COMPUTER-ASSISTED ASSESSMENT OF LEARNING OUTCOMES IN THE LABORATORY OF METROLOGY

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ABSTRACT

In the paper, didactic experience with broad and rapid continuous assessment of students' knowledge, skills and competencies in the Laboratory of Metrology, which is an example of utilisation of assessment for learning, is presented. A learning management system was designed for manage, tracking, reporting of learning program and assessing learning outcomes. It has ability to provide with immediate feedback, which is used by the students to identify their misconceptions. The computer-assisted assessment is implemented in the system using four methods: ABCD test, real time continuous assessment scattered throughout the 10 training tasks, summative assessment at the end of the training, and ranking all students from the course. The strategy of assessment is presented on the basis of theoretical background. The results of summative assessments that have been carried out during ten years of system exploitation are investigated to examine the efficiency of implemented strategy.

KEYWORDS

Strategy of assessment, engineering workspaces, active learning, CDIO Standards: 6, 8, 11

INTRODUCTION

Metrology plays important role in manufacturing process and requires professional engineering skills in order to apply it in industry. Not only knowledge but also practice, professional ethics, abilities and good habits are necessary to perform high quality measurements. In order to improve the teaching and support faculty in the Laboratory of Metrology of Department of Electronics, Telecommunications and Informatics at Gdańsk University of Technology, a learning management system was designed for manage, tracking, reporting of learning program and assessing learning outcomes.

The particular assessment strategy was thoroughly designed and implemented in the system. After ten years of system exploitation, analysis of education results was performed on the basis of a large amount of data.

The structure of the paper is as follows. Section II describes the learning management system. In Section III detailed learning outcomes for disciplinary knowledge as well as specific, detailed learning outcomes for personal and engineering skills, acquired from the laboratory training are considered. Section IV presents designed assessment strategy. In Section V the results of metrological education performed with the aid of the learning management system are summarized.

The paper relates mainly to [CDIO Standards, 2010], number 11 (Learning Assessment), but is connected also with Standards 6 (Engineering Workspaces), and 8 (Active Learning).

A LEARNING MANAGEMENT SYSTEM

A major challenge for educators is the development of an appropriate pedagogy to prepare students to meet their future vocational demands [Liao C.H. at al., 2013]. Laboratory of Metrology is a workspace that emphasizes hands-on learning in which students are directly engaged in their own learning in accordance with [CDIO Standards, 2010]. The laboratory is devoted to the first year students of engineering course and for many of them it is the first contact with metrology. To prepare students for the challenges they will face in their future working lives, it is necessary to equip students with an appropriate mix of skills, attitudes and competencies.

The learning management system was designed in 2003 [Kowalewski M. at al., 2003] for only one exercise in the Laboratory of Metrology. Its subject is *Digital multimeters and integrating analog to digital converters*. The system consists eight sets of basic measuring equipment: power supplies, oscilloscopes, signal generators Agilent 33120A, multimeters Agilent 34401A and Metex ME-21, and two types of analog to digital converters (ADC) connected with computers via interface bus. Active learning methods are used in the laboratory that engage students directly in thinking and problem solving activities based on experiments.

Laboratory exercise is decomposed into introductory test and 10 tasks. Six of them are obligatory and four are additional. Main part of training program includes the following tasks:

1. Voltage measurements using dual-slope integrating voltmeter.
2. Investigation of dual-slope ADC immunity to outside electromagnetic interference from 50 Hz sources.
3. Resistance measurement.
4. Current measurement.
5. Investigation of performance of dual-slope integrating ADC.
6. Investigation of performance of voltage to frequency ADC.

Non-obligatory part of training program includes some additional features found on digital multimeters: diode test, audible continuity test, measurement of capacitance. Additional part of training includes the following tasks:

7. Measurements of the diode forward voltage drop using forward biased diodes made of different kinds of semiconductor (Ge, Si, GaAs).
8. Identification of some discrete components (R, C, diode) in a "black box".
9. Consideration of program for data transfer from multimeter to PC.
10. Measurements of DC voltage in presence of noise and interferences, and statistical analysis of results.

Laboratory tasks, which are real-world problems, integrate technical and professional subject matter so that students see relationships between those areas. The tasks requires students to learn a variety of skills.

Instructions, schematic diagrams as well as wiring diagrams are displayed on the screen successively during students' work. Such an instructional practice has great didactic value in the laboratory.

The computer-assisted assessment is implemented in the system using four methods: multiple-choice test with automated marking, real time continuous assessment scattered throughout the training tasks, final assessment at the end of the training, and ranking all students from the course.

System assesses students' skills and competencies, allowing to see learning progress in real time. Numbers of scores are assigned to tasks taking into account difficulty level and the assessment strategy described further on. Many forms of students' false activities are monitored, for example: mistakes in measurement circuit arrangement, setting of incorrect measuring range or function of measuring equipment, setting desired value of physical quantity without precision, non-correct result of calculations, violation of measurement procedure. Students obtain detailed feedback about the learning process. Information about incorrectness of particular activity, during realization of training program, has form of short comments. Each activity, assessed as a false step, brakes the program and requires repetition. Questioned activity can be repeated many times but each unsuccessful attempt is penalized by scores deduction.

LEARNING OUTCOMES

After successfully completing the laboratory tasks students are expected to be able to:

1. Discuss the performance and applications of digital multimeter (DMM).
2. State typical performance specification for the measuring instrument.
3. Discuss the terminals and controls on the front panels of typical hand-held and bench-type DMMs.
4. Explain how a DMM operates during measurements of voltage, current and resistance.
5. Use the correct terminals and set the function switch correctly for the meter application desired.
6. Explain how digital meter ranges can be extended by the use of high-voltage probes, high-current probes and high-frequency probes.
7. Answer the question how select the range to achieve greatest accuracy of measurement.
8. Define and explain the types of errors that occur in digital measurements.
9. Use basic statistical methods for analyzing measurement errors.
10. Explain how analog-to-digital conversion is achieved, and discuss conversion accuracy and resolution.
11. Sketch the block diagram and waveforms for an ADC using a dual-slope integrator.
12. Discuss the advantages of the dual-slope ADC.
13. Expressing the values of various electrical quantities using SI units symbols and names, including prefix symbols and names for the various decimal multiples and submultiples of SI units, according to [Bureau International des Poids et Measures].
14. Use rules and style conventions for expressing values of quantities according to [Bureau International des Poids et Measures].
15. Expressing the measurement uncertainty in the value of a quantity according to [JCGM 100:2008].

Specific, detailed learning outcomes relevant for personal and professional skills, required from metrological point of view, are as follows:

1. Mapping schematic and wiring diagrams into real measuring circuit.
2. Ability to act in accordance with measuring procedure.
3. Setting desired value of signal with necessary precision.
4. Proper reading of measurement results.
5. Proper specification of a measurand (the most common students' mistake is the lack of differentiation between direct and alternating voltages during measurements).
6. Configure laboratory equipment in order to accomplish the objectives of a measuring task.
7. Stress management and perseverance.
8. Professional ethics.

The aforementioned learning outcomes are suited for computer-assisted assessment with the exception of professional ethics. This is a great disadvantage because importance of professional ethics in measurement has been appreciated since 3 500 years. Part of ancient Egyptian funereal text *The book of the dead* is an evidence "I have not added to the weight of the balance; nor have I made light the weight in the scales" [Wallis Budge E.A., 1895].

ASSESSMENT STRATEGY

Assessment is the planned and systematic process of gathering and interpreting evidence about learning [Isaacs T. at al., 2013]. Assessment should provide inclusive and trustworthy representation of student achievement. Assessment methods strongly influence the priorities and actions of the students [Anderson N. at al., 2012].

In this section the assessment strategy, implemented in the learning management system, is presented on the basis of theoretical background. The aim of the work done in the year 2003 [Kowalewski M. at al., 2003] was to design assessment in a way that makes didactic process more attractive, which motivates students to work more efficiently and increases learning outcomes. According to [McAlpine M., 2002] there are four points to consider when designing any assessment strategy: the purpose, the overall quality, the referencing of the assessment, and the construction quality of assessment items.

Assessment can be formative and summative, depending on the purpose for which it is designed. In the metrological laboratory both kinds of assessment are necessary, formative assessment to assist the learning process by providing feedback to the student, and summative assessment, that takes place at the end of an exercise, to make a summary judgement and to report achievement and progress. Providing feedback for direction and motivation purposes is known as "assessment for learning". Formative feedback can be used to drive student learning and activity towards the achievement of quality learning. It can help students to learn from their own mistakes. Most educationalists are proponents of formative assessment. Pupils learn more when they receive feedback about particular strengths and weaknesses of their work, along with advice on what they can do to improve [Gioka O., 2006]. Online assessments are an opportunity for more efficient teaching [Whitworth D.,E., Wright K., 2014]. Efficiency of feedback depends on its type and promptness. According to [Black P., Wiliam D., 1998] the feedback by comments only yields highest level of improvement, the feedback by grades and comments leads to medium improvement, feedback by grades only may lead to a decline in students' achievement. One of the possible reasons is that students may focus on scoring higher grades rather than knowing the subject [Isabwe G. M. N., at al., 2013]. To make this effect less strong, the feedback by comments and scores is used in the system but scores are revealed only after successful completion of a piece of job.

The assessment should be continuous and instant. Students obtain detailed feedback from the learning process, which provides them with an opportunity to take corrective action. Computer system can provide a powerful means of rapid continuous assessment. Instant feedback is often more educationally effective than when delivered after a delay, possibly of days or weeks, for human marking [Thelwall M., 2000]. Results of assessment of gradually completed tasks are stored, because in our case continuous assessment serves a dual purpose, both formative and summative.

The assessment should be formal. Formal assessment gives possibility of testing students' perseverance and ability of stress management. Motivational effects are also possible because ranking engenders the competitive spirit within students. Assessment is formalized in the system by inform students that the task that they are doing is for assessment purposes and exactly on how to fulfil the criteria and what must be done to receive a higher score.

In the metrological laboratory the learning is skill and competence-based, hence the assessment should be rather process driven, than a product driven. The system fulfils this requirement.

Owing to the limited duration time of exercises in the laboratory, the assessment should be convergent (each question has one correct answer). In the system, convergent assessment of student’s knowledge is performed in time limited to 15 min, using well designed short questions in multiple-choice test. Questions are randomly chosen, individually at each of eight laboratory stands in order to avoid cheating. Random-based test can have a number of major advantages over fixed assessments, including: increased lifespan, security and flexibility [Thelwall M., 2000].

The assessment should be valid (any assessment measures what it has been designed to measure). A necessary condition of validity is reliability. It means consistent results across many assessment attempts [Isaacs T. at al., 2013]. In the system, a well-defined rubric assures the validity and reliability of assessment.

The basis of the judgement is the referencing of an assessment. In our case two ways of referencing can be considered, criterion referencing and norm-related referencing. Criterion referencing is derived from an external set of standards for attitudes, behaviours, skills or particular knowledge [Isaacs T. at al., 2013]. Criteria refer to performance against learning objectives. The norm-related referencing is where learning is graded by judging each student's performance against that of larger group of students (peers) known as the normative group. The designed scoring system is both norm and criterion referenced. Student is required to pass all obligatory tasks but also an overall judgement of the quality of the work through aggregating scores is possible. Norm referencing enables to sort students across a range of abilities.

In the system negative marking is used. Each task has its own difficulty level determined by available scores. Student starts with a maximum number of scores and has scores deducted for wrong activity. The total number of scores available at the beginning is 1000, in particular 700 for the obligatory part of the training (six tasks) and 300 for the additional part (four tasks). Continuation of a task broken by student’s false activity is not possible without removing a mistake. So completion of the obligatory part of the training program guarantees that student has achieved the intended learning outcomes, irrespective of scores gained by formative assessment. The value of total scores informs about personal abilities. The lower output limit was set arbitrarily at the level of 350 scores.

Table 1. Rubric implemented in the computer-assisted assessment system

Category of students' activity	Criteria of students' false activity	Coefficients of scores deduction δ_j	
		First mistake	Following mistakes
Interpretation of instructions in measurement procedure	Incorrectness of reading of measurement result	0,2	0,2
	Violation of measurement procedure		
Configuration of measuring equipment	Incorrect function of measuring instrument in relation to specification of a measurand	0,2	0,2
	Incorrect measurement range		
	Wrong setting of integration time in multimeter		
	Incorrect shape, frequency or amplitude of waveform from generator		
	Wrong setting of auto/manual mode		
	Activate of not necessary additional function of measuring instrument	0,1	0,1
Carrying out experiments	Incorrect voltage of power supply	0,2	0,1
	Incorrect value of resistance decade box		
	Badly realized current measurement		
	Wrong frequency at the output of U/f converter		
	Measuring range overload		
	Badly realized time measurement		
Calculations	Error in calculation of resolution of voltmeter	0,2	0,2
	Error in calculation of reference current of ohmmeter		
	Error in calculation of internal resistance of ammeter		
	Error in determination of conversion coefficient of U/f converter		
Inference	Not all components in the “black box” are identified properly	0,2	0,2

The rubric implemented in the system (Tab. 1) outlines criteria of students' false activity that are grouped in five categories. Criteria are associated with coefficients of scores deduction. Coefficients indicate the weighting that has been determined for each criterion. Scores F_i gained in task $i = 1, 2, 3 \dots k$ are calculated using following equations

$$For \quad \sum_{j=1}^{m_i} \delta_j \geq 1 \qquad F_i = 0 \tag{1}$$

$$For \quad \sum_{j=1}^{m_i} \delta_j < 1 \qquad F_i = \left[\left(1 - \sum_{j=1}^{m_i} \delta_j \right) s_{\max i} \right] \tag{2}$$

where: k - total number of tasks, $s_{\max i}$ - maximum number of scores obtainable for task i, m_i - number of mistakes committed in task i, δ_j - coefficient of scores deduction with values from the range $< 0, 1 >$.

According to equation (1) succeeding mistakes committed in task i cause deduction of scores down to $F_i = 0$, or to the value between zero and the maximum number of scores obtainable for task i (Eq. 2).

The summative assessment is given by value of total scores S, calculated by aggregation of results of formative assessment

$$S = \sum_{i=1}^{k} F_i \quad (3)$$

A well constructed assessment should provide the high quality information needed and implement guide-lined strategy. There are two indicators of quality, difficulty of tasks, and adequate discrimination between strong and weak students. Recommended in [McAlpine M., 2002] difficulty level is 0,5. This means that the tasks should be neither too complex, nor too simple. Scoring system should be adjusted accordingly. Using statistical description, it gives average value of scores that is half of the scores available, so students are separated out as much as possible. For fulfilment the guide-lined strategy, coefficients for the second and following mistakes in the category “carrying out experiments” (Tab. 1) are shifted down a little in order to obtain the average value of total scores higher than 500.

RESULTS

An example of assessment results obtained by rather a weak student is presented in Tab. 2. In the third column of Tab. 2 the available scores are attributed to each task, according to the difficulty level. In the fourth column, the numbers of mistakes committed by the student are specified, which gives a profile of student's abilities. In the last column results of formative assessments, for each undertaken task, are presented.

Table 2. Example of formative and summative assessments obtained by a weak student

Task number	Undertaken task	Scores available $s_{\max i}$	Number of committed mistakes m_i	Formative assessment F_i
1	Y	140	3	56
2	Y	120	4	24
3	Y	80	0	80
4	Y	80	5	8
5	Y	140	1	112
6	Y	140	2	84
7	Y	80	1	64
8	Y	120	3	48
9	N	20	0	0
10	N	80	0	0
Total	8	1000	19	S = 476

The advantage of continuous assessment is seen at the final stage when the summative assessment is based on evidence gathered over the span of the learning period. Summative assessment S is presented in the last row of the fifth column of Tab. 2.

The results of metrological education performed with the aid of presented learning management system are summarized in the histogram (Fig. 1). Analysis is based on a large amount of data that have been carried out during ten years of system exploitation. The asymmetrical shape of histogram confirms fulfilment of guide-lined strategy. The average value of scores is 661. It is not half of the scores available, so the students are not optimally separated but, according to the implemented strategy, the psychological effect of despondency owing to "high crossbar" within main group of students is removed. In spite of this it is seen that the designed assessment very well differentiates between the best and the worst students, the 9% of those who achieved number of scores greater than 900, and the fraction of 5% students, with the number of scores less than 350.

The 48% of students had enough time for realization of additional tasks and achieved number of scores greater than 700. So, the duration time of laboratory session (2 h 45 min) is optimal and it is not necessary to extend it in order to obtain greater fraction of the best results.

From the students' perspective the learning management system is very well evaluated. They put forward attractiveness, facilities and didactic advantages of the system. Students were asked to write a critique at the end of semester. Many of students were positive towards computer-assisted assessment. Negative remarks in the students' personal comments concern severity of the assessment, contrasting with instructors' approach. But this impression was the result of defeat experienced during the first task, by those, who didn't read the instruction thoroughly.

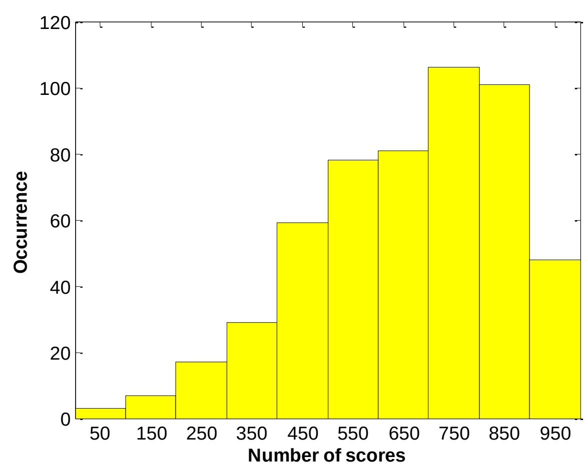

Figure 1. Histogram of summative assessments of 528 students at the end of the training that have been carried out during ten years of the learning management system exploitation

CONCLUSIONS

The Laboratory of Metrology is well suitable for implementation of a learning management system. Modern electronic test and measuring instruments are equipped with interfaces (USB, IEEE-488, RS-232) that can integrate several instruments together with a computer. The multitude of commercially available, user friendly software packages allow to design a system without going through a rigorous process. Many families of instruments are high performance sophisticated microcomputer systems which offer for users a plethora of functions and measuring possibilities. It is easy to create training programs in such rich laboratory environment.

The learning management system is based on monitoring of students' knowledge, activity and competence. It enables the direct, systematic observation of an actual students' performance. Well-defined scoring system provides for objective and consistent assessment, which is an integral part of the didactic process. System works as a formative assessment tool for students. It provides very effective instant feedback, that is not realizable by instructor in a laboratory arranged for large group of students and monitors students' progress. With such a formative and constructive feedback, didactic process proceeds more intensive and more emotional.

As a result of system implementation some positive psychological effects appear: strong justification to make up a deficiency of scores, better concentration on tasks, competition between students, sometimes like in sport disciplines. System promotes a positive attitude to the learning, all participants undertake non-obligatory tasks whereas in other exercises, which are realized without computer-assisted assessment, additional tasks are ignored.

The statistical results confirmed that the implemented in the system assessment strategy has been functioning effectively and in accordance with guidelines. The results show that the learning management system gives possibility of efficiently implementing desired strategy of assessment.

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BIOGRAPHICAL INFORMATION

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