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### ► To cite this version:

Natalia Kushik, Nina Yevtushenko, Tatiana Evtushenko. Novel machine learning technique for predicting teaching strategy effectiveness. International Journal of Information Management, 2020, 53, pp.101488:1-101488:10. 10.1016/j.ijinfomgt.2016.02.006 . hal-03124461

HAL Id: hal-03124461

<https://hal.science/hal-03124461>

Submitted on 22 Aug 2022

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# Novel machine learning technique for predicting teaching strategy effectiveness

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**Keywords:** Educational management, level of proficiency, evaluation/estimation/prediction, logic network/circuit, teaching strategy

**Abstract:** In this paper, we present an approach for evaluating and predicting the student's level of proficiency when using a certain teaching strategy. This problem remains a hot topic, especially nowadays when information technologies are highly integrated into the educational process. Such a problem is essential for those institutions that rely on e-learning strategies as various techniques for the same teaching activities and disciplines are now available online. In order to effectively predict the quality of this type of (electronic) educational process we suggest to use one of the well known machine learning techniques. In particular, a proposed approach relies on using logic circuits/networks for such prediction. Given an electronic service providing a teaching strategy, the mathematical model of logic circuits is used for evaluating the student's level of proficiency. Given two (or more) logic circuits that predict the student's educational proficiency using different electronic services (teaching strategies), we also propose a method for synthesizing the resulting logic circuit that predicts the effectiveness of the teaching process when two given strategies are combined. The proposed technique can be effectively used in the educational management when the best (online) teaching strategy should be chosen based on student's goals, individual features, needs and preferences. As an example of the technique proposed in the paper, we consider an educational process of teaching foreign languages at one of Russian universities. Preliminary experimental results demonstrate the expected scalability and applicability of the proposed approach.

## 1 INTRODUCTION

As information technologies (IT) and communications are rapidly progressing, they contribute more and more for a better human life. In some areas they are integrated very easily, while in the others IT development is hard to be accepted. Among the second group one can consider an educational process at classical (fully comprehensive) universities. The reason is that educational institutions of this type are known to be very traditional and conservative, and somehow it is hard for an experienced teacher/professor to give lectures online via any electronic communication channel instead of giving a typical oral presentation to the students. However, emerging e-learning systems, strategies and scenarios (Moore et al., 2011; Prodan et al., 2012) make it possible to somehow simplify the teachers' life and allow students to study a discipline individually wherever or whenever they need. The benefits and limitations of the e-learning, along with the analysis of a number of possible models, are presented in (Chang, 2016). In this paper, we aim at predicting which e-learning strategy can be more efficient for a student possessing a number of certain individual traits.

Massive Online Open Courses (MOOC List) can serve as a good example of using IT for educational needs that have been initially invented in North America and are now spread around the world. MOOC are known to be good for sharing outstanding lectures, potentially with everybody who has an access to the Internet. Nevertheless, for a university teacher/professor, it is not sufficient to share the knowledge with students but also it is necessary to evaluate the student's knowledge and thereby the level of education when the course has been completed. Exactly at this point the question arises how to assess the student's proficiency since such online evaluation is somewhat tricky as there is always a possibility for a student to cheat, e.g. 'ask Google' online, and no possibility for a teacher to have a live discussion with a student. Using Skype and video conferences can help a lot in solving this problem but at present written tests still remain the most widely used tools for the online evaluation of learner's abilities. Another question that arises in this context is how a learner can choose an online teaching strategy or combine several of those that can be most effective for him/her, i.e., a learner can get a maximal profit with minimal efforts. The objective of this paper is to propose and discuss a mathematical model to solve this problem.

The paper hypothesis is that the effectiveness of an e-teaching strategy can be evaluated and predicted based on a set of learner's abilities, namely dominating factors or parameters that influence the acquisition of the discipline. The latter allows to rely on machine learning techniques (or any other predicting engine) to effectively predict the score obtained by a student with  $n$  dominating parameters when a given ( $i^{\text{th}}$ -) teaching strategy is used (See Fig. 1).

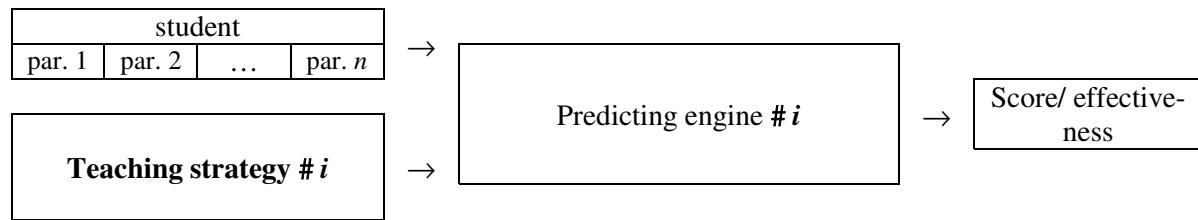


Figure 1: Schematic representation of the hypothesis of the paper (predicting engine)

For prediction, learner's abilities and his/her proficiency at the outcome are represented as combinations (vectors), with the input parameters being easily measured when the component values are scaled as integers. We need to perform the process of simulation of various combinations along with the process of adapting the model to new statistical data very fast; for the last purpose, a mathematical model of logic circuits can be applied (Villa et al., 2012), which has proven its effectiveness for calculating the Quality of Experience under the same conditions (Kushik et al., 2014). Such a technique will allow any user (teacher/student/parents) to easily choose the right teaching strategy for a certain student in a short time period and thus, to get the maximal profit with minimal efforts. In other words, we assume that there can be derived an efficient managing engine that executes the predicting engine for each teaching strategy and a given student represented as the combination of  $n$  dominating parameters. Analyzing the set of scores obtained for each teaching strategy the managing engine 'chooses' the best one (or a combination of those). Fig. 2 (together with Fig. 1) illustrates the hypothesis of the paper.

The main contribution of the paper is a proposal of using the logic circuit based approach in the area of educational management, and in particular, for predicting the effectiveness of a composite (combined) teaching strategy. This approach has been initially proposed for predicting a level of the user satisfaction with a given (composite) service. Therefore, followed by our hypothesis, we assume that the results obtained for evaluating and predicting 'the feelings' of an end-user about web/multimedia/electronic services and their compositions, can be applied to the case when these services are created for the educational needs. Moreover, we provide a technique for the effective use of available tools for logic synthesis and verification that support necessary operations and process combinations of integers encoded as Boolean vectors very fast. In particular, we provide examples of using software tool ABC developed at the UC, Berkeley, for scalable prediction of the effectiveness of a composite teaching strategy. We illustrate the applicability of a proposed approach, providing methodological details of experimental evaluation and prediction of the language proficiency of students that study a foreign language at technical faculties of Tomsk State University following different teaching strategies or the combination of those.

The rest of the paper is organized as follows. Section 2 contains the related work while Section 3 has the main hypotheses. A scalable machine learning technique for predicting teaching strategy effectiveness is given in Section 4. Section 5 presents the preliminary experimental results for a chosen case study. Section 6 concludes the paper.

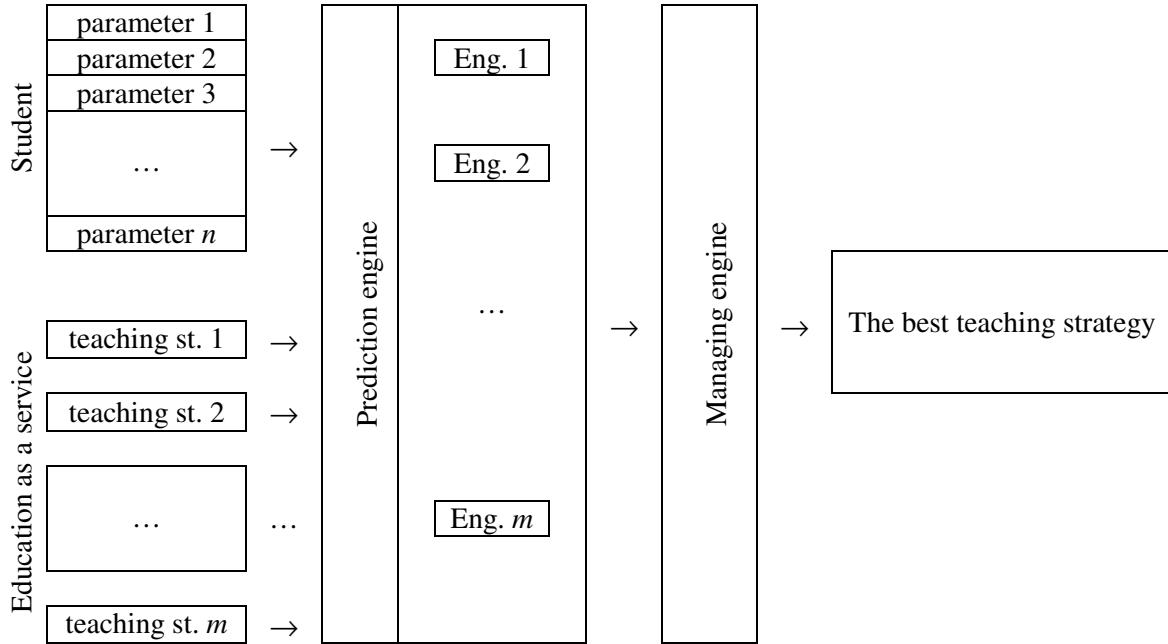


Figure 2: Schematic representation of the hypothesis of the paper (managing engine)

## 2 RELATED WORK

Different types of services are now developing for making life of a human being easier and more progressive. A huge domain in a service-oriented environment encompasses numerous implementations of electronic services implemented for various human needs. Internet connection allows almost everyone to use a web browser to access a service of a specific need. That is the reason why a technical field named ‘Software as a Service (SaaS)’ is nowadays progressing rapidly. The advantage using of such software is the absence of the need of its installation and download, i.e. a user does not have to obtain a license on the software he/she wants to utilize. Instead, he/she can ‘buy’ a subscription and can utilize the corresponding service from his/her web browser ‘on demand’. In this case, Cloud Computing makes a good job providing an opportunity of storage for services and related applications in the Cloud. Obviously, this direction implies more challenges to researchers and technicians in seeking for new ideas and scalable implementations for fast and reliable utilization of SaaS. Outstanding contributions in this area are presented in certain conferences and workshops (see for example, proceedings of the ESaaSA Workshop, 2014 and 2015).

This paper is focused on the effective testing and quality estimation of services that are used for educational needs. A reader may refer, for example, to (Chang and Wills, 2013) where the term ‘Education as a Service (EaaS)’ covers ‘Cloud architecture, applications and services delivered by Cloud to education in the form of lectures, quizzes, assignments, marking, tutorial, discussions, debates and student support’. It is stated by the authors that on the one hand, the higher education, its content and ways of delivering courses, can be trans-

formed by the use of Cloud computing services; however, the benefits of this form of education are still debatable. On the other hand, EaaS becomes an issue of business and marketing, which requires finding new solutions of how to study the quality of existing services and user satisfaction.

Nowadays, various education services (see for example, iTunes U, or Intel Education) offer different teaching strategies providing large-scale educational materials and include several options such as sharing lectures, organizing tests, verifying results, etc. Emerging online courses are very promising; however, there arises a problem how to evaluate the quality of these systems (Casey, 2008). Another service is provided by Moodle software (Moodle Courses & Content) that is widely used around the world. However, Moodle has its own drawbacks such as the complexity in usage for a teacher and the impossibility to use Moodle for a wide range of tasks in various disciplines. Moodle also does not allow to choose the most suitable teaching strategy for a certain student depending on his/her individual features and expectations. This type of software is most often used as an additional training or self-evaluating tool for homework or self-study activities supervised by the teachers. Therefore, in some cases, due to the absence of a possibility for a student to evaluate the effectiveness of a proposed teaching strategy it is reasonable and beneficial for an Institution not to buy a license for the software like this and waste IT resources on its installation and usage. Another option is to use a number of online services that support this or that teaching strategy, and to execute them whenever it is needed. It is also convenient for teachers and students when all the test results and materials to share are stored in the Cloud, and appropriate services are activated to access the necessary information on-the-fly. Such strategy seems to be very promising if a person who chooses a strategy could predict how effective the strategy would be for his/her personal needs. For this reason, special tools have to be elaborated that allow a person to evaluate proposed teaching strategies based on learner's background, his/her personal features which can be useful when studying an appropriate subject, etc. Such factors (parameters) can be evaluated and their values can be considered as values of components of an appropriate vector.

Assessing the effectiveness of teaching is a more complex procedure. It comprises the level of proficiency of students where a lot of other factors such as student portfolios, teachers' portfolios, questionnaires, etc. should be taken into account (Berk, 2005). Similar to evaluating the Quality of Experience (QoE), the question arises how to scale those additional factors and how to compare different factor combinations (Kushik et al., 2014). In general, for comparing, each combination is represented as an integer (or a constant in some logic), and a better strategy or a combination of several strategies appropriate for a given user can be selected. There are various approaches for such folding: some researchers use a linear combination where the coefficients are considered as 'know how'; another group of researchers use different self-adaptive machines. Therefore, there is a strong need for developing efficient and scalable prediction algorithms to make prognoses about the effectiveness of educational strategies, or their composition of the corresponding services. As such prediction relies on the knowledge about how 'a student brain works and what it can process and acquire easily and why', it is natural to address the use of self-adaptive models to simulate the prediction.

A wide range of definitions of methods, techniques, and strategies in education are presented in manuscripts and guides on methodology of teaching (see, for example, Jacobsen et al., 2009; Richards, 2001). However, the differences between all these are irrelevant for the current study. Thus in this paper, a method, or a teaching strategy, refers to a way of teaching using certain techniques, procedures and materials depending on the goals of the educational process. As the online education is not usually supervised by a teacher and implies mostly the electronic feedback (electronic testing), we need to introduce the term of the intensity of learning which will cover all the efforts and time contributed by a student for the learning process.

The effectiveness of a teaching strategy depends on how well and fast the students acquire new knowledge. There are a number of internal and external differences, namely individual abilities, needs and preferences of the target group, that influence the learning process, and thereby the choice of the teaching strategy (see, for example, Jacobsen et al., 2009; Richards, 2001). Traditional forms of education (classroom) do not provide a possibility for a teacher to use an individual approach in a group of students with mixed abilities. Online courses make it possible for a student to choose the most effective teaching strategy, or even combine them when necessary, based on learner's individual features and expectations.

When the learner's abilities and his/her proficiency at the outcome are represented as combinations of dominating factors that influence the acquisition of the discipline, the problem of evaluating the effectiveness of an e-teaching strategy becomes very close to evaluating and predicting 'the feelings of an end-user about web/multimedia/electronic services and therefore, self adaptive models which model 'human brains' can be used for this purpose. Most popular self-adaptive models for predicting service quality are decision trees (see,

for example, Mitchell, 1997; Pokhrel, J., Mallouli, W., and Montes de Oca, E., 2013), neural networks (Ahmed et al., 2012; Al-Masri and Mahmoud Qusay, 2009), fuzzy logic formulae (Lin et al., 2005; Torres et al., 2011), and logic circuits (Kushik et al., 2014) which can be considered as scalable representations of decision trees. All these models have their own advantages, as well as drawbacks. The most common criterion that should be always taken into account is the prediction ability of the model and its scalability when re-building (if necessary for appropriate statistical data). All of these models are widely used to predict user's satisfaction with a given service, and it has been previously shown that the approach proposed by Kushik et al. in 2014 allows to adequately predict the end-user satisfaction with a given service, and, at the same time, to perform the model adaptation in a scalable way (Kushik et al., 2014). This approach is based on logic networks, in particular, combinational circuits. The initial logic network is derived based on statistical data that are gathered from experts, developers and/or end-users who agreed to provide a feedback about the service quality. When new statistical data appear the circuit is checked for having the corresponding behaviour and if the behaviour does not correspond to newly emerged data the circuit is resynthesized. Such resynthesis can be efficiently performed using various tools (see, for example, Berkeley Logic Synthesis and Verification Group, ABC). In this paper, we propose to use the same model when evaluating the effectiveness of a teaching strategy and verify the hypothesis by preliminary experimental data.

To sum it up, in the area of Educational Management, Emerging services are progressing rapidly. Therefore, new methods and techniques to estimate the quality of such services are also developing nowadays. In this paper, when predicting how promising this or that (combined) teaching strategy is, the quality of the corresponding e-service is considered as its effectiveness. When such teaching strategy is derived as a combination of two or more strategies, the effectiveness of the composition can be predicted based on the knowledge of the effectiveness of each component strategy. The authors are not aware of any related results in the area of such prediction for combined teaching strategies and thus, we present one of possible machine learning approaches that is based on the effective use of logic circuits.

### 3 HYPOTHESES

The major hypotheses of the current paper are related to the possibility of improvement of the quality of the education services using mathematical models that can quickly process combinations of dominating factors and be adapted to the obtained new statistical data autonomously, i.e. without the additional help of a teacher or a designer. Namely the following items are considered.

**A** The learner's abilities are represented as a combination of values of dominating parameters and the value that assesses the effectiveness of the chosen teaching strategy (score). Representing these combinations as appropriate vectors allows us to use mathematical models for fast processing of these combinations. On the one hand, using such limited representation of human abilities and knowledge does not allow to fully describe the details of an educational process and assess the effectiveness. Calculation errors become another limitation of this approach; however, this can be neglected when the percentage of wrong calculations is around 10 %, since it corresponds to ordinary human factor and such description is thus used in many applications.

**B** Each parameter value is scaled as an integer. This assumption simplifies the process of collecting data from learners as well as makes possible to process the combinations very fast. Nevertheless, we realize that this can affect the accuracy of measurement which will be decreased compared with a more precise evaluation performed in fuzzy logic with floating point numbers (Zadeh, 1965).

**C** The problem of evaluating the effectiveness of an e-teaching strategy is very close to evaluating and predicting 'the feelings' of an end-user about web/multimedia/electronic services as 1) it also deals with the user satisfaction and is supposed to meet the needs and expectations of its user (teacher) and 2) it tries to predict and formally describe how the human brain works. Thus, we believe that the machine learning techniques can be used for the purposes of the current study.

## 4 METHODOLOGY

In this paper, to test the stated hypotheses, i.e. to demonstrate the possibility of prediction of the teaching strategy effectiveness before taking the course and choosing a teaching strategy we propose to use a novel machine learning technique, namely logic circuit based technique, that allows to effectively predict the quality of a teaching strategy in the area of educational management. The logic circuit based approach has been adapted to the prediction of the quality of a composite service (Kushik and Yevtushenko, 2015), and we believe it can be also used for the educational needs. Indeed, given a set of services providing different teaching strategies, the teacher/professor plans to combine some of those to achieve a better result for a student within a given (fixed) time period. The question arises: which services can be composed so that the level of proficiency of a student will be close to its maximum. In other words, the process of simulation of various combinations needs to be quickly performed and this process has to be able to be automatically adapted to new statistical data of the score evaluation (if necessary). One of the ways to provide the scalability of machine learning approach is to encode all the information as Boolean vectors and use logic circuits for representing corresponding combinations of dominating factors and the score. In this paper, we mainly focus on the application of the proposed technique to the educational needs, and in particular e-learning needs.

Given two services/strategies and two logic circuits for predicting the learner's level of proficiency which would demonstrate the effectiveness of the chosen teaching strategy applied for a certain user, we propose a technique how to synthesize the resulting logic circuit that predicts the overall level of proficiency of a student that follows two educational strategies simultaneously. The technique relies on scalable operations over logic networks, such as introducing additional inputs and connecting nodes in the circuit to combine particular circuit parts. The proposed approach takes into account not only services implementing various educational strategies, but also the percentage of how much these strategies are involved in the overall teaching strategy. We mention that this approach has been previously proposed to predict the quality of service composition and has been presented on the ESaaSA Workshop in 2015.

### 4.1 Student's abilities as a combination of parameter values

To evaluate the student's abilities for studying a discipline following this or that strategy we need to identify the main factors that influence the teaching and learning process and somehow derive the scale for each factor to formally describe the student's ability to study a certain discipline. In this paper, learner's individual differences are referred to as *factors* or *parameters*. A student is thus 'represented' as a combination of parameter values. Depending on students' goals of learning a subject and which parameters are dominating a teacher can choose an appropriate method (strategy) which would be the most efficient for a certain student.

Since the students are active participants of the educational process, their opinion is of great importance to our study. The students (180 respondents) were offered to scale a number of factors that seem to be the most significant for the language acquisition and teaching strategy choice. According to the questionnaire, among the most important factors are fast tongue (42%), good ear (28%), and homework (19%). Other factors such as grammar rules, entertainment (watching movies and playing computer games in English) and regular attendance of the lessons were considered as less significant (11%). The diagram in Fig. 3 shows the distribution of the significance of the mentioned parameters according to student opinions.

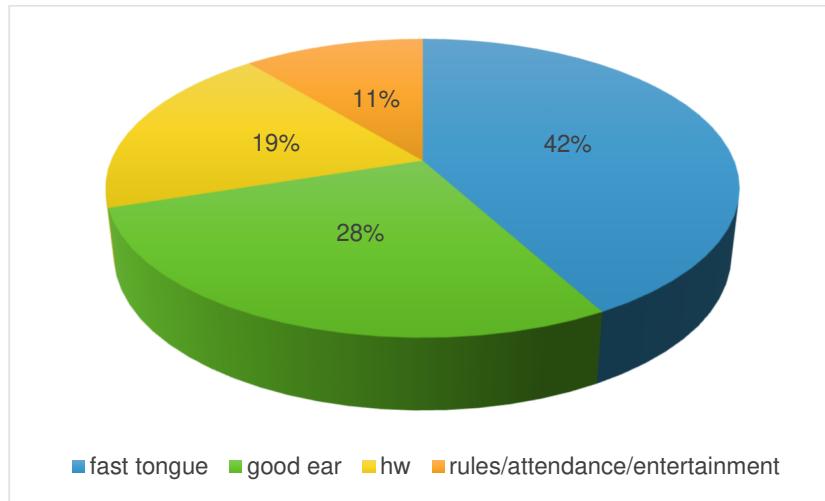


Figure 3: Parameters influencing language acquisition (student opinion), 180 respondents

**Example.** As an example, consider students who study English as a foreign language. A sample of factors and abilities for these students is represented in Table 1. Rows of this table correspond to students identified as Student\_1, Student\_2, ..., Student\_N, while columns refer to the values of different parameters of interest. In this example, we consider only three parameters and the communicative teaching strategy which is focused on the development of communicative language competences (Richards, 2001). For instance, if a student has no problem with expressing his/her thoughts then we say that he/she has a *fast tongue*. A *good ear* corresponds to the absence of serious problems with listening comprehension. The last parameter *homework* refers to his/her readiness to diligently complete home assignments. Each parameter has a scale from 0 to 10 while the score/effectiveness is scaled from 0 to 5. According to the teacher's experience, if a student has a problem with expressing his/her thoughts in a foreign language (*fast tongue* = 3), has no serious problems with listening comprehension (*good ear* = 7), and is ready to fairly perform the homework (*homework* = 10) then his/her score after completing the course is predicted to be 4 if he/she follows this teaching strategy.

Table 1. Communicative teaching strategy

Student	Fast tongue	Good ear	Homework	Score
Student_1	3	5-7	10	4
Student_2	8-9	8-9	7-8	5
Student_3	8-9	5-6	0	3
Student_4	5-6	5-6	4-5	4

Given now a student for which dominating parameters are measured, we would like to evaluate/predict the effectiveness for a student to use a corresponding (electronic) teaching strategy. In the running example, we assume that three most significant parameters according to Fig. 3, namely, *fast tongue*, *good ear* and *homework*, are measured and collected in Table 1. The objective now is to derive a prediction engine based on machine learning techniques that effectively predicts the score of a given student after completing a given teaching strategy (Fig. 4).

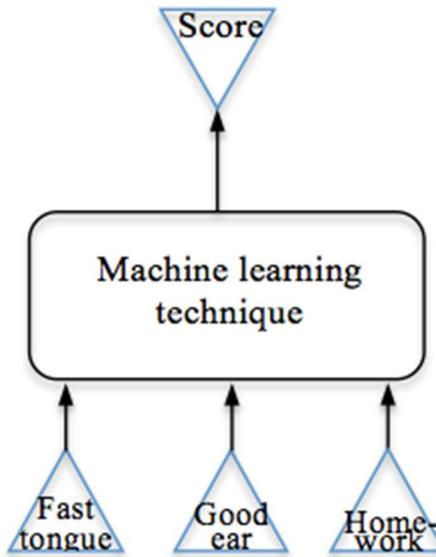


Figure 4: Using a machine learning technique for predicting the score of a given student after following the communicative teaching strategy

The machine learning technique utilized in this paper is based on pre/post conditions for which logic circuits can be considered as a compact and efficient representation. Therefore, we further remind the notions corresponding to logic circuits.

#### 4.2 Using logic circuits for effectiveness evaluation

A *logic network* (circuit) consists of logic gates. Each logic gate has an input (-s) and a single output. Outputs of some gates are connected to inputs of the others. The inputs of some gates that are not connected to any other gate output are claimed to be primary inputs while the outputs of some gates are claimed as primary outputs. In this paper, we consider combinational circuits, i.e., feedback-free circuits which have no latches.

Each gate implements a *Boolean function*. Most common 2-input gates are AND/OR/XOR/NAND/NOR/XNOR that implement conjunction/disjunction/xor and their inversions. There are also 1-input gates such as NOT/BUFF that implement the inversion and the equality function, correspondingly. By definition, a logic circuit *implements* or *represents* a system of Boolean functions. A circuit accepts a Boolean vector as an input and produces a Boolean vector as an output according to the corresponding system of Boolean functions. Each logic circuit can be described by a Look-up-Table (LUT). A LUT contains a set of input/output pairs of a given circuit: if for the input  $\mathbf{i}$  the circuit produces an output  $\mathbf{o}$ , then the pair  $\mathbf{i}/\mathbf{o}$  is included into the LUT. In our case, an input Boolean vector  $\mathbf{i}$  represents the combination of the values of dominating factors while an output vector  $\mathbf{o}$  represents most probable score for a student with abilities encoded by  $\mathbf{i}$ .

A LUT can be used as the specification when deriving a logic circuit, and there exist a number of methods how to synthesize a logic circuit for a given LUT. In this paper, we use the ABC tool (Berkeley Logic Synthesis and Verification Group, ABC) to design a circuit for a given LUT.

We derived a LUT for the example given in Table 1. The corresponding LUT describes a system of partially specified Boolean functions, and the number of input pattern where the circuit behaviour is defined, equals 29. The reason is that each dash ‘-’ is converted into the whole interval of integers, and each integer that belongs to the corresponding interval is encoded as a Boolean vector. The fragment of the corresponding LUT for Table 1 is represented in Table 2 where the upper line shows the correspondence between the parameter values in Table 1 and their Boolean representations.

Table 2. A fragment of a LUT for the communicative teaching strategy

Fast tongue				Good ear				Homework				Score		
$x_1$	$x_2$	$x_3$	$x_4$	$x_5$	$x_6$	$x_7$	$x_8$	$x_9$	$x_{10}$	$x_{11}$	$x_{12}$	$y_1$	$y_2$	$y_3$

0	0	1	1	0	1	0	1	1	0	1	0	1	0	0
0	0	1	1	0	1	1	0	1	0	1	0	1	0	0
0	0	1	1	0	1	1	1	1	0	1	0	1	0	0
1	0	0	0	1	0	0	0	0	1	1	1	1	0	1
1	0	0	1	1	0	0	0	0	1	1	1	1	0	1
1	0	0	0	1	0	0	1	0	1	1	1	1	0	1
...														
0	1	1	1	0	1	0	1	0	1	0	1	1	0	0
0	1	1	0	0	1	1	0	0	1	0	1	1	0	0
0	1	1	1	0	1	1	0	0	1	0	1	1	0	0

We synthesized a circuit  $S$  for the LUT in Table 2 with the use of ABC tool. The total number of circuit nodes (logic gates) equals 110. We mention that the circuit has been synthesized based on 29 defined input patterns, partially listed in Table 2. The rest  $2^{12} - 29 = 4067$  Boolean vectors represent the Don't Care input patterns and thus, the circuit behaviour on those ones has been defined by ABC in an appropriate way.

In this paper, we skip the techniques and related criteria for scalable logic synthesis, however we note that in the area of educational management the effectiveness prediction ability of the circuit can be considered as one of essential criteria when deriving an optimal logic circuit.

### 4.3 Scalable approach for predicting the effectiveness of a composite teaching strategy

In this section, an approach for automatic evaluation/prediction of the effectiveness of a composite/combined teaching strategy is proposed. Without a loss of generality, we consider two strategy components  $S_1$  and  $S_2$  that are somehow combined when implementing the whole composite strategy  $S_1 @ S_2$ , where  $@$  is a composition operator. We mention that for e-learning/e-teaching educational strategy, components  $S_1$  and  $S_2$  can be represented as corresponding interactive (electronic) services. If the number  $k$  of such (service) components is greater than two, this approach can be applied iteratively, i.e. first, the effectiveness of the strategy/service  $S_1 @ S_2$  is estimated, then, this effectiveness for the composition  $(S_1 @ S_2) @ S_3$  is estimated, etc. At the final step, such effectiveness is predicted for the teaching strategy  $(S_1 @ \dots @ S_{k-1}) @ S_k$  that is obtained when  $k$  educational strategies/services are applied all together. The question about communicative and associative properties of the composition operator is out of the scope of this paper.

Given two teaching strategies, probably, implemented as the corresponding electronic services  $S_1$  and  $S_2$ , consider two logic circuits  $C_1$  and  $C_2$  that predict their effectiveness. These circuits can be derived similar to that for the user satisfaction with given services, for example, as proposed in (Kushik et al., 2014). We provide an algorithm for designing a logic circuit  $C_1 @ C_2$  that predicts the teaching effectiveness of the composition  $S_1 @ S_2$ .

At the first step, the set of inputs of this circuit is determined. In fact, this set contains all the inputs that correspond to  $S_1$  parameters (factors) and  $S_2$  parameters (factors). In other words, the set of inputs for  $C_1 @ C_2$  is the union of the sets of inputs for  $C_1$  and  $C_2$ . If the sets of  $S_1$  and  $S_2$  factors do not intersect, the set of inputs for  $C_1 @ C_2$  is the set of inputs for  $C_1$  plus inputs of  $C_2$ .

At the second step, the special circuit  $C_{formula}$  is designed. This circuit will be used to implement a corresponding linear combination that identifies the proportions (percentage) for the time spent for the first and the second teaching strategies, correspondingly. Each circuit  $C_1$  or  $C_2$  produces the Boolean vector of correspond-

ing length. These vectors correspond to integers  $\mathbf{I}_1$  and  $\mathbf{I}_2$  that represent the effectiveness for the components  $S_1$  and  $S_2$ . The circuit  $C_{\text{formula}}$  returns the Boolean vector  $\mathbf{o} = (o_1 o_2 o_3)$  that corresponds to the integer that is calculated with a formula  $(\alpha_1 \mathbf{I}(i_1 i_2 i_3) + \alpha_2 \mathbf{I}(i_4 i_5 i_6))$ . The coefficients  $\alpha_1$  and  $\alpha_2$  represent the percentage of the time spent following the first and the second strategy during the educational process. A scheme that illustrates the procedure for deriving the circuit  $C_1 @ C_2$  such that the overall effectiveness of a combined teaching strategy is computed as the linear combination  $(\alpha_1 \mathbf{I}(i_1 i_2 i_3) + \alpha_2 \mathbf{I}(i_4 i_5 i_6))$ , is shown in Fig. 5. The items of the set  $P$  correspond to Boolean vectors which represent the values of factors  $p_1, p_2, \dots, p_k$  of the first strategy/service  $S_1$  whereas the items of the set  $Q$  correspond to Boolean vectors which represent the values of factors  $q_1, q_2, \dots, q_l$  of the second strategy/service  $S_2$ . The set  $P \cap Q$  corresponds to the Boolean vectors which represent the same factors for  $S_1$  and  $S_2$  teaching strategies. Therefore, the set  $P' = P \setminus P \cap Q$  denotes the set of Boolean vectors for the factors of  $S_1$  that are not shared with  $S_2$  while the set  $Q' = Q \setminus P \cap Q$  denotes the set of Boolean vectors for the factors of  $S_2$  that are not shared with  $S_1$ .

The circuit  $C_{\text{formula}}$  that computes the linear combination  $(\alpha_1 \mathbf{I}(i_1 i_2 i_3) + \alpha_2 \mathbf{I}(i_4 i_5 i_6))$  in the circuit  $C_1 @ C_2$ , can be implemented in different ways. Nevertheless, this implementation is reduced to implementing two arithmetic multiplications and one addition.

Formal description of the proposed approach (algorithm for deriving a resulting composite circuit) can be found in the Appendix.

We notice that the complexity of such procedure is polynomial as it is mostly ‘hidden’ in the last step. The arithmetic evaluation of the number of primary inputs and outputs (Step 1) of the circuit  $C_1 @ C_2$  can be performed in ‘no time’ while the circuit  $C_{\text{formula}}$  can be derived just once for various teaching strategies/services  $S_1$  and  $S_2$ . Therefore, the complexity of this approach can be estimated as the number of operations required to connect each output of circuit  $C_1$  (or  $C_2$ ) to a corresponding input of the circuit  $C_{\text{formula}}$ , and these operations are very scalable. The latter provides the scalability of the overall approach.

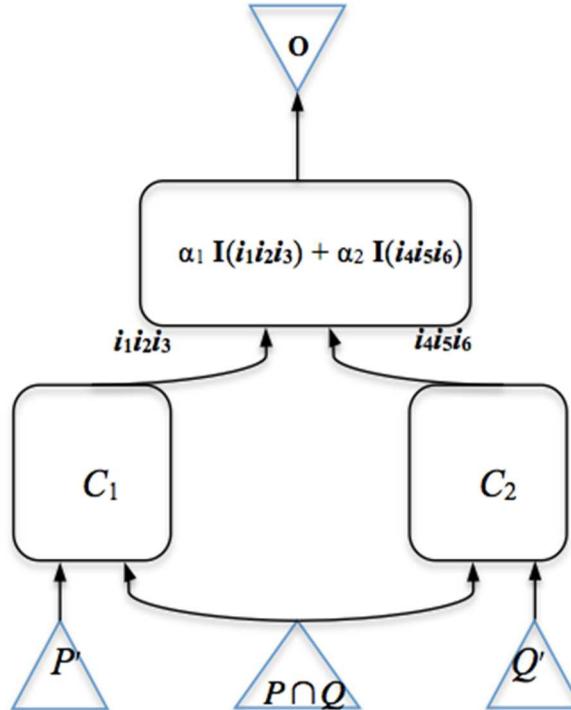


Figure 5: A scheme to derive the circuit  $C_1 @ C_2$ , where  $P' = P \setminus P \cap Q$  and  $Q' = Q \setminus P \cap Q$

Another more precise way to construct the circuit  $C_{\text{formula}}$  is to use statistical data again. In other words, a developer collects the statistical data how the score is evaluated when appropriate time is spent for using each

of teaching strategies, and a LUT is then derived that is used for constructing an appropriate circuit. However, in Section 5 we illustrate the use only of the first approach when deriving the circuit  $C_{formula}$ .

## 5 USING THE LOGIC CIRCUIT BASED TECHNIQUE FOR CHOOSING A TEACHING STRATEGY

In this section, we present a case study for verifying a proposed hypothesis for effective choosing of a composite/combined teaching strategy. Students of technical faculties of Tomsk State University that study English as a foreign language (EFL) took part in the experiment.

As usual, one of the key parts of teaching is the assessment of the level of proficiency/student's knowledge which can be formal or informal depending on the course requirements and intended outcome. Upon the completion of the course students are supposed to have a certain oral or written test and/or a questionnaire. The grading system may vary at different universities. For example, one of the most famous scale for assessing student's proficiency in foreign languages is Common European framework of Reference for Languages, where it is scored on 100% basis (international standards) following by specifying the level from A1 to C2 (e.g. B2 - upper-intermediate, C1 - advanced, etc.) (Cambridge ESOL, 2011). However, at universities the command of the discipline is often graded on a 5-point scale from A to F (A - excellent, F - failed, etc.).

The previous results obtained in the classroom of students of technical sciences when studying an EFL suggest that the individual differences (considered here as factors or parameters) influence the acquisition process of the EFL. Those are goals, fast tongue, good ear, the knowledge of grammar rules, previous educational experience in EFL, diligent completing of self-study assignments, watching movies and playing computer games in this language (English, for example), attendance of the lessons, the intensity of learning. If these parameters prove to be insufficient for the model description the list of student's abilities affecting the learning process can be extended or revised (as a proposed approach is generic with respect to the list of parameters of interest).

All teachers as well as corresponding e-services even having the same goals and using the same teaching materials put an emphasis on different aspects of education and formation of student's portfolios, depending on a method (communicative, grammar-translation, or combining both of these, etc.) that he/she uses which can be good for one student while being not effective for the other one.

As mentioned above, the parameters influencing the second language acquisition are scored between 0 to 10. Zero corresponds to the complete absence of the ability/the lowest competence level, whereas 10 implies the highest level. For instance, if a student does not do his/her home assignments he/she gets 0, and 10 implies that this student diligently completes all the tasks. The grades are scaled between 0 and 5. If a student is awarded grades from 3 to 5 he/she is supposed to pass an exam in this discipline.

The following data have been collected during a two-year period. The experimental groups were groups of students of the faculties of technical sciences. Both male (60%) and female (40%) students took part in the experiment. All the research participants were nearly of the same age from 17 to 19 years old (from the first to the third year of studies). The division into groups at this faculty is often made based on their English proficiency (their background level after a high school). The scope of the research is rather wide since the level of English varied between elementary and upper-intermediate. There were four groups of the elementary level (30% of students who took part in the experiment). The level in other 8 groups ranged from pre-intermediate to upper-intermediate level (70%). Only 5% of students had a certificate (FCE, IELTS) confirming their level of proficiency. In most cases English was the only foreign language for the participants. However, the questionnaire results showed that 7% of students also studied French as a second foreign language, which somewhat influences the language acquisition process and the motivation to study General English.

These are all mixed ability classes. Having come from different schools, EFL learners demonstrated different skills and abilities. Depending on what approach the English school teacher had chosen (teacher-centered or student-centered approach), the number of communicative tasks performed at school and the kind of manuals s/he had used, a university student (a participant of the experiment) prefers this or that kind of activity in the classroom at the university, which must be taken into account when teaching. The majority (65%) of participants had studied at school by manuals published by Oxford or Cambridge University Press aimed at building skills necessary for real communication. These university students did not have any difficulty with expressing their thoughts (speak English fluently), showed good results in listening comprehension and scanning reading for understanding the general idea, the main difficulty arose when they were asked to perform Grammar exer-

cises isolated from speaking activities, i.e. drills, not directly related to communication. Reading for details and writing of formal letters and reports was also difficult and not interesting for them.

The English courses are obligatory for three first years of studies, two or four hours a week depending on the schedule of the faculty, and the motivation is most often low: to pass an exam. The reluctance of the students can be removed in this case by choosing motivating tasks for students of different language proficiency based on the set of parameters mentioned above. The parameters that are chosen by the expert are considered as non-dependent on the gender and the level of English proficiency of the participants.

In the following case study the first teaching strategy uses the student-centered communicative method paying more attention to the development of speaking abilities of the students and providing the instruction mostly in L2 (English). Different types of facilitators and motivating tasks (movies, discussing things, games) are used focusing on meaning rather than form.

Teaching strategy #2 offers a teacher-centered grammar-translation method with only traces of the communicative approach paying more attention to the fulfillment of the home assignments and grammar exercises, i.e. the accuracy in student's speech as a learning outcome is more important than fluency. Most of the instruction is in L1 (Russian). Tasks and exercises are intended mainly for the formation and polishing grammar skills and learning new vocabulary.

Suppose the combined teaching strategy coincides both with that of the first (70%) and the second (30%) one. For the prediction of the effectiveness of the overall teaching strategy of a certain group of students, whose factors are known, the logic networks are used. The data obtained using the proposed logic network approach allows to predict the effectiveness of the teaching strategy that 70% relies on strategy #1 (student-centered communicative method) and 30% on strategy #2 (teacher-centered grammar-translation method).

The teaching strategy is chosen based on the individual traits of the learners and also on their goals. Thus, students were asked which strategy they would like to follow: strategy 1 (communicative), strategy 2 (grammar rule-based approach) or a combined strategy. In most cases the students of technical faculties taking a course in General English prefer to improve their speaking skills above all, and thus, the large part of students voted for the use of strategy 1 (38%). Some students, of different level of proficiency, would like to follow the combined strategy (32%). The least number of students prefer strategy 2 (22%). A number of respondents (8%) could not specify their interest at all and chose 'I do not know' answer. Fig. 6 shows the students' preferences when selecting a teaching strategy where 'S1' denotes the communicative strategy, 'S2' is used to denote the grammar rule-based approach, while 'S1 + S2' represents the combination of both techniques.

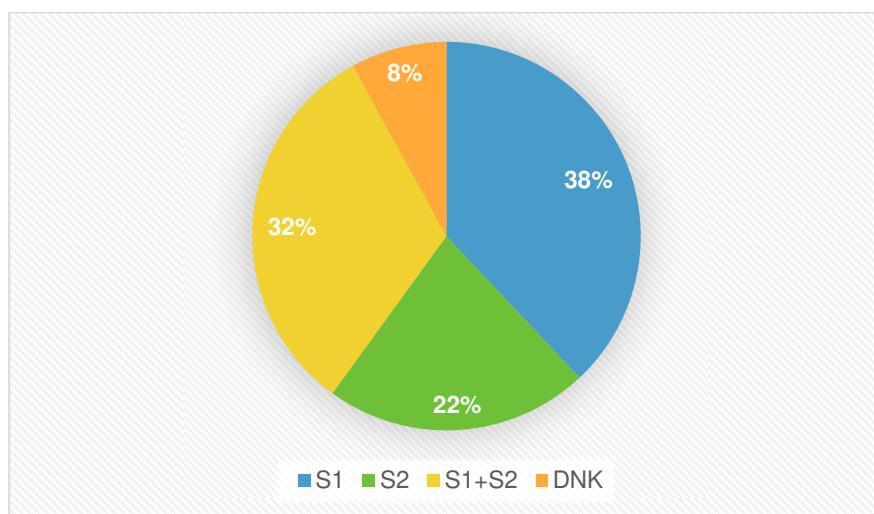


Figure 6: Student choice of the strategy, 180 respondents

The influence of the choice of a teaching strategy on the effectiveness of learning English was estimated according to the score (grades) the student gets upon the completion of the course. The peculiarity of the Russian system of teaching languages to the students of technical faculties is that much attention at the exam is paid to the speaking abilities of the student. Even when the results of the Grammar test are just satisfactory but a student speaks fluently easily using constructions of the elementary level his proficiency is rarely estimated

lower than 4. Thus, as is shown in Fig. 7 the effectiveness of using both strategies is rather close (68% and 64% of grades 4 and 5, respectively). As usual, 'S1' denotes the communicative strategy while 'S2' is used to denote the grammar rule-based approach.

However, the preliminary results suggest that the use of the combined strategy will be more promising, i.e. the predicted percentage of the students having grades 4 and 5 is higher (70%). This can be specified by the fact that students eagerly perform motivating tasks in the classroom spending most of the time properly for communication, not drills. The use of grammar rules is acquired and tested using electronic devices and educational platforms as a self study activity, which requires much less time comparing to doing and analyzing grammar exercises in the classroom. As it appears, the motivation for learning English grammar performing interactive exercises on different type of gadgets is much higher.

Combined strategies seem to be most efficient for e-learning. However, the question arises which component strategies should be selected taking into account the intensity of each component strategy.

Suppose that we have a student with the following factor values: *fast tongue* – 3, *good ear* – 6, *grammar* – 5, *background* – 6, *homework* – 10, *watching movies in English for entertainment* – 2. Suppose also that the student studies with the intensity 70% when using the first strategy (the intensity equals 7 of 10). In this case, according to the first strategy evaluation (Table 1), the student will get the score four (4) when passing final tests, i.e. when the values of the student parameters are represented as a vector (3, 6, 5, 6, 10, 2) the quality of the strategy is 4. However, if the second teaching strategy is considered then the following factors remain crucial: *grammar*, *background* and *homework*. As an example, consider that the second strategy under the given factor values returns the score equal 3, i.e. the student will get the score three (3) when passing final tests. Let this strategy is involved with the intensity 30% (3 of 10). In this case, when utilizing the composite teaching strategy with intensities 70% and 30% correspondingly, the student is likely to get the score  $q = 0,7 * 4 + 0,3 * 3 = 3,7$  that is approximated with the closest integer four (4).

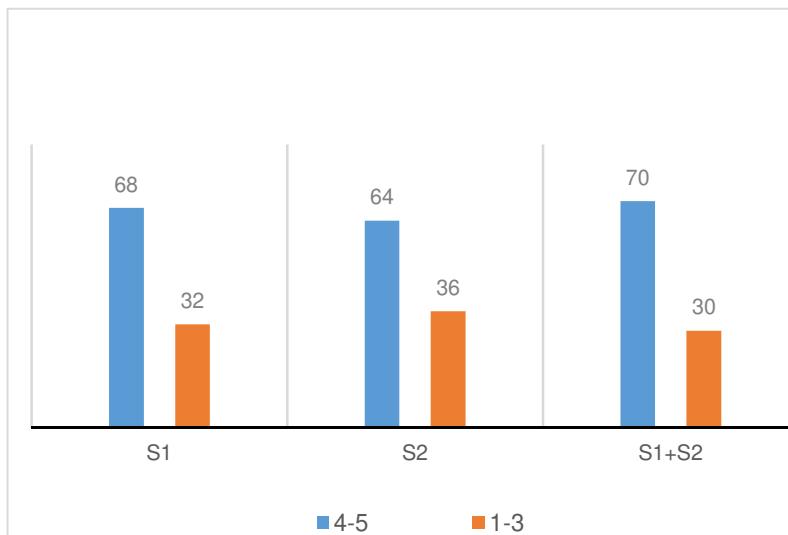


Figure 7: The dependence of the effectiveness of learning on the use of teaching strategy, 180 respondents

When both strategies are combined the resulting logic circuit is able to predict the quality of a composite teaching strategy, when the first one is used with 70% intensity and the second – with 30%, correspondingly. As mentioned above, the complexity of the composite circuit is ‘hidden’ in the complexity of the resulting  $C_{formula}$  circuit.

We run the ABC tool to synthesize the circuit  $C_{formula}$  in the running case study. The circuit we obtained contains 121 gates and the synthesis of this circuit is performed almost ‘in no time’ (less than a second). Therefore, our preliminary experimental evaluation proves the scalability of a proposed approach applied to an educational management in academic institutions.

Preliminary experimental results demonstrated on the example with a combination of two teaching strategies given above show that the effectiveness of the educational process can be evaluated using logic circuits representing learner’s abilities (dominating parameters) as vectors and measuring parameter values and the effectiveness (score) as integers. The logic circuit based approach seems to be very promising as it provides the

opportunity for a user to automatically select an appropriate teaching strategy without answering long questionnaires or doing research based on students' or teachers' portfolios. The obtained results are very close to those obtained when using logic circuits for the QoE prediction of the multimedia services (Kushik et al., 2014). When dominating factors are thoroughly analyzed and selected, a machine is stabilized at some point where the 'real' score value and the score value produced by the logic circuit machine are very close for 90 % of students under experiment. As usual, those 10% fluctuations cannot be eliminated as they are related to the well known human factor.

## 6 DISCUSSION AND CONCLUSIONS

As it was shown in previous sections, the problem of evaluating the effectiveness of the educational process is an interdisciplinary research which needs not only the understanding of educational methodology but also the application of formal models which allow us to compare the values, and automatically measure the level of proficiency of a student at the outcome and adapt the measurement to new statistical data on the score evaluation. Student's abilities can be efficiently represented as vectors where all the components have integer values and such representation seems to be adequate enough for the score evaluation when dominating parameters are well selected based on the teacher's experience. The use of logic circuit based approach for prediction of the student's proficiency upon the completion of the course has proved to be fast as well as the resynthesis process of a corresponding logic circuit if the circuit needs to be adapted to new statistical data for the score evaluation (Kushik et al., 2014).

The main contribution of the paper is an approach for scalable prediction of the effectiveness of a teaching strategy also in the case when two or more teaching strategies are combined. To the best of our knowledge, those results are novel in the area of Emerging services in the field of Educational Management. As nowadays various electronic/interactive services are developed for educational purposes, we, in fact, propose a technique of how to estimate whether a given educational service or combination of two (or more) educational services is going to be productive for a learner with the set of individual features, i.e. abilities, goals, etc. The approach relies on logic circuits that are designed to predict the effectiveness of each teaching strategy (service component). The corresponding algorithm returns the logic circuit which predicts the level of proficiency of a student or a group of those, who follow two (or more) teaching strategies simultaneously and the technique takes into account the intensity of each teaching strategy being used. However, we notice that the small scheme based on a linear combination proposed in this paper must be more complicated as it describes the phenomena going on in a person's mind. Therefore, more factors and parameters should be taken into account when analyzing the composition of two educational processes. Nevertheless, preliminary experimental results show the scalability of the proposed approach.

We realize that more experiments with different (online) educational services/teaching strategies considering different parameters/factors are needed and we plan to perform them as further research. On the other hand, in this paper a logic circuit is used as a prediction engine and thus, it would be also interesting to (experimentally) analyze how applicable it is for adaptive learning. Finally, industrial applications of the obtained results remain challenging and are also planned for the future work.

## ACKNOWLEDGEMENTS

This work is partially supported by RFBR grant № 14-08-31640 мол\_a (Russia).

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## APPENDIX

### Algorithm 1 for deriving a circuit $C_1 @ C_2$

**Inputs:** Teaching strategies  $S_1$  and  $S_2$  or electronic services, implementing them.

$S_1$  has the set  $P = \{p_1, p_2, \dots, p_k\}$  of dominating factors; each  $p_i$  value is bounded an integer  $M_{p_i}$ .

$S_2$  has the set  $Q = \{q_1, q_2, \dots, q_l\}$  of dominating factors; each  $q_i$  value is bounded an integer  $M_{q_i}$ .

The circuit  $C_1$  has  $\sum_{i=1}^k \lceil \log_2 M_{p_i} \rceil$  inputs while the circuit  $C_2$  has  $\sum_{i=1}^l \lceil \log_2 M_{q_i} \rceil$  inputs; both circuits have three outputs, assuming that each score/effectiveness scale is from 0 to 5.

**Output:** a logic circuit  $C_1 @ C_2$ .

**1.** Determine the number of primary inputs of  $C_1 @ C_2$ :

The number of primary inputs equals  $(\sum_{i=1}^k \lceil \log_2 M_{p_i} \rceil + \sum_{i=1}^l \lceil \log_2 M_{q_i} \rceil) - \sum_{i=1}^t \lceil \log_2 M_{g_i} \rceil$  for all  $g_i$  that belong to the  $P \cap Q$ , where  $|P \cap Q| = t$ . The number of primary outputs of the circuit of  $C_1 @ C_2$  equals three.

**2.** Design the circuit  $C_{formula}$ . This circuit has six inputs  $i_1, i_2, \dots, i_6$ , and returns the value  $(\alpha_1 I(i_1 i_2 i_3) + \alpha_2 I(i_4 i_5 i_6))$ .

**3.** Synthesize the circuit  $C = C_1 @ C_2$  identifying inputs which correspond to the same parameters of services  $S_1$  and  $S_2$ ; the outputs of  $C_1$  are connected to inputs  $i_1, i_2, i_3$  of  $C_{formula}$  while the outputs of  $C_2$  being connected to the inputs  $i_4, i_5, i_6$  of  $C_{formula}$ .

**Return  $C$ .**