	26	45	36
The combined assessments of HOT skills	57	46	57	43	60	53

F. Assessment of collaborative skills of students

An assessment of collaborative skills of a student is done by taking into account assessments of his (her) HOT skills acquired as a result of collaborative PBL. The collaborative group is skill heterogeneous with realization of a condition of maximal mutual supplementation of skills of the collaborative group of students. It fosters and facilitates skill-sharing among students.

Assessment of collaborative skills is based on analysis of assessments of HOT skills of students after collaborative problem solving. The objective of the analysis is to determine the student (or students) who obtained a maximal assessment. Such assessment is a result of the acquisition of HOT skills by students due to collaborative problem solving. It can serve as a measure of success of collaboration of a student with other students of the collaborative group and also with students of other collaborative groups. Hence, a student with a maximal assessment of HOT skills possesses the best collaborative skills. The assessments of collaborative skills of students in a study group are calculated proportionally to the assessments of HOT skills on the basis of fixed assessment of collaborative skills.

The combined summative assessments characterize outcomes of PBL. These assessments are determined by the summation of combined assessments of HOT skills and assessments of collaborative skills.

Example 5:

A student s_5 has the best collaborative skills since the combined assessment of HOT skills of this student is maximal (Table 5). A student s_4 has the worst collaborative skills since the combined assessment of HOT skills of this student is minimal (Table 5).

The fixed assessment of collaborative skills is 20%. This assessment is obtained by the student s_5 since the assessment of the student is maximal and equals 60. Hence, the assessment of collaborative skills obtained by the student s_4 equals 14%.

Assessments of collaborative skills of remaining students are calculated analogously. The results of calculations are shown in the second row of Table 6. The results of calculating the combined summative assessments of students are represented by the last row of Table 6.

Table 6. Assessment of collaborative skills

	S1	S2	S3	S4	S5	S6
The combined assessments of HOT skills	57	46	57	43	60	53
Assessment of collaborative skills	19	15	19	14	20	17
The combined summative assessments	76	61	76	57	80	70

4. Conclusion and Future Work

This paper has introduced an approach to organizing adaptive PBL leading to the development of HOT skills and collaborative skills of students. HOT skills development of students during study of a subject is realized through a two-stage process of adaptive PBL. Adaptability of PBL is expressed by changes in fixed instructor assessments caused by the dynamics of HOT skills development, dynamic choice of control tests and problems for students, and adaptive formation of HOT skills heterogeneous collaborative groups.

The approach stimulates active, personalized, and collaborative learning, induces the students to develop HOT skills and collaborative skills needed for problem solving, and facilitates realizing PBL. Adaptability of PBL is realized by taking into account the values of the proposed coefficient of HOT skills development. HOT skills development of individual students confirms the effectiveness of adaptive formation of fixed assessments of the skills. Assessments of collaborative skills of students are caused by assessments of their HOT skills after collaborative problem solving.

Further research will be directed towards developing an approach to organizing adaptive PBL, and enhancement of efficiency in its practical use.

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