

Computer-supported Adaptive Management of Problem-based Learning

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Abstract

We propose an approach to a computer-supported adaptive management of problem-based learning (PBL) aimed at development of the higher-order thinking (HOT) skills in students. PBL is represented by the three-stage PBL process favoring adaptive management of intensive development of HOT skills in the students. The determined order of developing the HOT skills and solving the instructional problems is set. Adaptability of the management is provided by the dynamic assessments of the separate HOT skills, skill aggregates, one-skilled and multi-skilled instructional problems and personalized choice of instructional problems of suitable complexity for the students on the basis of the intermediate results of PBL. The learning results are evaluated by the coefficient of the HOT skill development. Adaptive management of the HOT skills development is supported by an adaptive management tool (AMT). Interactions an instructor and students with AMT are described.

Keywords: Problem-Based Learning, Higher-Order thinking, Adaptive Management, Computer-support

1. Introduction

The Problem-based Learning (PBL) model is the most suitable model for development of higher-order thinking (HOT) skills needed for problem solving (Amador, Miles&Peters, 2006; Barell, 2006; Barret & Moore, 2011). Problem solving abilities of students are caused by analytical and creative thinking skills. The analytical thinking skills are ordering, comparing, contrasting, evaluating, and selecting. The creative thinking skills are problem finding (identifying the problem), efficiency (producing many ideas of problem solving), flexibility (producing a broad range of ideas), originality (producing uncommon ideas), and elaboration (developing ideas) (Bednarz, 2011; Cottrell, 2013)

The effective implementation of the PBL model requires formation a student-centered environment characterized by personalized PBL. It requires adaptive management of PBL through the dynamic assessments and personalized choice of the instructional problems on the basis of the intermediate results of developing the HOT skills in the students. Yet, adaptive management is the labour intensive process requiring computer-support.

An approach to a computer-supported adaptive management of the three-stage PBL process directed towards the HOT skills development in students is proposed in this paper.

2. Related Research

The approaches, methods, models, and tools directed towards realization computer-supported adaptive management of PBL are examined here relative to various aspects. The aspects are computer-supported PBL and adaptive management of learning.

Gooding (2002) demonstrated that combination PBL strategy with a computer supported learning environment encourages the collaborative, and learner centered activities of students.

Raiyn & Tilchin (2015) developed approach to computer-mediated adaptive assessment of HOT skills development of students. Adaptation of assessment to the process of HOT skills development is attained by changes in an instructor's assessments while crossing from one phase of PBL to another. 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.

Aguilar & Kaijiri (2007) developed an adaptive computer-based assessment system, which provides initial, formative, and summative assessments. The system generates questions adapted to the learners' knowledge. Lazarinis, Green & Pearson (2010) proposed computerized adaptive testing system, which adapts based on student performance, instructional goals, and test participants existing knowledge of the subject matter. The authors provided examples where instructors set different adaptive assessments for various scenarios.

Burgos, Tattersall & Koper (2006) described a modern adaptive system providing the adaptation based on learning behavior of students, personalized and collaborative learning, and adjustment of the instruction type to the needs and preferences of the student. Brusilovsky & Maybury (2002) defined an adaptive system as one that distinguishes between users including their knowledge goals and interests, and an adaptable system as one requiring the user to specify exactly how the system should be different. Mennin (2007) investigated a PBL group as a complex adaptive system. Complexity of a student group is expressed by dynamic network of interactions among students. Adaptability of a group is expressed by its variability corresponding to the change.

Burgos, Tattersall & Koper (2006) proposed 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 students. Soller (2007) described various tools of adaptive support for collaborative learning to promote interactions and knowledge sharing. Brusilovsky & Peylo (2003) considered adaptive collaboration support providing an interactive support of a collaboration process assisting an individual student in solving a problem, and adaptive group formation using knowledge about collaborating peers.

Barret & Moore (2011) claimed that PBL compatible assessment should be aligned with learning outcomes, development of student capabilities, and PBL process. Papanastasiou (2014) defined adaptive assessment as one that is specific for each student and takes into account that student's previous performance, thus making it more accurate in terms of individual ability.

Raiyn & Tilchin(2016) proposed a method for the adaptive complex assessment of the HOT skills needed for problem solving, and examined the impact of the method on the development of HOT skills of students in the PBL environment. Adaptability and complexity assessment, and combination of personalized and collaborative PBL foster the development of HOT skills.

The publications discussed above indicate that no an approach exists to computer-supported adaptive management of developing the HOT skills in students while the PBL. The proposed approach will promote effective development of the HOT skills due to: a constructive learning environment represented by the three-stage PBL process; the determined order of development of HOT skills and solving the instructional problems; adaptability of the management through the dynamic assessments and personalized choice of the instructional problems; computer support of adaptive management of the HOT skills development.

3. Computer-supported Adaptive Management of Problem-based Learning

The aim of adaptive management of PBL is to promote students' HOT skills development through adaptive management of the PBL process. Adaptability of the management is provided by setting of the adaptive assessments based on results of students' HOT skills development and a personalized choice of instructional problems for solving by students. Adaptive Management of PBL is computer-supported by the Adaptive Management Tool (AMT)

3.1 Computer-supported adaptive management of HOT development

Adaptive management of HOT skills development is realized while the three-stage process of PBL. The primary development of the separate analytical skills is realized during first stage. It is based on the determined order development of analytical skills. The primary development of creative skills and the higher-order development of the analytical skills and are realized during second stage. It is based on the determined order development of creative skills and use of multi-skilled aggregates of the analytical skills. The higher-order development of the creative thinking skills is realized during third stage. It is based on use of the multi-skilled aggregates of the creative skills.

Adaptive management of developing HOT skills in the students on the first stage of PBL

The objective is to promote the primary development of the analytical skills in study group students. Adaptive management of the primary development of the analytical skills in students is realized by a sequence of the steps.

The step1: AMT gains the data from an instructor. The data are a list of the analytical skills, a list of control questions for assessment of the students' analytical skills and their aggregates (combinations).The data are filled in the Form, an example of which is represented by Table1.

The step2: Setting the adaptive assessments of the analytical skills and their aggregates.

The adaptive assessments of the analytical skills and their aggregates are set by an instructor. Setting the assessments is aimed at to promote acquiring the analytical skills by students. The total adaptive assessment is set equal to100%. The total adaptive assessment is divided on the total adaptive assessment of alone analytical skills and the total adaptive assessment of the aggregates of the analytical skills. The total adaptive assessment of the skills' aggregates is set significantly more than the total assessment of the alone analytical skills. It is caused by the intention to induce students to development of the higher-order analytical skills.

The adaptive assessments for each from the analytical skills are set by division of the total adaptive assessment of a set of alone analytical skills according to the order of developing the analytical skills. The order characterizes the sequence of the development of students' analytical problem-solving abilities. It means preliminary development of a predecessor skill in the sequence is required before development of a certain skill. So, the development order of the analytical skills can be set is Comparing, Contrasting, Ordering, Evaluating, and Selecting. The adaptive assessments are set by descending. The highest assessment corresponds with the first skill in the sequence of the analytical skills.

The total adaptive assessment of a set of the skill aggregates is divided on the adaptive assessment of the

separate aggregates according to the intention to induce the students to development of the higher-order analytical skills. Hence, the adaptive assessment set for the aggregate containing Evaluating and Selecting skills is more than the adaptive assessment for the aggregate containing Comparing, Contrasting, and Ordering skills.

The step3: Submission of the instructional questions and setting their adaptive assessments.

Some one-skilled questions are submitted by an instructor. A one-skilled question is designed for assessment development a separate analytical skill in students. The adaptive assessment of the question is determined by AMT as a result of division the adaptive assessment of corresponding skill on the number of the one skill questions.

Some multi-skilled questions of different complexity are submitted by an instructor. A multi-skilled question is designed for assessment development of the analytical skills aggregates. The adaptive assessment of the most comprehensive multi-skilled question is set equal to the adaptive assessment of the corresponding aggregate. The adaptive assessments for the rest multi-skilled questions are determined by ATM according to their complexity.

The step4: Assessment of the separate analytical skills of student.

An instructor assesses analytical skills of the students as a result of performance by them the corresponding one-skilled questions. The formative assessments he (she) enters in the Form.

Example1. The adaptive assessments of the analytical skills, their aggregates, and a list of the control questions, are presented in Table1. The formative assessments received by the students as a result of performance by them the one-skilled questions also presented in Table1.

Table1. The operational data form

The PBL stages	The skills and their aggregates	The HOT and their aggregates	The adaptive assessments of the HOT skills and their aggregates	The instructional questions and problems	The adaptive assessments of the questions and problems	The formative assessments of students		
						S1	S2	S3
The first stage of PBL	Comparing	14%		q ₁	7%	12	10	7
				q ₂	7%			
	Contrasting	10%		q ₃	5%	9	8	5
				q ₄	5%			
	Ordering	8%		q ₅	4%	7	6	3
				q ₆	4%			
	Evaluating	3%		q ₇	3%	2	2	1
	Selecting	2%		q ₈	2%	2	1	1
The second stage of PBL	Comparing, Contrasting, and Ordering	26%		q ₉	20%	24	18	15
				q ₁₀	26%			
	Evaluating and Selecting	37%		q ₁₁	31%	34	28	27
				q ₁₂	37%			
	Problem finding	10%		p ₁	10%	8	7	5
	Elaboration	8%		p ₂	8%	7	6	4
	Originality	6%		p ₃	6%	6	5	3
	Efficiency	5%		p ₄	5%	4	3	2
Flexibility	4%		p ₅	4%	3	4	2	
The third stage of PBL	Problem finding and Elaboration	31%		p ₆	27%	29	25	22
				p ₇	31%			
	Originality, Efficiency, and Flexibility	36%		p ₈	30%	35	33	27
				p ₉	36%			

Adaptive management of development of HOT skills in students on the second stage of PBL

The objective is to promote the primary development of creative skills and development of the higher-order analytical skills. Adaptive management of the primary development of the creative skills and further development of the analytical skills in students is realized by a sequence of the steps.

The step1: AMT receives from an instructor a list of the creative skills and their aggregates, and a list of control

problems for assessment of the students' creative skills. The data is filled in the Form (Table1).

The step2: Setting adaptive assessments for the creative skills and their aggregates.

The total adaptive assessments for the creative skills and their aggregates are set by division of the total assessment which is equal to 100%. The total adaptive assessment of the aggregates of the some creative skills is set significantly more than the total assessment of a set of the separate creative skills. It is caused by the intention to induce intensive acquirement of the creative skills by students.

The adaptive assessments for each from the creative skills are set by division of the total adaptive assessment for a set of the separate creative skills according to the order of them development. The order is caused by dependence of skills. It means developing the following skill requires preliminary development of the predecessor skill. Hence, the order of the creative skills development is Problem finding, Elaboration, Originality, Efficiency, and Flexibility.

The assessments should induce the students to consistent development of the creative skills according to the determined order. So, the adaptive assessments are set by descending. The highest assessment is set for first skill in the ordered sequence of the creative skills.

The total adaptive assessment for a set of the aggregates of creative skills is divided on the adaptive assessment of the separate aggregates according to the intention to induce the students to development of the higher-order creative skills. Hence, the adaptive assessment for the aggregate containing Originality, Efficiency, and Flexibility skills is set more than the adaptive assessment for the aggregate containing Problem finding and Elaboration skills.

Example2. The adaptive assessments for the creative skills and their aggregates are presented in Table1.

The step3: Assessment of the separate creative skills of students.

An instructor assesses creative skills of the students as a result of performance by them the corresponding one-skilled questions. The formative assessments are filled by the instructor in the Form (Table1).

The step4: Determination of the coefficient development of the analytical skills in students.

The values of the coefficient development of the different sets of the analytical skills are determined by AMT in the following way. The analytical skills corresponding with the skills containing in the skills aggregate are selected from Form (Table1). The total adaptive assessment of these analytical skills is determined by summation of the adaptive assessments of the separate skills which was set on the first stage of PBL. The total formative assessment of these analytical skills of the students is determined by summation of the formative assessments received as a result of performance by them one-skilled questions after completion of the first stage of PBL.

The values of the coefficient development of a set of the analytical skills are calculated by formula:

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

where

$\delta(k_j)$ is a coefficient of developing k_j set analytical skills in the student,

$g^f(k_j)$ is a total formative assessment of k_j set of analytical skills of the student,

$g^a(k_j)$ is a total adaptive assessment of k_j set of analytical skills.

Example3. The analytical skill aggregate designed for control of developing higher-order analytical skills in students on second stage of PBL contains skills "Comparing", "Contrasting", and "Ordering" (Table1). The total adaptive assessment of the set of the skills determined by summation of the adaptive assessments of the separate skills is equal to 32%. The total formative assessments of these skills of student s_1 , s_2 , and s_3 are 28, 23, and 15, accordingly. Then, the values of the coefficient development of the set of analytical skills calculated by formula (1) for student s_1 , s_2 , and s_3 are -0.13, -0.28, and -0.53, accordingly. Similarly, the values of the coefficient development relative to the skill aggregate combining skills "Evaluating" and "Selecting" for student s_1 , s_2 , and s_3 are -0.2, -0.4, and -0.6, accordingly.

The step5: Submission to students the multi-skilled questions and assessment of their performance.

The multi-skilled questions are submitted to students by ATM according to a bottom line of the coefficient development value of the set of the corresponding analytical skills. A bottom line is set by an instructor. If the coefficient development value of the student is less than the bottom line, then the student receives the multi-skilled question having lower adaptive assessment. If the coefficient development value of the student is more than the bottom line, then the student receives the multi-skilled question having higher adaptive assessment.

Example4. A bottom line is equal to -0.25. Then, ATM submits to the students s_2 , and s_3 the multi-skilled question q_9 having the adaptive assessment is equal to 20% and to the student s_1 the multi-skilled question q_{10} having the adaptive assessment is equal to 26% (Table1).

An instructor assesses performance of the multi-skilled questions directed towards control of development of the aggregates of the analytical skills by students and fills the student assessments in the Form (Table1).

Adaptive management of development of HOT skills in students on the third stage of PBL

The objective is to promote development of the higher-order creative skills.

The step1: Determination of the coefficient development of the creative skills in students.

The values of the coefficient development of the different sets of the creative skills are determined by AMT in

the following way. The creative skills corresponding with the skills containing in the skills aggregate are selected from Form (Table1). The total adaptive assessment of these creative skills is determined by summation of the adaptive assessments of the separate skills which was set on the second stage of PBL. The total formative assessment of these creative skills of the students is determined by summation of the formative assessments received as a result of performance by them one-skilled problems after completion of the second stage of PBL.

The values of the coefficient development of a set of the creative skills can be calculated by formula (1).

Example5. The creative skill aggregate designed for control of developing higher-order creative skills in students on third stage of PBL contains skills “Problem finding” and “Elaboration” (Table1). The total adaptive assessment of the set of the creative skills determined by summation of the adaptive assessments of the separate skills is equal to 18 %. The total formative assessments of these skills of student s_1 , s_2 , and s_3 are 15, 13, and 9, accordingly. Then, the values of the coefficient development of the set of creative skills calculated by formula (1) for student s_1 , s_2 , and s_3 are -0.17, -0.28, and -0.5, accordingly. Similarly, the values of the coefficient development relative to the creative skill aggregate combining skills “Originality”, “Efficiency”, and “Flexibility” for student s_1 , s_2 , and s_3 are -0.13, -0.2, and -0.53, accordingly.

The step2: Submission to students the multi-skilled problems and assessment of their performance.

The multi-skilled problems are submitted to students by ATM according to a bottom line of the coefficient development value of the set of the corresponding creative skills. A bottom line is set by an instructor. If the coefficient development value of the student is less than the bottom line, then the student receives the multi-skilled problem having lower adaptive assessment. If the coefficient development value of the student is more than the bottom line, then the student receives the multi-skilled problem having higher adaptive assessment.

Example6. A bottom line is equal to -0.25. Then, ATM submits to the student s_3 the multi-skilled problem p_8 having the adaptive assessment is equal to 31% and to the students s_1 , and s_2 the multi-skilled problem p_9 having the adaptive assessment is equal to 36% (Table1).

An instructor assesses performance of the multi-skilled problems directed towards control of development of the aggregates of the creative skills by students and fills the student assessments in the Form (Table1).

3.2 Interactions AMT with an instructor and students

The interaction between an instructor and students is as follows. An instructor leads PBL of the students. He also offers the one-skilled and multi-skilled questions and problems of different complexity for students, sets adaptive assessments for the HOT skills, questions and problems, and assesses the HOT skills development. The students interact with an instructor during PBL and present answers for the control questions and the results of problem solving.

During the interactions between an instructor and the AMT, an instructor fills in the aforementioned data on the Form (the Table1). The AMT provides an instructor with the next outcomes: the formative assessments of the analytical and creative skills of individual students relative to a certain stage and all PBL process; average formative assessments of the analytical and creative skills of a study group relative to a certain stage and all PBL process; the values of the coefficient development of the analytical and creative skills in individual students; the summative assessments of the analytical and creative skills of individual students as a result of PBL; the thinking skills that revealed poor and improved development relative to every student and a study group; and the best student and the worst student relative to HOT skills development.

During the interactions between a student and the AMT, a student inquires of the AMT about assessments of his (her) HOT skills. The AMT gives to a student: formative assessments of the analytical and the creative skills relative to a certain stage, and the summative assessment of the HOT skills after completion of PBL; the list of the thinking skills that had poor and improved development.

4. Conclusion

The approach to computer-supported adaptive management of PBL is introduced in this paper. The approach enables to induce the students to acquisition of HOT skills and facilitates teaching in the PBL environment. Efficiency of the PBL process is provided by the three-stages its performance, setting of the determined order of developing the HOT skills and solving the instructional questions and problems.

Effectiveness of adaptive management of PBL is attained by change of the adaptive assessments and dynamic choice of the multi-skilled instructional questions and the problems on the basis of the intermediate results of developing the HOT skills in the students. It provides personalization of the PBL process.

Computer-support is realized by the AMT on the basis of the information received from an instructor. The ATM sets the adaptive assessments of the instructional questions and problems, determines the values of the coefficient development of the different combinations of the HOT skills for each student, submits to each student the most suitable multi-skilled questions and the problems, and calculates the summative assessment of the HOT skills after completion of PBL. Interactions of the AMT with an instructor and students demonstrate the central role of the ATM in the PBL process.

Further research will be directed towards enhancement of intelligent ability of ATM.

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