# A COMPUTER METHOD TO STUDY THE ENTIRETY OF STUDENTS' KNOWLEDGE ACQUIRED DURING AN EDUCATIONAL COURSE

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***Abstract***: *This paper considers the experimental research of measuring interconnections between the basic concepts, acquired during completion of a course in Computer Architecture. A special computer technique for estimating of students' knowledge entirety was developed and successfully tested. An original mode of experimental data visualization is proposed. Several pedagogical regularities were revealed by assessing how students digested the main concepts of the course.*

***Keywords***: *entirety, concept, knowledge structure, education, course.*

***ACM Classification Keywords***: *K.3.1 Computer Uses in Education; I.2.6 Learning – Knowledge acquisition.*

## Introduction

Methodology and consistency are always noted as the chief mainframe principles of education in all pedagogical books from classics to modern manuals. «A man has veritable and real knowledge only when clear-cut picture of the outer world, which is represented as a system of interrelated concepts, is reflected in his brain; … if you do not keep up methodology and consistency in education, the process of pupil's cultivation slows down.» [Podlasiy, 2002] It is emphasized, that «formed system of knowledge is the most important recipe to prevent its loss. Forgotten knowledge is quickly restored in a system, and hardly without it. … Do not forget J.A. Komensky's advice: all must be pursued in an indissoluble sequence, so that all today's knowledge confirms yesterday's and paves the way for tomorrow.»

The well known Russian lecturer A. Kushnirenko, who is the author of several informatics textbooks, generalized the idea about necessity of learning process's unity, using the following capacious and exact thesis: pupils must «digest such minimum of knowledge, accumulated by the mankind, **that permits shaping the entire representation of outward things, nature and society** » [Kushnirenko , 1998].

Unity of interrelated concepts in any concrete educational course in many respects determinates the success of learning, and the entirety of educational material is always identified as a mandatory pedagogical requirement. In a publication [Zorina, 1992], which analyses the didactic problems of selecting knowledge to include in a textbook, the entirety of course’s contents is marked out as the second principle by its significance (straight after the necessity of science matter reflected in a learning subject). More detailed citation is the following: «Constructing a scientific content of the educational discipline we need to orient oneself to its entire reflection in a textbook. … The entirety of the whole course realizes itself in a scientific picture of the world. The entirety of reflecting different elements of knowledge realizes through their constitution and structure.»

To avoid ambiguity in the discussion, let us arrange that the term «**entirety of the concepts’ system**, built for the learning course», means the presence of the essential relations between all basic categories of this system. As follows from the proposed statement, those students, who see more associations between studied terms, have a higher rate of knowledge entirety, and, hence, digested this learning course better.

This paper is an attempt of experimental research, aimed at studying the structure of concepts interrelations, which was formed as a result of the course «Computer Architecture». The special computer method was developed and tested in order to estimate the rate of entirety of the system from basic concepts, which students acquired by studying the material. Several gauges that can characterize student’s knowledge entirety were proposed and tested; new complex method to visualize the research results is described. Some pedagogical regularity was discovered during the analysis of digesting the course’s foundation.

## General Plan of Concepts’ System Research

In order to examine the entirety of concepts, formed after studying the course, the following strategy was developed and realized.

1. Using existing textbooks (see books [Tanenbaum, 1998; Hamacher et al., 2001; Cilker et al., 2004 and Broydo et al., 2006] for example) and personal teaching experience [Eremin, 2003], the author formed a list of basic terms and concepts. It was assumed, that the rate of digesting and mastery of these terms verified the success of the course.

2. Relying on these resources, the most significant links between terms from the list were fixed. This part of work had an evaluative character and was aimed at a theoretical goal a scrupulous student should achieve. The results of this analysis and course’s contents systematization were published in [Eremin, 2007 and Eremin, 2008].

3. Special computer program was written to check the associations between the concepts that students have and fix them in the text file, suitable for further computer analysis. This program uses as input data the list of terms, which was obtained after implementation of item 1, and the list of relations, worked out during the analysis in item 2.

4. Another computer program allows experimenting teacher to analyze the results of knowledge checking, get in the previous item, and output different statistics. Further this software was modified for drawing graphic representation of calculated data.

Let us review these stages of research more specifically.

## Organization of Experiment

**The full list of concepts** for the architecture course, used as experimental base, contains more than 120 terms. The most general concepts – like *computer*, *software* and *hardware*, *theoretical foundations* etc., complemented by the terms that expand the previous ones – *operating system*, *processor*, *memory*, *DMA*, *principle of hierarchy*, *byte* and many others, were included in this base. The terms from related disciplines such as microelectronics, logics and number notations were added into the list. Contrary, the list did not include the names of concrete operating systems, external devices and their manufacturers, and other similar data, less essential from the position of learning the main course’s regularities. Using the standard terminology from object-oriented programming, we may say, that classes of the concepts were under consideration, but not their instances.

The wide list of concepts, obtained as described above, forms the set of terms that, from the lecturer’s point of view, a literate student must know and understand. The list was found to be large enough, so, as further experiments shows, competent students usually used a little more than the half of it in their answers.

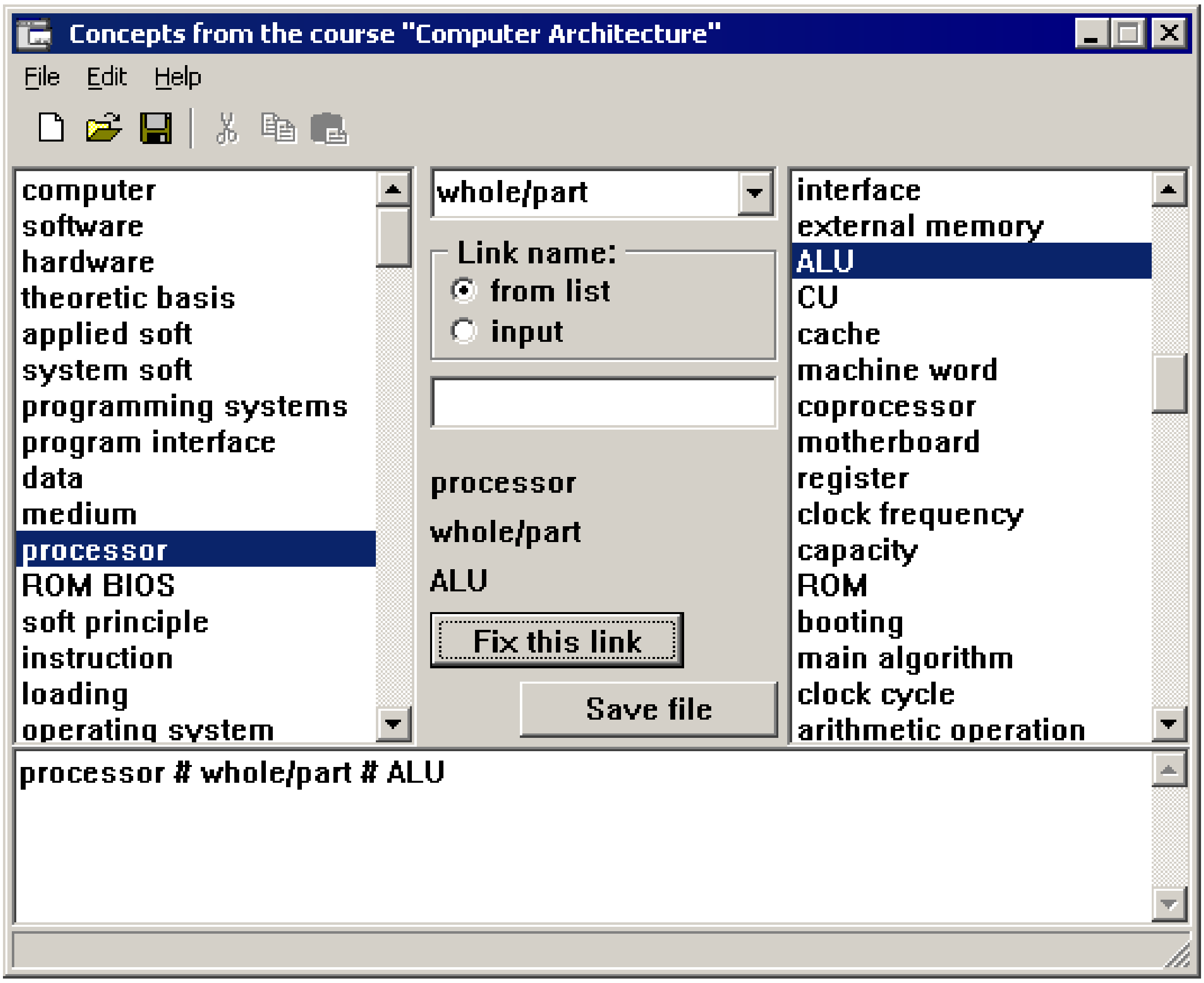
The next step was to analyze **the links between the selected terms**. Non-trivial result of this work consists in the fact, that a limited set of relations was enough to describe the subject. The final set consists of standard relations such as, for example, *whole/part* or *class/subclass* as well as several links, specific for the course, like *base* (*principles of hierarhy* and *addressing* – *base* – *memory*, *program counter* – *base* – *the main algorithm* of instruction execution) or *connection* (*controller* – *connection* – *bus*, *input devices* – *connection* – *system block*). The full table of relations with concrete examples for each can be found in publications [Eremin, 2007 and Eremin, 2008]: it consists of only 11 base associations.

The results of analysis, published earlier, are of independent interest. From the point of view of this paper, constructed lists are original data, which are used during the experimental testing of student mastery of the knowledge domain under consideration. As knowledge control was realized with the help of computer, both lists (of concepts and relations), being input data for control program, were saved in the form of text files.

Now let us proceed to the description of **computer software for students’ knowledge check**. It was developed in Delphi programming environment and is simple enough. There are three lists (see fig. 1), using which a student forms a relation looking the following way:

term 1 – relation – term 2

(for instance, the relationship *processor* – *whole/part* – *register* can be easily decoded as phrase «processor and register are linked by association whole/part» or, more exactly, «register is a part of processor»). After student constructs a linked pair of concepts, s/he fixes it clicking the control button «Fix this link». Then the constructed text is added to multi-line text field, arranged in the bottom of the program window.



whole/part

● from list
○ input

processor
whole/part
ALU

```
processor # whole/part # ALU
```

Figure 1

Except the list of associations, loaded from pre-arranged file, the program covers a potential possibility to input additional (not provided by the author) name of relation between the terms: special radio buttons and text field in the center of the window allow such input. As experiments shows, students did not use this alternative, preferring to select link type from the available list.

When a student finishes his/her work, the results are saved in a text file, designed for the further computer analysis. Such testing of knowledge was realized twice – before learning the course and after it: the research was aimed at comparison of these results for assessment of the course digesting.

At the last step all text files with the results of knowledge control fall under **computer processing by means of the second program**. Its main aim was to educe linked groups of concepts for every student. For example, when computer, processing a file, finds associations *functional units* – *class/subclass* – *processor*, *functional units* – *class/subclass* – *memory*, *functional units* – *class/subclass* – *input devices* and *functional units* – *class/subclass* – *output devices*, it joins all five concepts, mentioned there, into one group. Later on some other terms will be added to this group: for instance, relations *processor* – *whole/part* – *ALU* and *processor* – *whole/part* – *CU* join two new terms to the group – *arithmetic and logic unit* and *control unit*.

In ideal case all concepts of the course are interrelated; test running of the program with thoroughly prepared author's file, built according to full results from publications [Eremin, 2007 and Eremin, 2008], confirms this. But experiments show, that real students' files represented more scattered picture, which consists of several isolated groups of concepts, and some groups were very small (2-3 terms). Such small groups must be interpreted as a separate fact that student does not associate with other facts from the course. You must note that an increased rate of fragmentation indicates student's knowledge is sparser.

Experimental check of knowledge entirety was organized the following way.

The experiments estimated knowledge of students, who studied on the third course of the physical faculty. Knowledge control took place twice: at the beginning and at the end of semester, that is to say before and after the learning of the referenced discipline «Computer Architecture». Unfortunately, the number of students, who learned the course and took part in the experiment, was small. Additionally, several students missed one of the tests for a variety of reasons, so their results were incomplete and could not be considered.

Students did not know that the aim of the experiment was entirety of concepts' system because it could artificially improve their results. They were simply told that testing tries to verify the rate of digesting the material. Their instruction was not to think about the parameters of evaluation, but just try to demonstrate digested knowledge the best way they could.

As the students did not study the types of relations between concepts before, they were given a special table (with all 11 referenced links and numerous examples for each one) before testing. The results shows, that it was insufficient and the students unsatisfactorily differentiated the types of links. Often they even missed classical relations *whole/part* and *class/subclass*, not to mention other link types. The aim of the experiments was to estimate the general entirety of the basic concepts – so from this point of view concrete kinds of links are not too important. Such effect became a motive to neglect the errors in this part of the task on the first stage of experiments, and just fix the existence of relation but not it type. This simplification of method notably facilitated the process of results processing and analysis.

The time for implementation of the task was not limited, the work finished individually at students' will. Presumably, it brought some uncertainty into experiment, since some students really indicated all interrelations they knew, but others just got tired and finished their work. The task execution employed about an hour in average. According to my observation of computer testing, the students' reaction was mainly neutral («we just get one more task»), so the checking procedure did not lead to any difficulty.

## Discussion of Results

As it follows from described experimental method, the results are fixed in a text file with pairs of concepts, linked together with association of some kind. It was also validated above, that the links' types are not considered on this stage of research. Special software was developed for processing of final files; it combined related concepts into groups and then calculated a set of statistical characteristics.

Let us discuss what parameters can claim to be the characteristics of student's knowledge entirety.

Primary parameters are evident: *total number of terms* and *total number of links* between them; they can be easily counted from any student's file with the results. The ratio of these values, that means *average number of links per one concept*, also may be introduced into consideration. It is evident, that the more these values are, the better student mastered the material.

Another set of parameters may be built while arranging interrelated terms into groups. We can offer here *total number of concepts' groups* (this value must be as small as possible, in ideal case all terms must form the only group) and *size of the largest group* (this factor we want to see as large as possible). Additionally we can divide total number of terms by number of groups, i.e. get *average size of group*, which must be large when student learned the course profoundly.

All listed above characteristics were calculated for every student, and then compared for testing before and after the course. The most interesting seems to be the results for **average number of terms per group** (T/G). Unfortunately, limited number (N=12) of students, who took part in the experiment, does not allow to validate with statistical significance, that this factor is the best integral parameter for the process.

Diagram of values for selected measure is presented on fig. 2. Let us consider this picture more detailed.

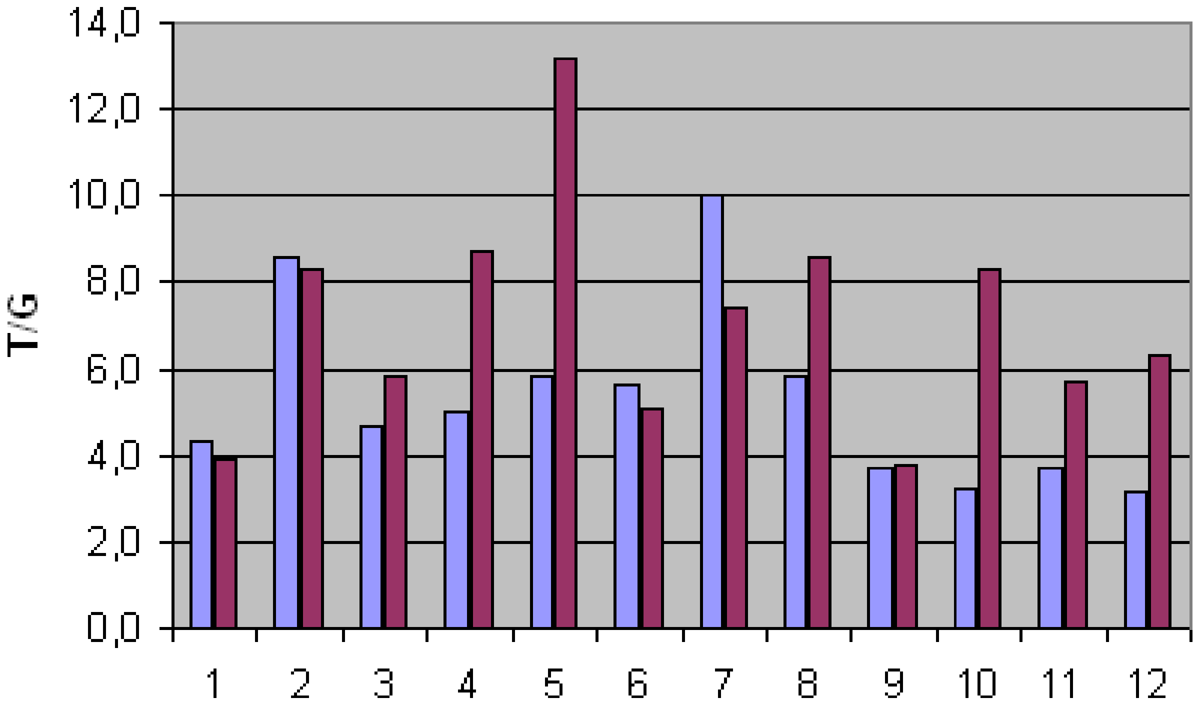


Figure 2

Fig. 2 shows the results of knowledge entirety check for 12 students (points on the X-axis are marked by their numbers from 1 to 12). In Y direction diagram's columns are built: their height are proportional to average size of concepts' groups, i.e. total number of terms T divided by number of groups G, formed from them. The left columns describe data before learning the course, and the right ones – after its studying.

It's important to mention that students on the diagram are rank-ordered according to some rating: the criterion of such arrangement was time of finishing all the tasks, given by the teacher. The students with small numbers finished the course earlier; hence they are supposed to demonstrate better results in learning the course content. In opposite, columns for «the slowest» students form the right part of the picture. Subjective impressions and interview with students during learning process confirm the acceptability of selected criterion as measure of learning success, at least for this group of students.

Let us analyze the values of average concepts in a group, to say more exactly, their changing after finishing the course. It is clearly seen from the diagram, that students have different changes of factor T/G. Some of them (for instance, student number 1, 2, 6, 9) have practically the same values before and after learning the course, but some others (4, 5 and 10-12) show notable growth. It is interesting to mention one feature of the diagram: all weaker students, who have large numbers, improved the entirety of their knowledge, but students with the best rating, contrary, did not demonstrate significant growth. The last fact may be interpreted as good preliminary knowledge of such students – they had some experience in computer architecture before the beginning of study. Unfortunately, the available data are not sufficient to make a pedagogic generalization.

We must pay attention to the magnitude of average group size. As fig. 2 shows, the best result for investigated students lies near value 13, whereas in ideal case for set of terms, used in experiment (more than 100), it can not be less than the last value.

One more (fundamentally new) form of visual representation for entirety of concepts’ system for the same group of students is demonstrated on fig. 3.

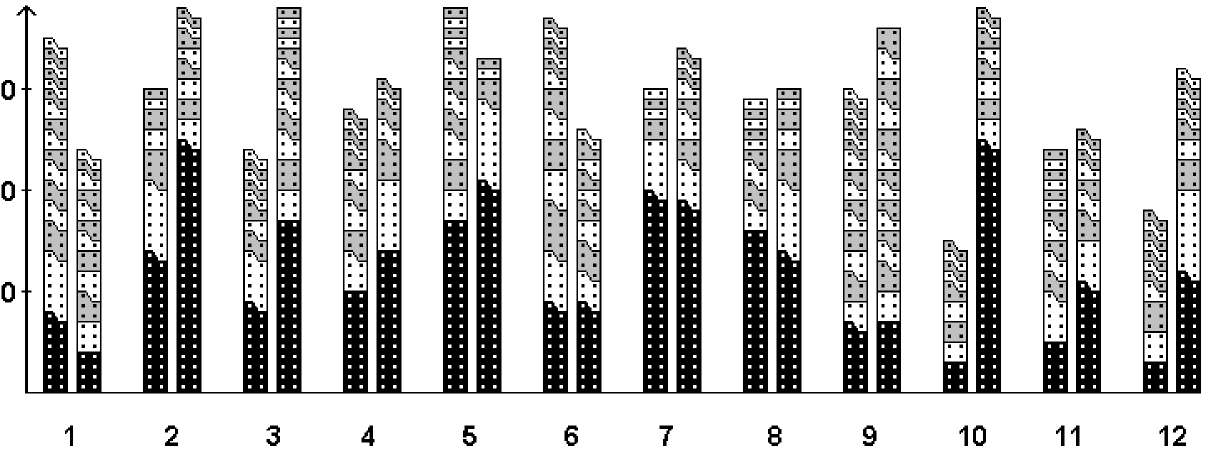


Figure 3

This «spotted» diagram is organized the following way. Pairs of columns we see on it represent input and output testing: the right bar in every pair indicates final results. Height of any column is proportional to the number of concepts that student selected during assessment. Every dot in a column means one individual concept. All columns are divided into several areas; each of them represents a group of interrelated concepts, learnt by every student. For better visibility, neighbor areas are painted in white and gray colors. The black region in the bottom, which is always the largest, symbolizes the kernel of student’s knowledge. As you can notice, all groups in every bar are regularized by size, so the smallest groups from 2-3 concepts (such groups may be interpreted as separate facts out of common picture) are always placed to the top of the bar.

Thus form of complex visual data representation, proposed in this work, clearly reflects the following information:

- the height of the columns is proportional to the number of the learnt concepts, which have at least one relation with the other terms;
- the number of the multicolored areas characterizes the rate of grasped data’s scattering (fragmentation indicator) in selected knowledge domain;
- the size of interrelated concepts groups (proportional to their square) also shows the entirety of student’s knowledge in analyzing part of the course;
- size of the largest area in the bottom of the column (filled with black color on fig. 3) characterizes the volume of the basic block of course’s concepts.

As it was mentioned above, in ideal case the diagram bar must be heterogeneous black bar (consisting from the only group), and its height must include all the concepts of the course. Real picture, as you can see from fig. 3, is far from ideal: students’ knowledge comes apart on several independent groups of terms and the highest bar includes less than 70 concepts from more than 120 ones that were offered in the task.

Examining fig. 3, we may get several practical conclusions about successfully digesting of the course content. The results for students number 4-9 and 11 (numeration is the same as on fig. 2) had slightly changed after learning the course; students 4, 5 и 11 stand out of the list, because the structure of their diagrams is rather better: the number of areas decreases, and their width, in opposite, increases. At the same time students 2, 3, 10, 12 demonstrate more essential growth of factors. And one more observation. The height of some bars (especially for students 1 and 6), which depends from the number of digested concepts, fall off after the course. We may assume, that this paradox can be explained by students’ intention to pass the last test quicker and get their long-expected credit. Of course, this assumption needs in further experimental check.

At last, carefully analyses shows, that there are some identical columns on fig.3: for instance, compare right columns for students 2 and 10. This means that one of them cheated: just copied the result file from other student. Unfortunately, I noticed it too late to enforce students to rewrite their work. So anti-cheating measures must be developed for further experiments.

## Conclusion

The computer method for experimental research is offered, that allows to study the entirety of system of basic concepts after educational course learning. This method was tested on students’ learning the course content in «Computer Architecture» and the results showed its efficiency. This paper also describes a new original visual form of data representation, which clearly demonstrates the structure of interrelations between concepts in student’s knowledge. Some interesting preliminary pedagogical results were discovered during the research, for instance, how knowledge entirety depends on the level of student’s background. Work on the research method and a more detailed study of the process of how basic concepts’ system is formed will be continued.

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*Major Fields of Scientific Research: Knowledge representation, Computer Learning, Computer architecture*