# Modeling language learning using specialized Elo ratings

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## Abstract

Automatic assessment of the proficiency levels of the learner is a critical part of Intelligent Tutoring Systems. We present methods for assessment in the context of language learning. We use a specialized Elo formula used in conjunction with educational data mining. We simultaneously obtain ratings for the proficiency of the learners and for the difficulty of the linguistic concepts that the learners are trying to master. From the same data we also learn a graph structure representing a domain model capturing the relations among the concepts. This application of Elo provides ratings for learners and concepts which correlate well with subjective proficiency levels of the learners and difficulty levels of the concepts.

## 1 Introduction

A key goal of Intelligent Tutoring Systems (ITS) is to provide students with individualized learning, and thus support their learning process. Several systems for various subjects have proven to be effective, (Ritter et al., 2007; Arroyo et al., 2014; Klinkenberg et al., 2011). Our work is part of an international collaborative effort to developing large-scale Intelligent Computer-Aided Language Learning (ICALL) systems for use in real-world environments. Our system, Revita (Katinskaia et al., 2018), is in use in official university-level curricula at several major universities, to enhance language learning and teaching.[1]

To develop automated methods for personalized tutoring, robust models for assessing the current proficiency of learners are required. Such models enable quantitative evaluation and comparison of teaching methods with respect to the rate of development of the learners, which enables us to evaluate the performance of the ICALL system.

Several approaches for modeling knowledge have been proposed, such as Bayesian Knowledge Tracing (Corbett and Anderson, 1994), Learning Factor Analysis (Cen et al., 2006), and its more advanced variant—Performance Factor Analysis, (Pavlik Jr et al., 2009). These models, however, are complex and time-consuming to implement for ITS, and require large amounts of data for each learner, (Pelánek, 2016).

In this work, we present a simple and effective method for assessing the proficiency of language learners, as well as the difficulty of linguistic concepts, by utilizing the Elo formula, (Elo, 1978)—in an unsupervised fashion. The result is a set of rated concepts and a method for assessing the current and historical proficiency of each learner. We also present a concept graph—learned from the educational data—representing the dependencies between concepts.

We use educational data, collected from real language learners, in two assessment contexts. One context is where learners take language proficiency tests. During the test the system samples questions from a database, each question linked to a specific linguistic concept. Examples of concepts are collocations, certain type of verb inflection, certain word-order rules, etc. In the second context, learners do exercises based on "authentic" texts—chosen based on the learners' interests—that have a difficulty estimate, assigned by a statistical model. In each context, the result is a numeric Elo-based rating describing learners' proficiency in the target language.

The paper is organized as follows. Section 2 outlines out data generation process. In Section 3, we describe the Elo rating system, and discuss our modifications to the formulas in the two assessment contexts. In Section 4, we discuss our approach for building a domain model, represented by a concept graph. Section 5 describes simula-

[1] https://revita.cs.helsinki.fi/



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tions and experiments on obtaining Elo ratings for concepts and for assessing learner competency. In Section 6, we discuss preliminary results on correlation between Elo ratings in different assessment contexts, and the correlation between the Elo ratings and the performance levels assigned by teachers. We also demonstrate a graph of concepts, each with Elo difficulty estimates. In Section 7, we discuss current problems. Section 8 concludes with current directions of research.

## 2 Data

This work builds on educational data we have collected through a collaborative effort with language teachers at several universities. In this paper, we focus on students learning Russian as a second language (L2) at different levels on the CEFR scale, ranging from A1 to C2, (Little, 2007). The students yield data in two assessment contexts:

**Language tests:** In the testing context, the students take online language tests on a platform provided by the system. Each test is time-limited, and comprised of approximately 300 test items, sampled from a database of 3390 multiple-choice questions. The questions were prepared by language teachers and linguistic experts over a period of 20 years, (Kopotev, 2012, 2010). Each question is linked to one of 140 linguistic "concepts," also predefined by the experts. At the time of this writing, the response data consists of 600 000 test answers, by approximately 1000 learners. For each answer we record to which concept the question belongs, whether the answer was correct, as well as timestamps.

**Language practice:** In the practice context, students practice the language by doing exercises based on a text. The response data consists of student answers to the exercises: one set of exercises is associated with a *snippet* of text (e.g, one paragraph). The system offers various types of exercises, including multiple-choice questions, "cloze" quizzes (fill-in-the-blank), and listening comprehension, which are generated automatically based on the text chosen by the learner. Each text has been assigned a difficulty rating by a linear model, described in 3.4. Currently, we do not use information about to which linguistic concepts each exercise belong. For each attempted set of exercises, we use the percentage of correct answers, text difficulty, and the timestamp.

## 3 Rating methods

This section describes how we calculate and update ratings of users and linguistic concepts. We cover the two assessment contexts in which the data were generated: first, the testing context, and second, the practice context. The estimator of text difficulty is described at the end of this section.

### 3.1 Elo ratings

The Elo rating, introduced by Arpad Elo, (Elo, 1978), was originally used for rating the skills of chess players, and evolved versions of it are now widely used in a variety of domains, ranging from video-games to Tinder.

The Elo formula defines the *expected* result of actor $A$ in a match against actor $B$ according to:

$$E_A = \frac{1}{1 + 10^{\frac{R_B - R_A}{\sigma}}} \tag{1}$$

$E_A$ is a value between 0 and 1, indicating the expectation (probability) of success/win. $R_X$ refers to the current rating of actor $X$, and $\sigma$ is a scale variable. The scale is traditionally set to 400 (in chess). This controls the spread of the resulting ratings. In the present work, we used $\sigma = 600$.[2]

The rating of actor $A$ *after* a match with another actor is completed is updated according to:

$$R'_A = R_A + K(S_A - E_A) \tag{2}$$

The factor $K$ controls the maximum rating adjustment that is possible at one time. We use a static $K$ value of 32. $S_A$ denotes the outcome, or the score of a match for actor $A$: loss, draw and win for $A$ is denoted as 0, 0.5 and 1, respectively.

The Elo rating method has three important properties. First, the formulas are symmetric: $A$ and $B$ switch places when calculating with respect to $B$. This leads to the zero-sum property of the Elo rating distribution, when $K$ is static—the amount of Elo lost by the losing actor is transferred to the winning one. As a result, the mean of the ratings of all actors will be whatever the initial rating is set to. We initially set the rating of all players (concepts and learners) to 1500.

Second, the magnitude of the rating update depends on the difference between the outcome $S_A$

[2]The reason for this is largely aesthetic; the number of users is currently small (about 1000), which results in a somewhat narrow spread of the rating distribution. A larger spread is more comparable to actual chess ratings, which is more familiar and easier to conceptualize.

and the expected score $E_A$. This means that a highly rated actor failing against a significantly lower rated one will have a severe loss in Elo, approaching the value of $K$. Conversely, the success of a higher rated actor is expected, thus it yields a small update in the rating. If the actors are evenly matched the update is between the two extremes.

Finally, the final, or "*current*," distribution of Elo ratings in a system *depends on the order* of the matches. This implies that the Elo rating is a representation of an actor's *current* proficiency. Consider an actor who fails in the first half of 100 matches, and succeeds in the second half, and compare the result to the reverse order. Because the rating updates decrease toward the expected extremes, and are exaggerated at the unexpected extremes, the resulting rating of the actor will be high when his successes are in the second half of the matches and low in the reverse case—even though the two sequences are events are the same, and differ only in their ordering.

### 3.2 Language test ratings

In (Klinkenberg et al., 2011; Pelánek, 2016), it was shown that Elo ratings can be adapted for use in educational systems, to model the proficiency of students and the difficulty of questions. In our system, in the testing context, the analogue of an outcome of a "game" is a student attempting an exercise; the two rated "actors" are the student and the exercise. $S_A$ represents whether a student has answered the question correctly. The rating $R_Q$ of a question $Q$ captures the difficulty of the question.

An adjustment is made for *multiple-choice* problems to account for the fact that students have some chance of guessing correctly, even if they do not know the correct answer. For this, we adopt an approach recommended by Pelánek (2016), penalizing the expected value by the probability that a random guess is correct. A similar expectation formula is proposed in Item Response Theory (Embretson and Reise, 2013).

In (Klinkenberg et al., 2011; Pelánek, 2016), the focus was assessing the difficulty of each particular *question*. In our system, we model the concept category to which the questions belong; every question from a concept is a representative for the concept in the calculations. In our data, each question is linked to one linguistic concept. The formula for the expectation of student $S$ having a correct response on a question from Concept $C$ adjusted for guessing is:

$$E_A = \frac{1}{k} \cdot 1 + (1 - \frac{1}{k}) \cdot \frac{1}{1 + 10^{\frac{R_C - R_S}{\sigma}}}, \quad (3)$$

where $k$ is the number of choices in the multiple-choice question. We expect the Elo ratings for concepts to approach their true value after a large number of data points ("games" or exercise attempts) have been sampled. To obtain concept ratings of better quality, they are learned by re-adjusting all ratings by re-playing all games/attempts in chronological order over several epochs. We call this the Elo "*burn-in*" period, and describe it in Section 5.1. This is used to obtain "stable" concept ratings.

### 3.3 Language practice ratings

In the practice context, the exercises are different from the test context. Our method therefore differs in the two contexts in several ways. Here, the exercises sets that the learners have answered are composed of a variety of exercises, some of which may not be linked to a specific linguistic concept (recall, each test item is linked to a concept). This means we cannot share the ratings directly between the two learning contexts.

To address this problem, we make the simplifying assumption that *on average* the exercises in a given text correspond to the *difficulty* rating of the text. The method for estimating the difficulty of a text is described in the following subsection.[3]

Concretely, we define $S_A$ as the percentage of correct responses in a given set of exercises. $E_A$ for a set of exercises is set to the Elo rating of the *entire text* from which the exercises are drawn.

We update the learner's Elo after *each* set of exercises, but update the text's Elo only after an entire iteration through the text. Crucially, the system updates the Elo for the text only with respect to the *specific user* who practiced it. This models the notion that as I practice with the same text over and over, the text becomes "easier" for me—but not for other players.

### 3.4 Estimator of text difficulty

Modeling and characterizing the readability of texts is a well-studied problem with a long history, (Dubay, 2009). Experiments with lexical and

[3]This means that A. our difficulty model should return an accurate estimate of the complexity of the text, and B. that these difficulty estimates should be properly calibrated to the desired rating scale.

grammatical features have been conducted, (Chen and Meurers, 2016; Heilman et al., 2008).

We use a simple linear model for estimating the difficulty of a given text. The output of this model is scaled onto the Elo rating scale. This enables us to calculate the expected result of any rated learner solving exercises from any rated text.

**Lexical frequency** is known to be a powerful predictor of text readability, (Chen and Meurers, 2016). We use the normalized mean of the lexical frequencies of the tokens in a text as a feature. Additionally, we use **mean token length** and **mean sentence length**, as they are also used in classic readability measurements, (Kincaid et al., 1975; Flesch, 1979). These three features are scaled for a simple 3-variable regression model.

Currently, data for training this model are partitioned into two types: texts from sources with simplified language vs. texts from difficult sources. We label simple texts with a value of 0.2 and difficult texts with 0.8.[4] We aim for a model that produces a correct ordering of texts with respect to their difficulty. We do not need an exact estimate. If the learner Elo ratings based on these estimates correlate well with the ratings from the testing context, we consider this estimator accurate enough. In Section 5 we show that so far, this indeed seems to be the case.

The model outputs typically range between 0 and 1. We scale these values to Elo ratings according to formula 4. This transformation is based on the Elo rating distribution acquired in the testing context. The bounds are clamped at $(0, 1)$, as some texts may get a high difficulty value (sometimes even $> 2$, in extreme cases).

$$f(x) = \begin{cases} 600, & \text{if } x < -0.4 \\ 1000x + 1000, & \text{if } -0.4 \leq x \leq 1.4 \\ 2400, & \text{if } x > 1.4 \end{cases} \tag{4}$$

## 4 Concept graph

We are interested in finding a model for the "natural" order in which learners acquire linguistic concepts—directly from learner data. Learners will find some orders more natural than others—e.g., when some concept is a requirement for another. The fact that one concept "precedes" another is called the *surmise* relation in Knowledge Space Theory (Doignon and Falmagne, 1999).

Often the domain model in ITS is built by eliciting domain knowledge from experts. We devised a baseline model to infer such relations from user data, without supervision. As we mentioned, each test question is mapped to a certain linguistic concept, and we store all test results from all students. Based on these results, we know to what extent which users have mastered which concepts; from this, we can try to tell apart the more basic concepts from the more advanced ones.

The aim is to build a partial order over the set of all concepts $C$, which specifices which concepts are related—i.e., we write $c_2 \rightarrow c_1$ to mean concept $c_2$ *presupposes* (or implies) concept $c_1$.[5]

Given a set of users $U$, we build a matrix of "mastery" scores $M$, of dimension $|U| \times |C|$. Every element $M_{ij}$ is the proportion of correct answers that user $u_i$ has given for concept $c_j$. In the current implementation, we consider each "user" to be a single *test session*. If the same person completes the test at different times, they will be treated as different users for the purpose of computing consistency. This is done to take into account the fact that a user's level of proficiency changes over time.

For every pair $c_1, c_2 \in C$, we check whether $c_2 \rightarrow c_1$, $c_1 \rightarrow c_2$ or $c_1 \perp c_2$ . We compare all columns of $M$ pairwise. Let $c_j$ denote column $j$ of $M$ and $c_k$ column $k$. To check whether $c_k \rightarrow c_j$ is true, we define a logical function $CON_u$ which checks that user $u$ is consistent with this relation:

| $M_{uk}$ | $M_{uj}$ | $CON_u(c_k \rightarrow c_j)$ |
|---|---|---|
| 0 | 0 | 1 |
| 1 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 1 | 1 |

Again, here $c_k$ is the "harder" concept than $c_j$. Thus, if $M_{uk} = 0$ (user $u$ knows nothing about concept $c_k$), that is consistent with $c_k \rightarrow c_j$ regardless of the value of $c_j$. Conversely if $M_{uj} = 1$ (user $u$ mastered concept $c_k$ perfectly), that is consistent with $c_k \rightarrow c_j$ regardless of the value of $c_k$.

In practice, the values in $M$ are fractions between 0 and 1. Therefore we introduce two thresh-

[4] This is a simplification, which does not reflect reality accurately, as not all texts from a given source are of equal difficulty. However, simply fitting a low dimensional, high-bias estimator such as this yields a reasonable baseline model that generalizes well enough to other texts. We will explore more sophisticated models in the future.

[5] We would like to say that $c_1$ is a *prerequisite* for $c_2$, but that may be too strong a claim. However we *may* be able to learn from the data that *typically* $c_1$ is mastered before $c_2$.

old parameters to map $M_{ij}$ to zeroes and ones: we believe that a user $u$ really does not know the (harder) concept $c_k$ if $M_{uk} \leqslant \overline{\theta}_{guess}$: the "guessing" upper bound, below which we believe that the user does not know the concept, while sometimes only guessing the correct answer. Analogously, we say that a user $u$ has mastered quite well the (easier) concept $c_j$ if $M_{uj} \geqslant \underline{\theta}_{master}$: the "mastery" lower bound, above which we believe that the user knows the concept, while sometimes making a few mistakes.

To check whether $c_k \rightarrow c_j$, we compute the proportion $\sigma$ of all users who are consistent with this relation $c_k \rightarrow c_j$, as follows:

$$\sigma(c_k \rightarrow c_j) = \frac{1}{n} \sum_{u \in U} CON_u(M_{uk}, M_{uj})$$

where:

$$CON_u(M_{uk}, M_{uj}) = \begin{cases} 1 & \text{if } M_{uk} \leqslant \overline{\theta}_{guess} \\ 1 & \text{if } M_{uj} \geqslant \underline{\theta}_{master} \\ 0 & otherwise \end{cases}$$

$n$ is the total number of users. $\theta_{guess}$ and $\theta_{master}$ refer to the thresholds of guessing and mastering respectively. That is, we ignore all users where the level of proficiency in $c_1$ and $c_2$ suggests that user only partially understands both concepts, since they do not support to the consistency from $c_k \rightarrow c_j$.

We then apply a *consistency* threshold $\theta$ such that, if $\sigma(c_2 \rightarrow c_1) > \theta$, we add the relation $c_2 \rightarrow c_1$ to our partial order.

Finally, we represent the partial order as a directed acyclic graph (DAG), where each path in the graph represents a possible prerequisite route toward learning a concept. For example, if we wish to obtain a complete syllabus for a language course, then we can find a total order compatible with our partial order (i.e., a linear extension) by topologically sorting the nodes in the graph.

We tested this approach with a set of over 620K answers gathered from 700 users, and manually evaluated the results, setting $\theta = .7$.

Our domain experts confirm that the resulting graph provides a plausible model for the relations between the concepts in the language.

## 5 Experiments

### 5.1 Elo burn-in

In conventional Elo rating systems, the ratings of both actors are updated after each match. Our goal is to learn a stable rating for each language concept, which we can keep unchanged as learners take further tests and improve. The rationale behind this is that the concepts don't become less difficult for everyone if a learner masters it.

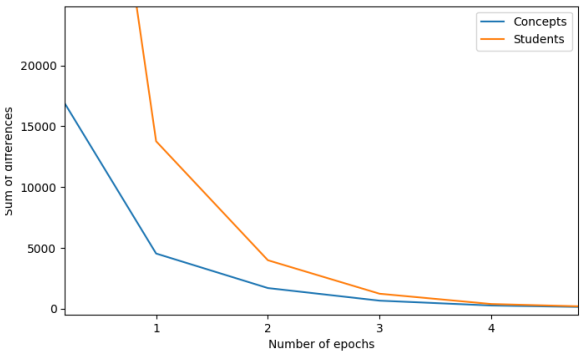


Figure 1: Learning concept Elo ratings with burn-in

To achieve this, we perform a burn-in simulation based on the user data we have collected. Specifically, we take the entire collection of data and calculate the Elo updates for each data point—user U doing exercise E—in chronological order. We do this for repeated epochs until the sum of differences between epochs nears zero. This is illustrated in Figure 1.

Once convergence is achieved, we reset the student ratings, and recalculate them from scratch with the *fixed* concept ratings. This yields a system where the learners' ratings are comparable and independent for any learner, including future ones.

### 5.2 Test and exercise simulation

To verify that one test (of 300 items) is sufficient for a learner to reach her current "true" rating, we performed simulation experiments. Concretely, we measured how many test items a new learner (e.g., with a rating of 1800 Elo) must answer in order to settle on her rating.

In this simulation, each student is initially rated as 1500, and complete some test items. We use the Elo expectation formula to get the response accuracy for the simulated actors. We perform randomized simulations of actors performing one 300-item test with this average response accuracy and observe the results, shown in Figure 2. The actors' responses—correct or false—are sampled randomly according to her supposed correct rate. We also add a small amount of normally distributed random noise. As Figure 2 shows, in this case, one 300-item test is enough to reach one's "true" rating.

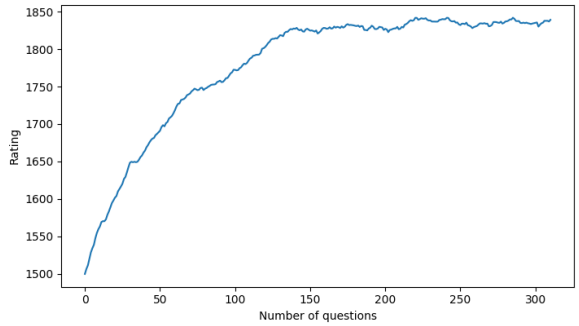


Figure 2: Simulation: test items

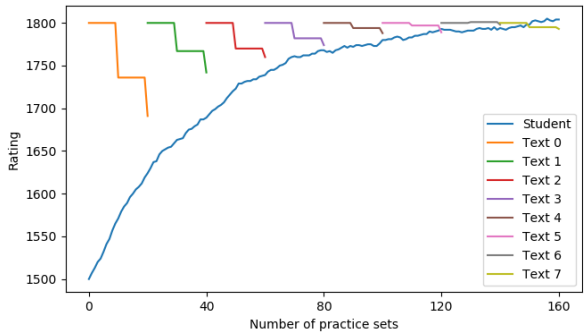


Figure 3: Simulation: exercises based on texts

In contrast to the test item context, in the context of text-based exercises, the Elo ratings will be updated over time both for for learners and practice texts. We conducted a simulation to visualize the rating trends.

In the exercise simulation, the simulated actor has the same starting point as in the simulation for tests—1500. We fix her rate of correct responses, e.g., as 50%, and the actor is practicing only simulated texts rated at 1800. This means that the theoretical upper bound of the actors' rating is, by definition, under 1800.[6] The same normally distributed noise is introduced in this simulation as above. The data in our system shows that texts typically contain 10 snippets (exercise sets) or fewer. After a full pass through a text, namely, 10 problem sets, the ratings for the text are updated with respect to this particular actor. In this simulation each text is to be practiced twice. Figure 3 shows the result of this simulation. We stopped the simulation after 8 texts (each practiced twice) because the rating of the actor had converged to 1800. Since the student begins far below 1800, the first several problem sets will have a substantial drop in their rating, due to the large initial difference between student's rating and text's difficulty estimate. This initial burn-in process soon ends, after the student practice several snippets. As we can observe in Figure 3, the initial burn-in process ends after 3 texts—10 snippets/practice sets per text, each text practiced twice, yielding 60 snippets—the subsequent ones showing only a slight change. The simulation is based on the assumption that the student will go though every problem set in strict order. In reality, this is not very likely. We can therefore infer that this student can reach a rating around 1800 rating after practicing with less than 140 snippets/problem sets.

[6] 50% success rate in a competition setting means the players are perfectly matched; since the text is rated 1800, the learner's Elo rating should also reach 1800 and remain there.

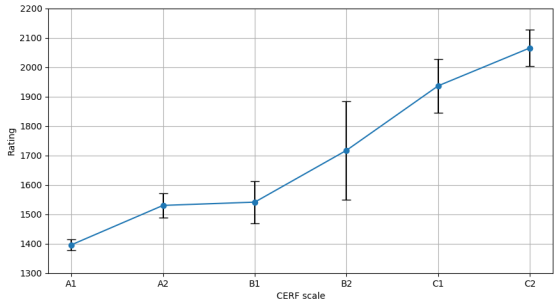


Figure 4: Expert annotated CEFR groups vs. mean Elo rating for each CEFR level

## 6 Results

The result of primary interest is how well the Elo ratings given by our system correspond to CEFR levels assigned to the learners by the expert teachers, who estimate the learners' proficiency based on a wide range of assessment criteria, including written essays and oral exams. The relationship between Elo and CEFR is illustrated in Figure 4.

The figure shows the means and 95% confidence intervals of the Elo ratings for the CEFR levels of students, assigned subjectively by the teachers. The numbers of students at each CEFR level in our experiments are given in Table 1. The data in Figure 4 comes from 142 students whose CEFR levels were established *independently* of these tests by the teachers. Although language competency encompasses several skills—reading, writing, aural comprehension, speaking—and the learner may be at different levels in different skills, we normally expect that the competencies across different sills are fairly well correlated. The correlation om Figure 4 is 0.90. Thus, the data in the figure indicate good correlation between our rating method and actual proficiency.

While assessing and modeling the improvement

| CEFR | Students |
|---|---|
| **A1** | 48 |
| **A2** | 31 |
| **B1** | 18 |
| **B2** | 6 |
| **C1** | 17 |
| **C2** | 22 |
| **Total** | 142 |

Table 1: Number of CEFR rated students in Figure 4

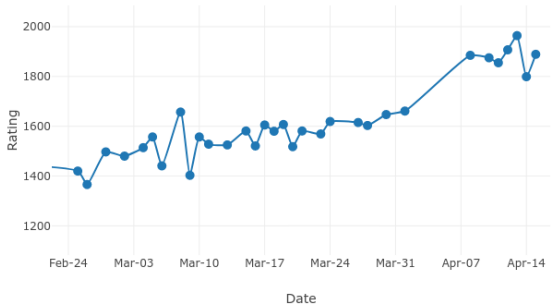


Figure 5: A representative student test Elo progress

of learners is largely in the realm of future work, we have interesting preliminary data of learners' improvement. Figure 5 shows an example of the progress of a typical actual learner taking tests. The learner takes (randomized) tests over a period of time, with the rating improving consistently. In this example, we see an increase of almost 300 in average Elo during the periods. The improvement is attributed to the fact that the learner has covered new material during the period, mastered more of the concepts in the test, and consequently scoring better on those questions.

Another crucial question is how well our Elo estimates from the exercise context correlate with Elo ratings from the testing context. For this we also have initial results, shown in Figure 6. We have so far collected only a modest amount of learner data, and therefore the conclusions drawn from the data are preliminary. Investigating this correlation requires substantial data from learners who have worked in both contexts: practicing with exercises based on texts, and completing tests. The figure shows results for the top 17 students, who have completed at least 1000 exercise sets (text snippets, in orange) and at least 300 test items (in blue)—sorted according to their *test* rating. The figure shows good correlation between the two rat-

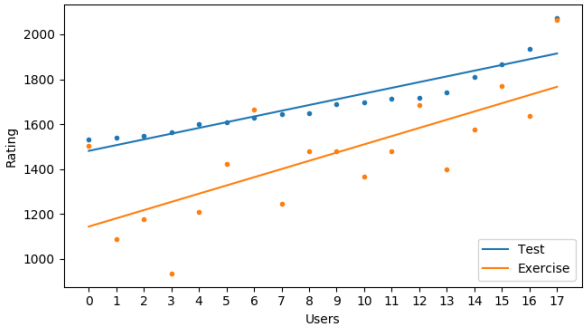


Figure 6: Correlation between test and text-based exercise ratings ($\rho = 0.79$)

ings for the students. At present, the correlation between test and practice Elo score is 0.79.

The last goal in our work is to investigate the relationship between the concept graph and the Elo ratings. Figure 7 shows a small sub-graph of the concept graph. The complete concept graph 8 can found in the Appendix. From Figures 7 and 8, we can see that typically (though not always), if concept A surmises concept B, A will have a higher Elo rating than B. This makes sense, as more difficult concepts should surmise easier ones. The Elo ratings and the graph structure do not correspond perfectly. Expecting that real-valued linear ratings can accurately describe the natural order of concepts is unreasonable. Since the graph and the Elo ratings describe different processes, it is not surprising to find inversions in the graph, such as between concepts 98 and 93, in Figure 7. The structure of the graph, its relation to the difficulty of concepts, and the natural learning order of concepts is an key future research topic.

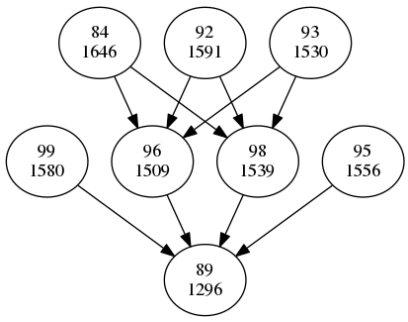


Figure 7: Sub-graph of the complete concept graph (see Supplementary Materials). Arrows denote implication. Top number: ID of the concept (appendix A); bottom number: Elo score of the concept (appendix B).

## 7 Current problems

We are in the process of collecting user data and evaluating the methods of assessment presented in this paper. Subjective CEFR ratings are being collected from the teachers for some of the students. While the number of hand-labeled CEFR ratings is modest at the time of writing, it is sufficient to indicate that using Elo-based ratings for measuring language proficiency shows promise. Building domain models based on the concept precedence graph is another direction of research.

Comparing our ratings and expert-annotated proficiency levels in larger quantities will raise the confidence of our method. We must note that a single value cannot be expected to describe the language proficiency of a learner completely, as there are several aspects of the language to master.

We plan to compare other Elo-based models, such as Glicko (Glickman, 1999), and TrueSkill (Herbrich et al., 2007), with our Elo rating formula. Robust methods for obtaining numerical estimates of skills enables us to develop ICALL systems, by facilitating the quantitative evaluation of skills, and the resulting improvement of the learners.

## 8 Conclusions

The main contributions of this paper are:

- We adapt and evaluate Elo-based rating formulas for modeling language learners' proficiency, as well as the difficulty of texts and linguistic concepts, not only the difficulty of questions/test items.
- We obtain static difficulty ratings for the linguistic concepts by performing an initial burn-in for the Elo ratings based on a large amount of learner data, and then assess students' proficiency using the learned Elo ratings. Feedback from language teachers/experts indicates that the ratings correlate with their estimates of learner competency.
- We use a linear-regression model of text difficulty as an estimator, to obtain Elo ratings for the texts. This enables us to rate the performance of learners, who practice with exercises generated from the texts. Preliminary results indicate that there is a positive correlation between ratings in the exercise and the test contexts.
- We build a partial order over all concepts found in the domain, and visualize the partial order as a DAG over concepts. The concept graph is not linear as the Elo ratings. The structure of the concept graph and the Elo ratings of the concepts generally agree in that the graph displays a strong tendency of decreasing rating from the more complex concepts to the more fundamental concepts, as indicated by the actual data collected from the learning process.

In sum, the proposed methods enable us to rate the proficiency of the current and future language learners, which is a fundamental goal in ITS and ICALL.

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# A List of concepts

| ID | Rating | Name of concept |
|---|---|---|
| 6 | 1602 | Lexicology. Lexical semantics |
| 7 | 1860 | Collocations |
| 8 | 1679 | Lexicology. Coordination of words |
| 9 | 1382 | Verb. Case government |
| 10 | 1541 | Verb. Prepositional government |
| 11 | 1550 | Adjectives |
| 12 | 1509 | Nouns |
| 19 | 1471 | Impersonal verbs (except verba meteorologica) and their government |
| 20 | 1482 | Predicative adverbs and their government. Existence, state, time |
| 21 | 1480 | Predicative adverbs and their government. Necessity, possibility, impossibility |
| 22 | 1577 | Negative constructions with predicative 'be' (and synonyms), genitive of negation |
| 23 | 1423 | Sentences with dative subject: 'Кате 25 лет' |
| 24 | 1445 | Expressions of time, place and manner. Preposition-free expressions |
| 25 | 1621 | Constructions with cardinal numerals |
| 26 | 1470 | Constructions with collective numerals |
| 27 | 1652 | Genitive plural of Pluralia tantum words |
| 28 | 1630 | I declension. Type 'музей-музеи, воробей-воробьи' |
| 29 | 1595 | I declension. Type 'санаторий' |
| 30 | 1662 | I declension. Fleeting vowels and alternations я, е, ё / й ('заяц-зайца, заём-займа') |
| 31 | 1608 | I declension. Type 'карандаш' |
| 32 | 1671 | I declension. Type 'адрес-адреса' |
| 33 | 1562 | I declension. Type 'солдат-много солдат, сапог-пара сапог' |
| 34 | 1586 | I declension. Type '-анин/-янин, -ин' |
| 35 | 1518 | I declension. Type 'дерево-деревья' |
| 36 | 1616 | II declension. Type 'армия' |
| 37 | 1603 | II declension. Type на -ня |
| 38 | 1713 | II declension. Type 'статья' |
| 39 | 1616 | Fleeting vowel in genitive plural |
| 40 | 1504 | Nouns with prepositions в/на ending in -у/-ю in prepositional singular |
| 41 | 1619 | Nouns ending in -у/-ю in prepositional singular and -а in nominative plural |
| 42 | 1644 | Possessive adjectives. Type 'лисий' |
| 43 | 1601 | Ordinal numbers. Type 'третий' |
| 44 | 1612 | Possessive adjectives. Type 'мамин' |
| 45 | 1543 | Cardinal numbers. 'Сто' vs. 'пятьсот, шестьсот, семьсот, девятьсот' |
| 46 | 1608 | Quantifiers. Collective quantifiers in oblique cases |
| 47 | 1528 | Quantifiers. Collective quantifiers 'оба, обе' |
| 48 | 1594 | I conjugation. Type 'плакать' |
| 49 | 1511 | I conjugation. Type 'рисовать' |
| 51 | 1560 | II conjugation. Type 'молчать' |
| 52 | 1674 | Preterite. Type 'исчезнуть' |
| 54 | 1570 | Regular verbs with vowel alternation |
| 55 | 1512 | Resultative |
| 56 | 1553 | Iterative / potential iterative / qualities |
| 57 | 1507 | Expression of duration - 'за какое время' |
| 58 | 1416 | Factual meaning of verbs |
| 59 | 1817 | Aspect, expression of action completed in the past |
| 60 | 1648 | Aspect, expression of capability/incapability. ('Тебе этого не понимать/понять!') |
| 61 | 1509 | Inception of action |
| 62 | 1525 | 'Забыть, успеть, удаться' + infinitive |
| 63 | 1539 | 'Уметь, нравиться, любить' etc. + infinitive |
| 64 | 1651 | 'Пора, скорее' + infinitive |
| 65 | 1553 | 'Нельзя, невозможно, не могу' + infinitive |
| 66 | 1499 | 'Не' + infinitive |
| 67 | 1501 | Negative sentences |
| 68 | 1411 | Imperative |
| 69 | 1559 | Proximal future |
| 70 | 1674 | Impersonal sentences. Infinitival sentences. Subordinate sentences ('если / прежде чем' + infinitive) |
| 71 | 946 | Impersonal sentences. Infinitival sentences. Modal expressions |
| 72 | 1580 | Impersonal sentences. Infinitival sentences. Sentences, with negative pronouns and adverbs |
| 73 | 1701 | Generis-personal sentences |
| 75 | 1516 | Passive and its relation to indefinite-personal sentences (equivalent of Finnish impersonal passive) |
| 76 | 1800 | Stress: forms of verbal preterite |
| 77 | 1706 | Stress: short adjectives |
| 78 | 1736 | Stress: participles |
| 79 | 1548 | Nouns. Type A: stress on the stem |
| 80 | 1719 | Nouns. Type B, B1, B2: stress on the ending |

| | | |
|---|---|---|
| 81 | 1633 | Nouns. Type C, C1: stress on the stem in singular, on the ending in plural |
| 82 | 1614 | Nouns. Type D, D1: stress on the ending in singular, on the stem in plural |
| 83 | 1610 | Nouns. Type ‘нож-ножом, сторож-сторожем’ |
| 84 | 1646 | Declension of adjectives. Type ‘хорошего’ |
| 85 | 1295 | Place of adverbs of time, place and manner |
| 86 | 1693 | Place of negation in the sentence |
| 87 | 1785 | Place of participles in the sentence |
| 88 | 1618 | Place of gerunds in the sentence |
| 89 | 1296 | Place of pronouns in a phrase |
| 90 | 1589 | Word order in sentences introducing direct quotations |
| 91 | 1681 | Second person singular imperative in conditionals (‘если’) |
| 92 | 1591 | Usage of ‘сам’ and ’один’ |
| 93 | 1530 | Sentences of type ‘Знаю его как врача.’ |
| 94 | 1567 | Sentences of type ‘Быть грозе’ |
| 95 | 1556 | Sentences of type ‘Лодку унесло ветром’ |
| 96 | 1509 | Genitive plural |
| 97 | 1537 | Frequent prefixed verbs of motion + prepositional constructions |
| 98 | 1539 | Animate noun object |
| 99 | 1580 | Unprefixed verbs of motion |
| 100 | 1121 | Unstressed fleeting vowels in roots and suffixes of nouns and adjectives |
| 101 | 1391 | Unstressed vowels in verbal forms |
| 102 | 907 | Unstressed vowels in roots |
| 103 | 1452 | Unstressed vowels in case endings |
| 104 | 1179 | Unstressed vowels in prefixes |
| 105 | 370 | Unstressed vowels in suffixes |
| 106 | 1557 | Unstressed vowels linking compounds |
| 107 | 1224 | Unstressed particles не and ни |
| 108 | 357 | Letter г in ending -ого (-его) |
| 109 | 1443 | Letter й |
| 110 | 1241 | Letter ч and ш before н and т |
| 111 | 1427 | Letters ъ and ь: |
| 112 | 1500 | Vowels in verbal endings |
| 113 | 1451 | Vowels in the infinitive (indefinite form) before -ть |
| 114 | 1365 | Vowels not after sibilants and ц |
| 115 | 1231 | Vowels after sibilants and ц |
| 116 | 1091 | Voiceless and voiced consonants |
| 117 | 1378 | Consonant clusters at the juncture of morphemes |
| 118 | 1654 | Double and single -н- in suffixes of adjectives and nouns |
| 119 | 2025 | Double and single -н- in suffixes of full and short forms of adjectives |
| 120 | 1706 | Double and single -н- in suffixes of past passive participles and corresponding adjectives |
| 121 | 1414 | Double and single -н- in words derived from adjectives and participles |
| 122 | 1341 | Double consonants in borrowed roots and suffixes |
| 123 | 1529 | Double consonants in native roots |
| 124 | 1131 | Double consonants at morpheme juncture |
| 125 | 997 | Silent consonants |
| 126 | 1050 | Peculiarities of spelling of certain roots |
| 127 | 1273 | Peculiarities of spelling of certain suffixes |
| 128 | 1868 | Joint vs. separate spelling of negation ‘не’: verb (+participles) |
| 129 | 1320 | Joint vs. separate spelling of negation ‘не’: pronoun |
| 130 | 1296 | Joint vs. separate spelling of negation ‘не’: adverb (+‘несколько’) |
| 131 | 1475 | Joint vs. separate spelling of negation ‘не’: adjectives (+full-short) |
| 132 | 1490 | Joint vs. separate spelling of negation ‘не’: noun |
| 133 | 1563 | Joint vs. hyphenated spelling: adjectives |
| 134 | 1590 | Joint vs. hyphenated spelling: numerals |
| 135 | 1059 | Joint vs. hyphenated spelling: pronouns |
| 136 | 1312 | Joint vs. hyphenated spelling: adverbs |
| 137 | 1555 | Joint vs. hyphenated spelling: common nouns |
| 138 | 1484 | Joint vs. hyphenated spelling: function words |
| 139 | 1836 | Joint vs. hyphenated spelling: proper names |
| 140 | 1555 | Capitalized vs. lowercase: astronomical/geographical names |
| 141 | 1664 | Capitalized vs. lowercase: posts, titles, awards |
| 142 | 1738 | Capitalized vs. lowercase: names of official organizations |
| 143 | 1898 | Capitalized vs. lowercase: names linked to religion, historical epochs and events |
| 144 | 1718 | Capitalized vs. lowercase: names of trademarks, documents, works of art |
| 145 | 1309 | Capitalized vs. lowercase: proper names of persons, animals |
| 190 | 1527 | Accusative/ergative subject + Impersonal verb: ‘Васю тошнит’ |
| 191 | 1467 | Prep+genitive subject + Impersonal verb: ‘У меня болит голова/шумит в голове’ |
| 230 | 1496 | Dative subject + adverb: ‘мне (стало) плохо/нужно/скучно’ |
| 231 | 1548 | Dative subject + impersonal verb: ‘мне идет/надоело/везет/хватит’ |
| 232 | 1431 | Dative subject + impersonal-reflexive verb: ‘мне нравится/кажется/пришлось’ |

## B Concept graph

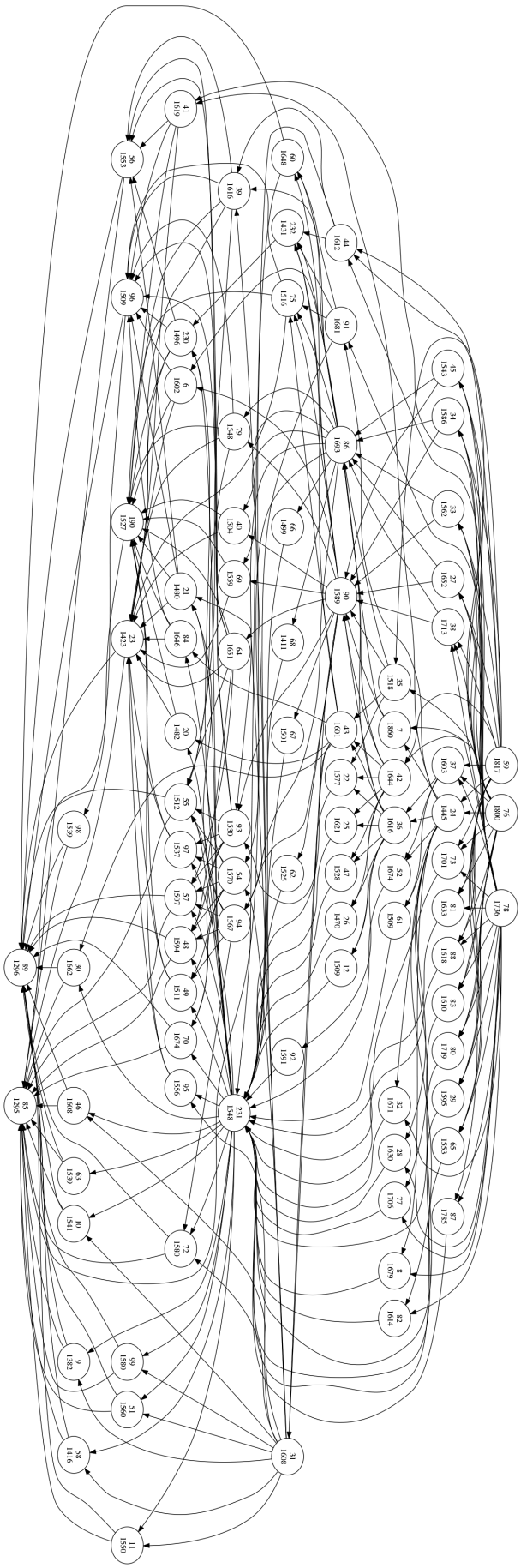


Figure 8: The full concept graph.