Linking Assessment to e-Learning in Microbiology and Toxicology for Undergraduate Students

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***Abstract*—An e-assessment formative multiple-choice questions experience using an auto-calibrated system is presented. The testing system is briefly described, and the testing and grading methodology used to certify abilities and knowledge in microbiology and toxicology achieved by undergraduate students are presented. The development methodology applied to multiple-choice questions bank has been introduced. The students were actively implied in creation of the multiple-choice questions bank. The paper highlighted the relationship between learning and assessment. The results had been shown the efficiency and effectiveness of the proposed assessment system for both students and teacher.**

***Keywords*—Quantitative e-evaluation, Multiple-Choice Questions (MCQs), microbiology and toxicology, tests analysis.**

I. Introduction

Development of communication and information technology opens the possibility to create new learning and assessments tools. Beyond the world wide access to education across the country and globe [1], the opportunity of running virtual experiments [2-6] and assisting processes modelling [7-9], the communication and information technology facilitate implementation of collaborative learning [10,11], promoting active implication of students in educational process [12-14]. Regarding the assessment process, its design had also been changed, the concept of computer-aided assessment being more frequently used at university and post-university level [15-17].

Various terms with distinct meanings are accepted to describe the use of computer for knowledge assessment: computer-assisted assessment, computer-mediated assessment, computer-based assessment, e-assessment, online assessment. Generally, all above terms refer the use of information technology for any assessment-related activity [18,19]. Computer-assisted/mediated assessment refers to any extrinsic or intrinsic application of computers within the assessment process [18]. Computer-based assessment refers to assessment that is build around the use of a computer; the use of a computer is always intrinsic to this type of assessment [18]. Online assessment refers to assessment activity that requires the use of the Internet into the assessment process [18]. In this process, the computer does not play an active role in assessment, its role being to facilitate the link between student and assessment method, capturing and transferring the responses. In addition, the computers play an important role in creating tests, recording answers, and analyzing the obtained results [20].

It could be consider that there are three cardinal reasons of assessment in higher education [21]: (1) to provide indicators of the quality of students' learning; (2) to maintain standards in higher education; and (3) to motivate students throughout their studies. Some authors consider that the assessment of the students' performance had profound effects on their learning [22, 23].

The assessment at the end of a course could be either qualitative or quantitative. The quantitative assessment involves asking questions that can be statistically tabulated and analyzed. This type of assessment limits students to respond using the options made available to them; from this point of view is considering more objective comparing with qualitative assessment. In contrast with quantitative assessment, the qualitative evaluation is more subjective, flexible and dynamic. Qualitative assessment did not limit the answer to pre-conceived topic, being more problematic to tabulate and analyze them.

The students' knowledge assessment is necessary to be as objective as possible. Starting with experiences obtained by creation of online assessment systems for general chemistry [24,25], and from the necessity of a valid and reliable assessment, an auto-calibrated system has been developed [26]. The aim of present research was to assess the microbiology and toxicology knowledge of fourth year students at the Faculty of Materials Science and Engineering from the Technical University of Cluj-Napoca, Romania by using the developed knowledge evaluation system.

II. Material and Methods

A. Testing System

Starting from the necessity of a valid (it tests relevant knowledge, skills or abilities) and reliable (the same results would be achieved if the assessment is repeated) assessment method, the proposed evaluation system has

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been developed as a formative assessment with multiple-choice questions.

The testing system comprises two main components: (1) an assessment engine (the hardware and software required to create, store and deliver a test, to create and to store users information and to manage with testing results), and (2) a multiple-choice question bank. A detailed presentation of the assessment engine is presented in [25]. The system has been built up in order to allow: (1) registration of the users; (2) creation of MCQs bank (creation and storing of new questions, and changing of previously created questions); and (3) students' knowledge assessment. The system compute the final mark by auto-calibration, based on all parameters stored into database, being able to display the interest parameters, and to plot the mark distribution. The system also displays all questions included into database as well as the questions with wrong answers.

The creation of the multiple-choice questions banking was time-consuming comparing with the creation and configuration of the assessment engine. The students were actively involved into this process of the multiple-choice question banking. Two main rules were imposed here: (1) each question has a statement and a list of five options; and (2) at least one and no more than four options are correct.

B. Students Sampling and Attendance

At the Materials Sciences and Engineering Faculty, Technical University of Cluj-Napoca, Romania, the curriculum contains for first semester as core course for the fourth-year of study the Microbiology and Toxicology course. According with course description and with the subject matter, the Microbiology and Toxicology course contains tutorials and laboratory sessions, and at the end of the course the students knowledge are assessed. In the present study were included students from two academic years: 2005-2006 and 2006-2007. All students participated at the lectures and laboratory sessions that included experimental and/or computer aided learning activities.

At the beginning of the course, the aim of the research was presented and the students had the possibility to enrol voluntarily into the team responsible with the creation of the multiple-choice questions (MCQs) bank. The Microbiology and Toxicology topics were divided between students enrol in MCQs bank creation, each student or team of two students being responsible with a specific topic. The methodology of MCQ has been presented to the students and they were engaged in creation of proportional number of questions with one, two, three, and four correct options, respectively. The students were informed that if they complete the assumed activities would receive bonus points to the final mark, according with the quality of work. Penalties were applied (a number of points were subtract from the bonus points) when the imposed rules in creation of MCQs were not respected and/or when the created questions were wrong (errors in statement and/or in option(s)).

C. Testing and Grading Methodology

The testing methodology imposed: (1) the place of the examination at the test centre; (2) the type of examination as computer- and teacher-assisted; and (3) the number of question per test (thirty). When a test is generated, a double randomization is applied: randomization of the statement, and randomization of the options' order.

The students had the possibility to familiarize with the testing system before the examination as many time as they wished. The students had the possibility to test themselves as many time as they desired, in accordance with the imposed period. Penalties were applied any time when students begin a test and give up without responding to questions.

The all-or-none rule was applied in grading of students responds (each question received one point if all the correct option(s) and none of the incorrect option(s) were selected). Two scores (the number of correct answers and the average time per correct answer) were took into consideration at the final mark. According with the Romanian Education Law [27] grading mark, and taking into consideration the individual score parameters, the system assigned to the lower score the mark equal with four (the exam is fail) and the highest score to the mark equal with ten (the best mark). The students' marks are auto-calibrated each time when a new test is performed.

D. Analysis of Results

A number of variables were collected from each test: students' first and second name, data and time when the test begin and end (yy.mm.dd hh.mm.ss format, where yy = year (e.g. 06 for 2006), mm = month (e.g. 02 for February), dd = day (e.g. 18 for eighteen), hh = hour (e.g. 09 for 9 am), mm = minute (e.g. 12), ss = seconds (e.g. 41)), the number of correct answers, the average time per correct answer, the points of evaluation. Data were collected into a database and were summarized and analyzed with Statistica software at a significance level of 5%. The 95% confidence intervals for proportions were calculated by using of an original method, based on the binomial distribution hypothesis [28].

III. RESULTS

The e-assessment system for Microbiology and Toxicology evaluation has been developed and it is available via the following address: http://vl.academicdirect.ro/general_chemistry/microbiology_toxicology/. The access to the e-assessment system is open just from the test centre.

A total number of 28 students were involved in development of MCQs banking, 12 out of 38 from 2005-2006 academic year (31.57%, 95%CI [7-18]), and 16 out of 28 from 2006-2007 academic year (57.14%, 95%CI [10-21]). The distribution of the questions with one, two, three, and four correct option(s) stored into MCQs bank is presented in Table I.

TABLE I.
QUESTIONS DISTRIBUTION IN MCQS BANK

Question with … correct option(s)	Academic year				Total
	2005-2006		2006-2007		
	f_a	f_r [95% CI]	f_a	f_r [95% CI]	f_a
One	237	65.29 [60.05-70.25]	183	45.19 [40.25-50.12]	420
Two	59	16.25 [12.67-20.66]	88	21.73 [17.78-26.17]	147
Three	38	10.47 [7.71-14.05]	78	19.26 [15.56-23.46]	116
Four	29	7.99 [55.10-11.29]	56	13.83 [10.62-17.53]	85
Total	363	100	405	100	768

f_a= absolute frequency; f_r = relative frequency; 95% CI = 95% confidence intervals

The range of days between evaluations, for the students that performed the evaluation at least twice, varied from zero (the student performed the second evaluation in the same day) to 20 days for 2005-2006 academic year, and from zero to four for 2006-2007 academic year.

Note that in both academic years the assessment period was of thirty days. In 2005-2006 academic year, the intervals between initial and final examination were less than 10 days (almost 90%).

The distributions of the number of evaluations expressed as absolute and relative frequencies and associated 95% confidence intervals are presented in Table II.

Analyzing the variables taken into consideration in calculation of the final mark revealed that there is a polynomial relationship between correct answers score (C_{ca}) and average time per correct answer ($C_{t\text{-}ca}$). The graphical representation of these relationships is presented in Fig. 1.

TABLE II.
THE NUMBER OF TESTS DISTRIBUTION

No. of tests	Academic year				Total
	2005-2006		2006-2007		
	f_a [95% CI]	f_r [95%CI]	f_a [95% CI]	f_r [95% CI]	
One	30 [24-34]	78.95 [63.23-89.40]	24 [19-27]	85.71 [67.98-96.30]	54
Two	5 [2-11]	13.16 [5.33-28.88]	2 [0-7]	7.14 [0.13-24.87]	7
Three	2 [0-7]	5.26 [0.07-18.35]	1 [0-5]	3.57 [0.13-17.73]	3
Four	1 [0-5]	2.63 [0.07-13.09]	1 [0-5]	3.57 [0.13-17.73]	2
Total	38	100	28	100	66

f_a= absolute frequency; f_r = relative frequency; 95% CI = 95% confidence intervals

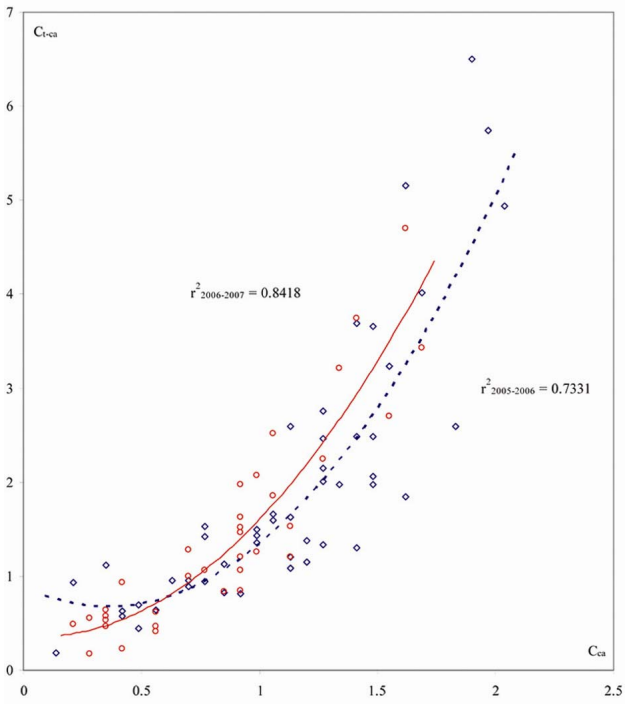

Fig. 1. Correct answer score versus average time per correct answer.

Following the specification of the e-assessment system, when was applicable, the less performing test (taking into account the correct answers score and/or the average time per correct answer) had not been took into consideration when the final mark was computed. Statistical characteristics of the evaluations included in computing of the final mark, express as correct answers score (C_{ca}) and average time per correct answer ($C_{t\text{-}ca}$), were summarized in Table III.

Seven students out of sixty-six (10.60%) performed the evaluation by three times (6_dl, 6_di, 6_mm, 6_sr, 6_vm, 7_cc, and 7_th).

Three students out of sixty-six (4.55%) chose to test personal knowledge by four times (6_sc, 6_pr, and 7_di) and two out of sixty-six by five times (6_po, and 7_po). The less performing test in terms of correct answers score and/or average time per correct answer was withdrawn. The distributions of the evaluation points given by these students are presented in Fig. 2.

TABLE III.
CORRECT ANSWERS SCORES AND AVERAGE TIME PER CORRECT ANSWER: STATISTICAL CHARACTERISTICS

Test	Year	C_{ca}/ $C_{t\text{-}ca}$	n_v	Mean	95%CI_m	Median	Min	Max	StDev
1	2006	C_{ca}	38	1.15	[0.99-1.31]	1.13	0.14	2.04	0.48
		$C_{t\text{-}ca}$		2.06	[1.56-2.56]	1.52	0.18	6.50	1.53
	2007	C_{ca}	28	0.90	[0.76-1.04]	0.92	0.28	1.69	0.37
		$C_{t\text{-}ca}$		1.47	[1.10-1.85]	1.24	0.17	3.74	0.97
2	2006	C_{ca}	8	1.03	[0.69-1.37]	1.17	0.21	1.41	0.40
		$C_{t\text{-}ca}$		1.59	[1.11-2.07]	1.48	0.89	2.49	0.57
	2007	C_{ca}	4	0.74	[0.00-1.68]	0.49	0.35	1.62	0.59
		$C_{t\text{-}ca}$		1.72	[0.00-4.89]	0.79	0.62	4.70	1.99
3	2006	C_{ca}	3	0.89	[0.00-2.35]	0.70	0.42	1.55	0.59
		$C_{t\text{-}ca}$		1.59	[0.00-5.16]	0.96	0.57	3.23	1.44
	2007	C_{ca}	2	0.49	[0.00-3.16]	0.49	0.28	0.70	0.30
		$C_{t\text{-}ca}$		0.92	[0.00-5.55]	0.92	0.55	1.28	0.52
All	2006	C_{ca}	50	1.12	[0.99-1.25]	1.13	0.14	2.04	0.47
		$C_{t\text{-}ca}$		1.96	[1.57-2.36]	1.52	0.18	6.50	1.39
	2007	C_{ca}	35	0.84	[0.70-0.98]	0.92	0.21	1.69	0.40
		$C_{t\text{-}ca}$		1.44	[1.07-1.81]	1.21	0.17	4.70	1.08

C_{ca} = correct answer score; $C_{t\text{-}ca}$= average time per correct answer;
n_v = valid sample size; 95%CI_m = 95% confidence intervals for mean;
StDev = standard deviation

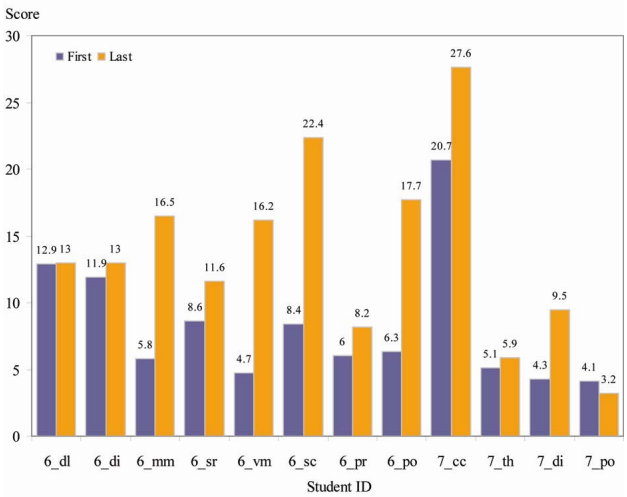

Fig. 2. Distribution of the evaluation scores for sample of students that performed the evaluation more than twice.

The character seven from the student's id inform us that the evaluation was performed on 2006-2007 academic

year while the character six inform us that the valuation was performed on 2005-2006 academic year. Descriptive statistics parameters of the correct answers scores (C_{ca}), average time per correct answer ($C_{t\text{-}ca}$) and of the evaluation points (P_e) for the sample of students that performed the test once or twice and for the sample of students that performed the test more than twice is summarized in Table IV. In Table IV were abbreviate with `i` the parameters obtained at the initial test and with `f` the parameters obtained at the final test.

Comparison of the average time per correct answer at the initial and final tests applied for the sample of students that performed the test more than two times revealed that the average time was significantly higher at the last (1.85) evaluation comparing with the first (1.00) evaluation ($p=0.0033$, $n_{valid}=12$).

The graphical representation of the average time per correct answer express as mean and 95% confidence intervals for the first evaluation and for the last evaluation applied overall is presented in Fig. 3.

TABLE IV.
PARAMETERS FOR CORRECT ANSWERS SCORE, AVERAGE TIME PER CORRECT ANSWER, AND EVALUATION SCORES: SINGLE OR TWICE VERSUS MORE THAN TWICE EVALUATIONS

Param	V_n	Mean	95%CI_m	Min	Max	StDev
One or two evaluations						
C_{ca}	54	1.12	[1.00-1.24]	0.14	2.04	0.44
$C_{t\text{-}ca}$		1.99	[1.61-2.37]	0.17	6.50	1.38
P_e		14.68	[12.60-16.77]	1.60	35.20	7.63
More than two evaluations						
$C_{ca\text{-}i}$	12	0.75	[0.48-0.92]	0.35	1.34	0.35
$C_{ca\text{-}f}$		1.05	[0.77-1.32]	0.21	1.62	0.43
$C_{t\text{-}ca\text{-}i}$		1.00	[0.51-1.49]	0.45	3.21	0.77
$C_{t\text{-}ca\text{-}f}$		1.85	[1.09-2.60]	0.49	4.70	1.19
$P_{e\text{-}i}$		8.23	[5.14-11.32]	4.10	20.70	4.86
$P_{e\text{-}f}$		13.73	[9.35-18.12]	3.20	27.60	6.90

C_{ca} = correct answer score; $C_{t\text{-}ca}$= average time per correct answer; P_e = evaluation points; Param = parameter; StDev = standard deviation

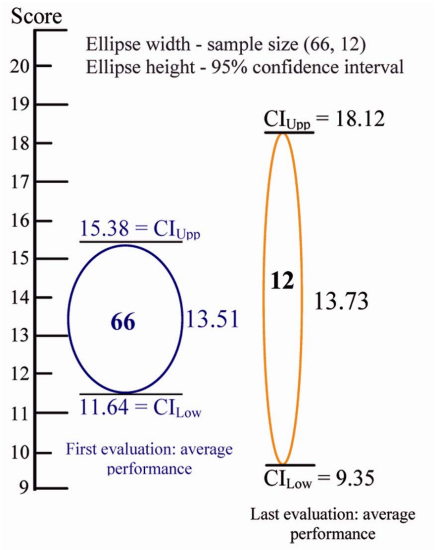

Fig. 3. Average time per correct answer at the first and last evaluation.

Comparing the evaluation scores obtained by students at the first and at the last evaluations (after withdrawn of the less performing test) it shown that the average of the testing scores were statistical significant higher at the last evaluation (13.73) comparing with the first evaluation (8.23) ($p=0.0039$, $n_{valid}=12$). The graphical representation of the evaluation scores express as mean and 95% confidence intervals for the first evaluation and for the final evaluation applied overall is presented in Fig.4.

Student t-test was applied in order to test the hypothesis that there is not a statistical difference between the parameters obtained by students that performed the test once or twice comparing with the students that performed the test more than twice. In this analysis, there were included the results of all tests for the students that performed more than two tests after withdrawing of the less performing test. The results are presented in Table V.

Student t-test was applied in order test the null hypothesis that values of scores and coefficients took into consideration on computing the final mark were not significant different for students that performed the test on 2005-2006 academic year comparing with those that performed the test on 2006-2007 academic year. The results are presented in Table VI.

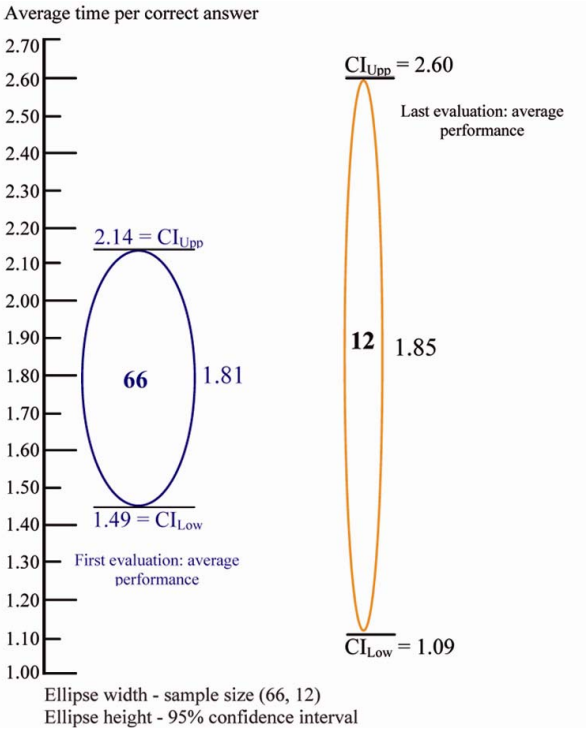

Fig. 4. Evaluation scores obtained by students at first and last evaluations.

TABLE V.
ONCE OR TWICE TESTS VERSUS MORE THAN TWICE TESTS: RESULTS OF COMPARISON

Param	1/2 Tests			≥ 2 Tests			t-value	df	p
	n_v	m	StDev	n_v	m	StDev			
2005-2006									
C_{ca}	30	1.26	0.47	20	0.90	0.39	2.85	48	$6.39 \cdot 10^{-3}$
$C_{t\text{-}ca}$	30	2.36	1.58	20	1.36	0.75	2.64	48	$1.13 \cdot 10^{-2}$
P_e	30	16.97	8.31	20	10.96	5.28	2.87	48	$6.08 \cdot 10^{-3}$
2006-2007									
C_{ca}	24	0.94	0.34	11	0.61	0.46	2.40	33	$2.23 \cdot 10^{-2}$
$C_{t\text{-}ca}$	24	1.52	0.92	11	1.26	1.39	0.66	33	$5.14 \cdot 10^{-1}$
P_e	24	11.82	5.63	11	8.67	7.98	1.34	33	$1.88 \cdot 10^{-1}$

C_{ca} = correct answer score; $C_{t\text{-}ca}$= average time per correct answer; P_e = points score
n_v = valid sample size; m = mean; StDev = standard deviation;
t-value = Student test parameter; df = degree of freedom; p = significance of the student test

TABLE VI.
2005-2006 VERSUS 2006-2007 ACADEMIC YEARS: RESULTS OF COMPARISON

Param	2005-2006			2006-2007			t-value	p-value	df
	n_v	m	StDev	n_v	m	StDev			
C_{ca}	50	1.12	0.47	35	0.84	0.40	2.85	$5.50 \cdot 10^{-3}$	83
$C_{t\text{-}ca}$	50	1.96	1.39	35	1.44	1.08	1.86	$6.59 \cdot 10^{-2}$	83
P_e	50	14.57	7.78	35	10.83	6.51	2.33	$2.25 \cdot 10^{-2}$	83
M_{test}	38	15.75	7.84	28	11.57	6.11	2.34	$2.23 \cdot 10^{-2}$	64

C_{ca} = correct answer score; $C_{t\text{-}ca}$= average time per correct answer; P_e = points score; M_{test} = mean of tests points; n_v = valid sample size; m = mean; StDev = standard deviation; t-value = Student test parameter; p = significance of the student test; df = degree of freedom;

IV. DISCUSSION

The evaluation of the students' knowledge is an obligatory task at the end of a course for undergraduate students. According with speed, accuracy, objectiveness and fairness [29], testing methods with multiple-choice questions are frequently used [30,31]. The presented study revealed that the proposed assessment system on microbiology and toxicology is efficient and effective, the aim of the research being reached.

The majority of students performed the test once or twice (see Table II.). A simple observation shown that the students that performed the test on 2005-2006 academic year had a large range between first and last evaluations comparing with the ones from 2006-2007 academic year. This could be explained by the interest accorded to microbiology and toxicology topic and/or the students' abilities to work with the e-assessment environment. Generally, the average of correct answers score obtained by students that performed the test on 2005-2006 academic year was greater comparing with the average obtained by students that performed the test on 2006-2007 academic year. The differences vary from 0.4 (for students that performed three tests) to 0.25 (for students that performed one test) (see Table III.). Regarding the average time per correct answer, the differences vary from -0.13 (for students that performed two tests) to 0.67 (for student that performed three tests) (see Table III.). As it can be observed from the Fig. 1., there is a strong polynomial relationships between correct answers score and average time per correct answer, showing that, as the average time per correct answer increased the higher the correct answer scores was. As it was expected, with one exception (for the student 7_po), the scores were increasing with the number of tests gave. The differences vary from 0.10 points (6_dl) to 14 points (6_sc). Four students out of twelve obtained at the final test an evaluation points greater with ten points comparing with first test (6_mm, 6_vm, 6_sc, and 6_po, see Fig. 2.). As the number of evaluations increases, the average time per correct answer increase too, students realizing that the speed is not as important as giving the correct answer (see results of average time per correct answer comparison between first and last test). Looking at the graphical representation of the average time per correct answer scores at first and last tests it can be observed that the upper and lower boundaries are closer tot each other at first evaluation while are far away at the final evaluation. The same observation could be seen for the evaluation scores too (see also Fig. 4). All these observations shown that the students realized that they need to read more carefully the questions and associated option(s) in order to make de correct chooses.

The comparison of the performances of students that performed the test on 2005-2007 academic year revealed that the average mean of the correct answers score was significant greater for students that performed the test once or twice comparing with students which performed the test more than twice (see Table V.). The same observation can be made for average time per correct answers score and evaluation scores. These results could be explained by the students' interest accorded to microbiology and toxicology course, those of them who were not interested presented to the first test hoping to cheat. The same phenomena could not be observed for the students that performed the tests on 2006-2007 academic year. For the students that performed the tests on 2006-2007 academic year, a significant differences could be observed just for the correct answers score, where the students that performed the test more than twice obtained a less score (see Table V). The comparison of the parameters obtained by students that performed the test on microbiology and toxicology on 2005-2006 academic year with those that performed the test on 2006-2007 academic year shown that significant differences are obtained for correct answer scores, average time per correct answer, and the test mean (see Table VI.). An overall analyzes of the questions and of the tests' difficulties are necessary in order to interpret these differences.

The research had some limitations. First limitation refers the absence of a control group, for example a group of students that to performed a paper-based test. We did not choose to split the students into two groups; there was considered that because of small number of students on each academic year splitting the sample in two samples is not a reliable solution. The second limitation refers the absence of the questions analysis in terms of: (1) coverage area; (2) question type; (3) difficulty levels (how difficult the question or the test was); (4) discrimination (how well the question/test separates the students with good performance by those with poor performance); (5) guessing (how well students performed with no knowledge on microbiology and toxicology); (6) differential performance (can be identify any sub-groups regarding the obtained performances?). The above-specified parameters could provide important information useful in analysis of the appropriateness of the method, of the difficulties of the questions and test, allowing improvement of the e-assessment system. The next step for our system development includes this analysis.

As any other computer-assessment methods, the proposed auto-calibrated online system had its advantages over traditional assessment (paper-based evaluation). From educational point of view, the main advantage is represented by the active implication of students in creation of MCQs bank. This activity motivates students to ask questions and to find answers, involving them into an active e learning and a real interaction with the teacher, processes useful in acquiring knowledge on microbiology and toxicology. According with the every test evaluation time, the proposed system provide an instant feedback to

students, displaying the correct answers score, the number of correct answers and the average time per correct answer. From the assessment objectiveness point of view, the system is more reliable, providing the same results any time when the same test is evaluated (machine making scores is much more reliable comparing with human making). By taking into consideration the average time per correct answer, the system discourages cheating and collaborations between students. More, with a number of seven-hundred and sixty-eight questions in database, it is also discourage learning of questions and answers; it is easier to learn the whole material than just the questions. Note that the number of distinct test that can be generated by the system is of C_{768}^{30}, almost $8 \cdot 10^{53}$ distinct tests. From this point of view, the test difficulty could be am important factor of final mark, approach that will be study in future research. From the updating point of view, the system has a greater flexibility in terms of question updating, test generation, and computing the final mark methodology. From the financial point of view, the proposed e-assessment system is lower long-term costs. More, the system allows storing the examination information electronically. The system disadvantages could not be leaving out from the discussion. The assessment environment could be considered as a disadvantage of the system: every student in Romania is able to write a paper-based assessment but not all students had minimum computers skills. In order to withdraw this disadvantage, the students had the possibility to use the evaluation environment before the examination in order to familiarize with interface, modality of choosing the answer and of navigation. Thus, the students had also the possibility to assess their knowledge and to identify personal gaps.

V. Concluding Remarks

The proposed e-assessment system proved to offer a stable and valid evaluation environment on microbiology and toxicology. Students' performances in terms of correct answers score and of average time per correct answer scores revealed to be improved at final evaluation comparing with first evaluation when was applicable, showing an improvement in acquired microbiology and toxicology knowledge.

Assessments of the questions and/or test difficulties are necessary to be investigated in order to improve the e-assessment system, this being the aim of our future research.

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