# CALL-Technolgy Based Approach to Control Acquisition of Foreign Language Skills *

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**Abstract**

Foreign language skills acquisition with the support of CALL technology constitutes the subject of the present research. In the absence of the model to estimate the state of the student knowledge level one could not apply classic control algorithms to steer the language learning process. A solution combining the hypothesis about the holographic memory structure and auto-associative sampling is proposed to overcome this gap. This requires one to state desired learning outcomes between two learning goals. Then the single element learning model may be applied to control grammar skills acquisition process. The proposed solution has been implemented in the form of computer-assisted language learning software providing all the necessary functions to support and test the skill acquisition process. Moreover, being executed in the frameworks of the mass experiment allows easy integration with the language learning courses of university curricula and provides the data describing reactions of the students to the shown stimuli-exercises. The last one is essential for any academic research in this area.

**Keywords:** *computer-assisted language learning (CALL), CALL-technology, language skill, learner model, algorithm controlling the learning process.*

# 1 Introduction

For many years, different approaches have been proposed to optimise the learning of a foreign language. While methods, trends and technologies of language learning have changed a lot, one component remains rock solid. Namely, language learning requires regular training in the form of performing numerous exercises of "stimulus – reaction" type. Regular independent training work is solely the responsibility of the student. While the teacher could not help the students to organise their regular independent training, it is possible to provide them with the software application that can facilitate, organise and, in a certain sense, optimise this part of his independent work. The application to support independent training of the student should implement the following functions:

- provide support for completing the curriculum assignments;
- take on the functions of managing the learning process;
- guarantee the required result;
- ensure this result at the minimum cost of valuable time.

These functions define the requirements for the computer-assisted language learning (CALL) technology, developed in the framework of the present research. The theoretical part of the research concentrates its attention on the foreign language skill acquisition process during the written stimuli-reaction type exercises, the practical part – on the development and implementation effective CALL technology for acquiring these skills in the frames of student independent studies. The research is based on the [Bush Mosteller, 2006] where the model of human memory is proposed. Also, some of the preliminary results of [Nymm et al., 2015] and [Nymm et al., 2017] are utilised in the development of the control algorithm.

# 2 Background and problem statement

From the viewpoint of the teacher, the purpose of learning is to reach desired (expected) state of the leaner at the time of completion, which may be expressed in terms of the results of the test work carried out after studying the topic or section, as

$$\frac{n_0}{N} < q \tag{1}$$

where $N$ is the total number of exercises presented in the test work, $n_0$ is the number of exercises performed with errors, $q$ is the allowable proportion of incorrect answers of the student. The learning goal presented in such form (here and after referred to as external) is natural from the teacher's viewpoint. The main drawback of this form is that the degree of achievement may be verified only after the completion of the learning process. This makes it impossible to apply external learning goal for the implementation of the algorithm controlling the learning process.

Regardless of the particular learning algorithm, the essence implemented computer-assisted learning process employing the "stimulus-reaction" type exercises may be described as follows. The process of computer-assisted learning is a sequence of elementary learning acts. Whereas, each act consists of three steps:

- Stimulus –exercise is given (shown) to the student.
- Answer (reaction) of the student in response to the given stimulus-exercise.
- Response of the system to the student's reaction, interpreted as the knowledge support (reinforcement). Usually indicates if the answer is correct or not and if the answer is not correct shows the correct answer and corresponding rule explaining the correct answer.

The control of the learning process is implemented using choosing the next exercise to be given to the student. The choice may be performed based on the following components:

- Information about previous reactions of students observed during the previous part of the learning process.
- Information about the current state of the student with respect to the learning subject.

If the algorithm is based on the function estimating the state of the student it is referred to as the algorithm with the learner model and the algorithm without the learner's model in the opposite case. The learning process is divided into the learning sessions of approximately the same time duration. The set of exercises for each session is determined by the algorithm controlling the learning process.

The present research is based on the results of [Rastrigin et al., 1988] where the problem of context-less lexical learning was studied. The learning goal was to achieve the state where the student could replicate in their native language lexical unit shown in English. Learning was based on sufficiently large collection of pairs of lexical units, where the first element is a lexical unit in English and the second one is its analogue in the student's native language. As the main result of [Rastrigin et al., 1988] the so-called *adaptive learning system with the model of the learner* was proposed. In [Rastrigin et al., 1988] the student has played the role of the controlled object, whereas the state of the student, with respect to the content of the course (set of lexical units), is described by the vector function $p(t)$.

$$p(t) = \big(p_1(t), p_2(t), \ldots, p_n(t)\big) \tag{2}$$

where $n$ is the number of lexical units to be learned by the student, $p_i(t)$ is the probability of wrong response reaction for the stimulus corresponding to the $i$-th ($1 \leq i \leq n$) lexical unit, in other words the probability not to know lexical unit $i$ at time instance $t$. Note that here every $i$-th coordinate expresses the relation between the learner and the $i$-th lexical unit. The function (2) is treated as the learner's model. To evaluate the learning outcomes at any time $t$, [Rastrigin et al., 1988] used the functional $Q(p(t))$

$$Q(p) = \sum_{i=1}^{n} \gamma_i p_i \tag{3}$$

where $\gamma$ is the weight coefficient, describing the frequency of the lexical unit in the corpus, based on which a list of lexical units composing the subject of training was formed. The learning goal expressed in this form will be referred as *internal*. Contrary to the external learning goal, expressing the viewpoint of the teacher, internal learning goal is suitable to be used with the algorithms controlling the learning process. The second goal considered in [Rastrigin et al., 1988] was to minimise the time required to achieve the following condition.

$$Q(p) < q. \tag{4}$$

Let us now discuss how this method may be generalised for the case of independent grammar learning. The approach proposed in [Rastrigin et al., 1988] assumes the possibility to strictly measure the time spent by each student on training. The experiment described in [Rastrigin et al., 1988] the training took place in classroom and training time was strictly fixed. For independent studies, the term "time spent by a student on the implementation of training work" loses its meaning. Instead of measuring the time spent by a student on the implementation of training work we propose to measure the total number of stimuli been shown to the student during the learning process up to the current time instance. In this context, minimising the total number of stimuli presentations as a statement of one of the possible learning goals seems to be more objective and convenient to use than minimising the learning time.

With respect to the operations performed by the student, "stimulus-reaction" type exercises may be classified into two groups. In terms of associations [Kohonen, 1977] distinguishes two major types of such operations: hetero-associative sampling and auto-associative sampling. The hetero-associative sampling operation is characterised by the fact that, the output image does not correspond to any of the key elements (or signs) of its input inverse image (i.e., stimulus) and is formed as a response to a specific key image. Non-contextual teaching of foreign language vocabulary is implemented on the basis of hetero-associative sampling operations. Learning processes of this type are quite homogeneous and well-studied. In [Rastrigin et al., 1988] different models developed in the frameworks of experimental psychology were considered whereas, approach of [Bush Mosteller, 2006] was used to compare the models and choose the best one. Most of written exercises for studying the grammar of a foreign language are implemented by performing exercises that relate to operations of auto-associative sampling. In exercises of this type, the search for the correct answer (or the correct reaction) is carried out according to some part or set of signs of its input prototype, represented by the stimulus. The processes of language learning implemented in the frameworks of operations of auto-associative sampling, on the contrary, are diverse and quite heterogeneous. Modelling of these processes substantially depends on the presence or absence of similar language phenomena in the native language of the student, differences in the means of their expression. In the best knowledge of the authors, there is no results available, modelling these learning processes.

Any practical foreign language course is divided into sections and further into subsections, topics and units. The division of the theoretical material of the unit, preceding the practical tasks, into individual linguistic phenomena is some kind of clustering. In a more strict form, the clustering mechanism based on the definition of auto-associative sampling should consist of:

- extract (by analysing the exercises used to teach language phenomena) the elements essential to choose the correct reaction;
- associate with each exercise a set $S$ of those key stimulus elements that determines the "correct" reaction (or its structure) $R$ for a given exercise;

- treat the pair $(S, R)$ as a formal model of the exercise;
- consider two exercises having the same model as equivalent or belonging to the same equivalence class.

Dividing the space of exercises (both existing and potentially possible) into equivalence classes, denoted $SR_i$, allows to represent the state of the student in relation to the subject of training at any time $t$ in the form of a vector $P$

$$P(t) = \big(P_{SR_1}(t), \dots, P_{SR_m}(t)\big) \tag{5}$$

where $m$ is the number of equivalence classes, and $P_{SR_i}(t)$, $1 \le i \le m$ is the probability that student makes a mistake when performing exercises of the class $SR_i$. Here, each $i$-th coordinate expresses the relationship between the learner and particular skill, represented by exercises of the $i$-th equivalence class. From this moment let us associate an equivalence class to the corresponding language phenomenon. Compared to (4), (5) allows to describe the state of the student at each time and with respect to each of the equivalence class. Moreover (4) may be formulated in the same terms as (5) which elements are not necessarily probabilistic. The nature of these elements is defined by the learning goals. Whereas, it is required that the values of these elements are either observable quantities or computed on the basis of observable quantities.

# 3 General scheme for solving the problem

Methodological foundation of the present research is based on the idea which [Rastrigin et al., 1988] referees as "computational experiment". Initially the idea of computational experiment was proposed in [Samarsky, 1979]. It is based on the fact, that priory knowledge about the modelled object is sufficient to construct initial approximation. Then this model may be improved in iterative fashion by comparing simulation and real testing data. During the recent time, the concept of the computational experiment has changed but its essence remained the same. Here, a computational experiment refers to an evolutionary strategy for constructing a model of the object, whereas each iteration consists of three successive stages: analysis, synthesis, and evaluation.

In the frameworks of this study, the simulated object is the CALL application, considered as a *reproducing model* of the learning control algorithm, together with its integral components (learning strategy, heuristics used, student model, etc.).

The ability to carry out computational experiment is based on the main advantage of CALL over the traditional language learning. Namely, the possibility to collect the data describing student reactions during the learning process constitute this advantage. Collected data may be used immediately by CALL application to control the language learning process and later for the purposes of the academic research aimed to acquire new knowledge about the learning and to improve existing algorithms controlling the learning processes.

In order to be used in the frameworks of the computation experiment the structure of software application was designed to encapsulate the parts of the code responsible for

- execution of different exercises
- algorithm controlling the learning process

Such structural design guarantees that new types of the language exercises may be executed easily. At the present moment it implements nearly all the exercises represented in the university textbooks.

In comparison to the entire code of the application, the share of the code corresponding to the parts implementing control of the learning process is very small. The structure of the application code, encapsulating all the different parts of the control algorithm into one class allows "painless" (e.g. without introducing any changes in other parts of the code) replacement of one learning algorithm by another. Moreover, it allows to maintain and use several copies of the application with different control algorithms.

The absence of the model to estimate the state of the student (5) compels one to use priory knowledge about the learner and learning process. But what is known about the process of language skill acquisition? The only available information (relevant to the present research) is that performing numerous exercises leads to skill acquisition. Roughly speaking, the process of any skill acquisition (learning to dance, learning to drive or speak a foreign language) requires one to follow the rules: slowly, tediously and consciously. Then the moment comes when the control is passed to the body [Dreyfus, 1992]. The moment when conscious execution of exercises is replaced by unconscious indicates that skill is acquired. Then the goal of learning of a language phenomenon is to acquire the skill of using,the means to achieve the goal - completion of the numerous exercises.

Based on the hypothesis about holographic memory structure [Rosenzweig, 1996], [Thompson, 1975] the process of learning may be described as follows. While completing numerous exercises (consciously or unconsciously) the students memorise the correct reactions in the context of exercises stimulus. This generates in their memory the kernel of contexts (or examples), generating the collective image of learning language phenomena. Later (when the skill is acquired), this image is used (by establishing appropriate associative relationships) to complete other exercises, to generate correct speech or text sentences.

While on the first view this idea to learn foreign language by means of memorising correct reactions to the given exercises may seem very simple it leads to good results. Figure 1 depicts proposed approach.

Acquisition of the necessary skills for each language phenomenon, represented in the corpora of learning exercises, is considered here as the external goal. The internal goal is to memorise correct reactions in the contexts of stimuli exercises of this corpora.

The indicators describing the degree of achieving external- and internal- goals are provided by two tests referred to here as the white- and black- box tests correspondingly. The names of the tests are borrowed from the area of software testing where they have a similar meaning.

White box test is meant to measure achievements with respect to the internal goal. The content of white box test is generated by sampling the corpora of learning exercises.

Black box testing measures the degree of achieving the external goal. While the internal goal refers to the limited set of exercises that represent a certain set of linguistic phenomena, the external goal refers to the set of all potential exercises that represent the same set of linguistic phenomena. Therefore black-box test work should not contain the exercises used during the learning process. In other words, one set of exercises is used to develop the skill and the other set is used to verify if the skill is acquired or not. Whereas, the content of the black box testing work must be based on the same system of clusters as the corpora of the exercises used during the learning process.

While the major goal of these two tests is to evaluate the results of learning their results play the role of feed-back channels. During the learning process, the CALL system collects the

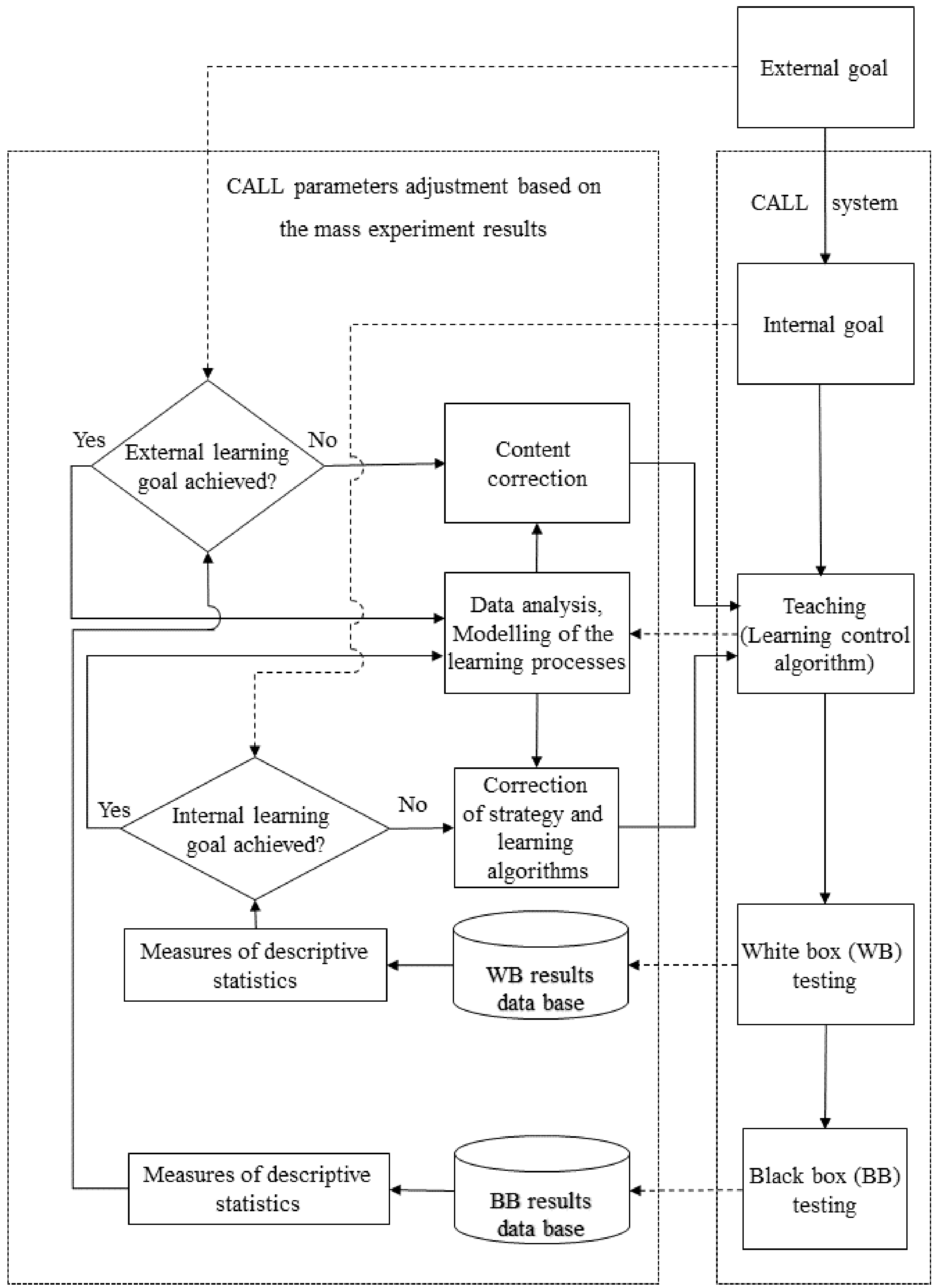


Figure 1: The scheme of the computational experiment on the basis of CALL-technology

data describing reactions of the student. This data is seen as the third channel of feedback.

Each use of the CALL - application is considered as an element of a mass experiment. In this context, the implementation of each feedback channel (represented by the dashed bold lines in Figure 1) should not be considered with respect to each use of program, but with respect to the results of a mass experiment.

Results of the mass experiment are analysed with the assumption, that for each learning goal a threshold of the maximally allowed deviation is set.

Deviation greater than the threshold for the internal learning goal indicates the necessity to correct the algorithm controlling the learning process.

Deviation greater than the threshold for the external learning goal indicates the necessity to increase the number of learning exercises corresponding to particular language phenomenon.

All the functions implementing the computational experiment, including the algorithm to control the learning process (the algorithm controlling memorising of the correct reaction in the context of the exercises presented in the corpora) together with the procedures of the white- and black- testing are implemented as the integral parts of the CALL application.

With respect to its main purpose, developed CALL-application may be easily integrated into the existing system of foreign language learning at a university. For this, it is enough to divide the corpora into separate units (corresponding, for example, to weekly home assignments) and apply the algorithm to each unit as to the whole corpus. This mode of using the application allows to coordinate independent studies of the student with the learning taking place in the classroom.

The learning process of each unit or topic is finalised by white- and black- box testing procedures. The student is allowed (by the CALL application) to undergo white box testing after the completion of the learning process. White box testing is performed by the CALL application without the participation of the teacher. Completion of the white box testing it the prerequisite to be admitted for the black-box testing, which is conducted in the computer-class with participation (under the supervision) of the teacher.

The CALL-application also includes service functions supporting the independent work of the student. For each session, the student has to login to the system and perform the exercises given by the system.

Different aspects related to the development of the CALL technologies on the basis of integration learning and creative activities of the students are discussed in [Nymm, 2015], [Samarsky, 1979], [Paneva-Marinova et al., 2019].

# 4 Control algorithms

One of the possible algorithms to control the learning process is based on the so called *single-element learning model* [Atkinson et al., 1969]. This model assumes that associative connection between the stimuli and reaction either exists or not. In other words, it could not be formed partially. Also it is assumed by [Atkinson et al., 1969] that if associative connection is formed it would exist for a sufficiently long period of time. This means that once particular stimulus-exercise is learned, correct answer would be given by student each time this exercise is given. Let $\Omega$ denote the set of $n$ exercises to be learned. In terms of the single element learning model one may rewrite (5) with respect to $\Omega$ as follows:

$$S(t) = \big(s_1(t), \dots s_n(t)\big), \tag{6}$$

Where $s_i(t)$ ,$i = 1, \ldots, n$ takes the value 1 if the associative connection is formed and 0 in the opposite case. Then the internal goal is given by:

$$s_i(t) = 1, \quad i = 1, \ldots, n. \tag{7}$$

In order to apply single –element learning model it is necessary to detect (or rather guess) the moment of time when associative connection is formed. In the frameworks of the present studies the following criteria is used. Let event $A_k$ = [during k following (but not necessarily consequent) sessions the student gives the correct answer to the exercise stimulus from the first (in the current session) try]. Occurrence of the event $A_k$ indicates that corresponding associative connection is formed.

Without loss of generality let us consider the case when $k = 1$. In this case $A_1$ =[in one of the sessions student gives the correct answer to the exercise stimulus from a first (in this session) try].

The constant $k$ used in the description of the algorithm denotes the number of exercises that make up the subject of training in one session. Value of $k$ is chosen such that the session time does not exceed 30 - 40 minutes.

The session begins with testing and compiling a list of exercises $L$ that make up the subject of training for the current session. First, $k$ exercises such that corresponding values of (6) equal to zero are selected from $\Omega$. In other words, selected exercises are first $k$ exercises not excluded from the learning process during the previous sessions. Selected exercises make up the list $L$ for testing. The testing procedure for the list $L$ is implemented. For the exercises answered correctly the values of corresponding coordinates of (6) are updated to 1. These exercises are replaced in the list $L$ by new exercises from $\Omega$ such that corresponding values of (6) are equal to zero.

Learning part of the algorithm contains two loops, one nested inside the other. The outer loop organises the passes through the list $L$. The passes are repeated as long as the list $L$ is not empty.

The inner loop organises each such pass. Each iteration of the inner loop operates with only one exercise of list $L$, implementing an elementary learning act as it was described above (presenting a stimulus to the student-students response - a reaction of the system). If the student gives the correct answer on the first (at the current iteration) try (attempt), exercise is excluded from the list $L$ (but corresponding values of (6) remain unchanged) else the implementation of the exercise is repeated.

Whereas, teaching function of the system is implemented as the system reaction to the student response – message which confirms the the correct answer or (if the answer is wrong) contains the correct answer and the corresponding rule explaining it.

Learning process is completed when all the elements of model (6) are equal to 1.

Collected stimuli-reaction data combined with the testing results provides a rich basis to compute parameters necessary for:

- assessment and comparison of various training process control algorithms and their correction;
- adjustments to the volume and content of set of exercises (differentiated by groups of exercises representing a particular language phenomenon);
- an analytical study of the dynamics of skills acquisition processes.

Comparison of different algorithms used to control the learning process is based on two indicators:

- The total number of sessions required to complete the training for each exercise.
- The total number of presentations of stimulus exercises during these sessions.

# 5 Conclusions

The present paper proposes an approach to managing grammar acquisition skills with the computer-assisted language learning within the university curricula. The core and the major novel point of this approach is the algorithm allowing to control the process in the absence of the learner model. Major attention is paid to the formal problem statement which splits the learning goal into two parts, external and internal. Based on the proposed approach CALL technology software is developed. On the one hand, it implements all the necessary functionality to control the acquisition of the language skills and conduct testing required by the university curricula. On the other hand, being used in the frameworks of the mass experiment it provides an opportunity to study the processes of language skill acquisition. The proposed technology can be easily integrated into any system of foreign language learning.

While the present version of the application supports only English language learning it is planned to develop the supports for other languages including Russian.

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