Laboratory Works Designed for Developing Student Motivation in Computer Architecture

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Abstract – **In light of the current difficulties related to maintaining the students' interest and to stimulate their motivation for learning, the authors have developed a range of new laboratory exercises intended for first-year students in Computer Science as well as for engineering students after completion of at least one course in computers. The educational goal of the herein proposed laboratory exercises is to enhance the students' motivation and creative thinking by organizing a relaxed yet competitive learning environment. The authors have developed a device including LEDs and switches, which is connected to a computer. By using assembly language, commands can be issued to flash several LEDs and read the states of the switches. The effectiveness of this idea was confirmed by a statistical study.**

Keywords – **Motivation, creativity, engineering education, assembly language.**

1. Introduction

Over the last years, a continuous decrease of student motivation for learning can be observed worldwide. This decrease was signaled in Brazil by [1]. Likewise, in [2] it is emphasized that, over the last few years, more and more students have continued to abandon the Computer Programming course, only a small percentage completing the course. The paper [2] proposes to enhance the students' feedback mechanism in order to identify some corrective methods. In [3] it is argued that, on average, 32.2%

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of the ICT (Information and Communication Technology) students in Estonia dropped out during the first study-year, considering the lack of motivation to be one of the main reasons for this situation. The reasons for engineering study dropouts are analyzed in [4] and [5] from several points of view.

The graduate's competences may not be appropriate, without having a strong study motivation. In assessing the quality of engineering education, an important issue is related to the integration of the graduates into the labor market [6]. According to [7], "three quarters of new graduates were unsuitable for employment because of skill deficiencies in creativity, problem solving and independent and critical thinking". It was also asserted that a continuing stimulation of creativity and motivation appears necessary.

Various methods [8] were applied to increase student motivation and their involvement in the didactical activity. One of the applied methods based on PBL (Project Based Learning) is described in [9]. Some authors [7] propose that students imagine solutions, which can be verified during laboratory sessions. In [10], are presented some positive results obtained after introducing PBL to the common subject of Electrical and Energy Systems. Several universities, which have established a common first study year for all engineering specialties, found out that large classes of students may generate negative effects in terms of individual motivation. The emphasis laid on the development of problem-solving skills, during laboratory activities, is intended to eliminate such negative effects.

The European Higher Education Area (EHEA) helps to promote a student-centered education in Europe. One of these European initiatives presented in [11], wherein an active learning method is applied to a Microprocessors course, aims to allow students a higher degree of autonomy and responsibility through work group. In order to keep the students' attention at the highest possible level, one author suggests sending messages relating to the studied content during class hours [12]. Attracting students in Computer Architecture concepts and Programming

Basics in a creative and enjoyable way is an issue described in many papers [5, 13, 14, 15, 16, 17].
One of the objectives pursued in the field of computer engineering education at Transylvania University of Brasov (România) is aimed at familiarizing the students with the concept of Embedded Systems already during the second study year. In [18], a spiral educational method is proposed, wherein the discipline of Embedded Systems is approached through PBL. To enhance the students' level of motivation, [18] proposes several attractive activities with rapidly attainable outcomes. PBL is also applied in Microprocessors courses in [19]. According to [19], students are constructing an Embedded System around a microcontroller. Functional testing is ensured through 8 LEDs connected to one of the microcontroller's ports.

In order to increase the students' interest and stimulate their motivation for learning, the authors of this paper have developed several laboratory exercises intended for the students from different academic study programmes (e.g. Applied Electronics, Telecommunications and Computers, offered by the Faculty of Electrical Engineering and Computer Science), as well as for engineering students (e.g. Applied Informatics in Materials Engineering) that pursue at least one course in Computers. For the students from the Faculty of Electrical Engineering and Computer Science, the first courses covering the area of computer architecture (e.g., Computer Architecture intended for students from Applied Electronics) include practical lab activities, which provide a descriptive presentation of computer structures. For the students in other engineering fields of study (e.g., Applied Informatics in Materials Engineering, Faculty of Materials Science and Engineering), the only course which provides information about computer structures is Computers. For this course, the laboratory activity consists of exercises in the field of operating systems. The significant lack of interest in this case, was attributed to the students' low motivation, determined by their passive participation in practical lab activities, in association with their different levels of pre-existing knowledge. Obviously, after completing this laboratory, the students' understanding of computer structures failed to improve.

Consequently, a different approach along two directions was adopted: firstly to stimulate student motivation; and secondly, to create a learning environment that would improve student understanding of basic computer concepts, such as the relationship between hardware and software. Because high school curricula include the study of different programming languages, the proposed applications were designed to use assembly language as a common "standard" during lab sessions. Assembler software assures an equitable start for all students in understanding newly introduced concepts. Therefore, assembler language proved to be suitable for simple applications, such as port sending and reading. Some aspects regarding lack of motivation in electrical engineering were investigated in [20] by analyzing the role of competition as a factor stimulating motivation. However, competition may cause the emergence of negative emotions, and [20] draws attention to this danger. Some positive aspects of competition are presented in [21]. The authors describe in [21] programming knowledge improvement through students' participation in a contest of robots since their first year of study. The use of assembly software has been applied in an activity described in [22], highlighting the benefits of educational records. Using the Linux operating system reduces laboratory setup costs.

A method based on the authors' initial concept of developing creative thinking skills in Electrical Engineering, using laboratory exercises, is described in [23]. All of the proposed lab exercises include visual elements (LEDs) or moving elements (motors). Familiarizing students with computer concepts started with the study of bit-level operations. One year later, this gradual approach proved its effectiveness by allowing the students attending the course in Embedded Systems, to start from a higher level of knowledge. Introducing the range of enhanced laboratory exercises significantly increased the students' motivation, which was illustrated by the large number of the students' requests for remote lab access and/or additional support. Moreover, some of the students even asked for the specifications and diagrams of the laboratory kit, being keenly interested in constructing their own model at home. All the documentation was available to students by using the course site and one LED module is remotely accessed accordingly to the MOOC (Massive Open Online Courses) principles [24].

2. Description of the laboratory works

The educational goal of the herein proposed laboratory exercises is to develop the students' creative skills and divergent thinking. "An important component of creativity is divergent thinking, which involves the ability to generate novel and useful problem solutions." [25].

At the end of every laboratory session, bonus points are given to those students who reach the desired result faster than their fellows, and likewise, in other types of sessions, to those who create the most spectacular visual effects. Practical laboratory activity offers students a high degree of independence and freedom. Topics are formulated in advance so that students can work at home to get better results and bonus points. To some extent, this activity can be considered similar to PBL.

For these laboratory exercises, the authors have developed a device including LEDs and switches, which can be connected to the parallel port of a PC. By using simple software resources, commands can be issued to flash several LEDs and read the states of the switches.

During their approach, the authors were confronted with difficulties while trying to make students truly understand the intimate structure of a computer's CPU as well as the importance of binary-to-hexadecimal conversions. Furthermore, students found that the notion of registers was difficult to understand since it was perceived as an abstract notion and therefore its importance was minimized. Another striking example of a partially understood concept is the fact that, although the students knew the importance of computer operating speed, they appear to be uncertain about the effects produced by this speed before commanding the LEDs.

The proposed device and the software

The parallel PC interface includes 2 output ports, one for the data (address 0378H) and another for control (address 037AH) along with an input port (address 0379H). This interface was devised for connecting a parallel interface printer LPT (Line Printer Terminal). The developed module has 8 LEDs connected to the data output port and 5 switches connected to the state port. In order to design, run and debug an assembly program, symbolic debuggers were utilized. The device was successfully tested under Windows 7, 8 and Linux. For computers lacking a parallel interface, USB-to-parallel converters were used.

The experimental procedures

The first laboratory session includes a revision of the theory relating to the conversion of numbers represented in bases 10, 2, and 16, as well as the operation of a CPU with a focus on registers, I/O ports, and instructions in assembly language for microprocessors of the x86 family. Debugger software is also presented, which can be used to run simple, short applications. The advantage of using a debugger program instead of an assembler is illustrated by the fact that, by running it step-by-step, the program allows the students to observe the content of every register, as well as the changes in the IP (Instruction Pointer) register, during a jump and to ascertain whether the program behaves as expected.

After the second lab session, every student is expected to be able to write a program for flashing the LEDs in accord with a freely chosen sequence, which is required to be as pleasing as possible to the viewer's eye. The program is then run step-by-step and the sequence is analyzed. The first student who finishes and the student who creates the most "eye-pleasing" sequence, as confirmed by the votes of the other fellow students, will receive bonuses. In the final part of the laboratory work, the program is looped and, due to the increased running speed, the human eye is tricked into seeing continuously illuminated LEDs. The students are then expected to provide an explanation with regard to this phenomenon until the next lab session.

The third session requires the students to formulate a response to the question asked in the previous session. The student who provides the correct explanation gets a bonus. If the students fail to come up with an explanation, the teacher will explain the phenomenon. A software delay loop was proposed to be introduced, and was created by using a subprogram/ subroutine, wherein the processor decrements several registers. The length of the delay is adjusted over repeated trials, so that the blinking of the LEDs becomes visible. During the 4th and possibly the 5th and 6th lab sessions, the students should develop their own dynamic LED flashing program using an "attractive" sequence. From this moment on, some students are beginning to obtain results faster, while others will continue working at a slower pace. The teacher should reorganize the groups accordingly, and even supervise individual students in order to prevent apathy or lack of interest in faster working students, while simultaneously encouraging their slower fellows to carry on with their work. A suitable assignment for students who reach results faster than their fellows would be to develop programs with flashing sequences of different lengths. At this point, the notion of a subprogram is introduced, and the advantages of using subprograms are presented. Different solutions for variable delays are suggested (e.g., the repeated call of a delay subprogram). The next laboratory session is dedicated to reading the switches and developing a program to be run step-by-step so that the LEDs will flash in a given sequence that can be altered if any switch is pressed. Next, two different dynamic sequences are selected that can be alternated by pressing a switch.

Generally, it can be ascertained that during this stage the differences between students become more pertinent, and therefore activities based on work groups should be extended. Additional requirements are then imposed such that the dynamic flashing sequence is changed, not by pressing any switch, but by pressing a particular switch as indicated by the teacher. An important step in this lab session is to identify the pressed switch before running the program that flashes the LEDs. The identification is made using a reading sequence of the input port of the switches and examining the accumulator register AX.

The next laboratory exercise requires the students to achieve a dynamic sequence (sequence 1) which should change after pressing a particular switch during sequence 2, and to change once again after pressing another switch during sequence 3.

During the subsequent laboratory session the students are assigned a task which requires a higher level of creative thinking. It consists of flashing the LEDs during the dynamic sequence 1, then change to sequence 2 by briefly pressing any switch and finally enter sequence 3 after a long press. Usually, only the best and most inventive students are capable of successfully completing this particular task.

One last aspect approached in this range of lab exercises, which may extend over one or more lab sessions, concerns the problem of issuing adequate commands to reduce LED brightness. Since the original commands only considered on/off states, at first, the students seem unable to find any way of solving this problem. So, they are reminded about the second session wherein, during a non-delayed sequence, a decrease in LED brightness could be observed. At this point, the notion of PWM (Pulse Width Modulation) will be introduced. This lab session is aimed at flashing some of the LEDs at maximum brightness while the remaining LEDs will operate at a lower brightness level. This task is a relatively simple one. The students are asked to think about how to develop a program that gradually increases LED brightness. Mobile phones with similar features are used to motivate the students. Usually, this task cannot be completed within a normal session's time and is assigned as homework. However, in several cases, exceptional students were able to solve the problem during the normal laboratory time. During the last laboratory session the students were given the opportunity to develop an original application and the best application received a bonus at the end of the session. The variety of possible applications is very broad and the most creative students always succeed to devise an original program. For example, one student created a program in which the LED flashing sequence was dependent on the number of times the switch was pressed. This program was inspired by the mobile phone keypad used I text messaging mode. The range of practical exercises ends with a laboratory test wherein the students randomly pick a question paper with the task they have to solve. The question paper asks the students to design a program consisting of 3 dynamic sequences and to provide the possibility of changing between individual sequences by pressing 2 switches. The scores depend on how much of this program has been completed before the end of the laboratory session, as follows: dynamic sequences – 5 points, change of sequence when one switch is pressed – 7 points, change of sequence when both switches are pressed – 10 points (highest score).

The developed laboratory exercises are based on aspects with which students come across in everyday life while using different electronic appliances. This type of approach was intended to increase the students' interest for developing and testing original programs. It was also specified that the students must devise a flowchart before writing the program. One particular program, which has drawn the attention of the students, changes sequence 1 into sequence 3 when the switch is briefly pressed, or into sequence 2 after a long press on the switch, according to the flowchart in Figure 1.

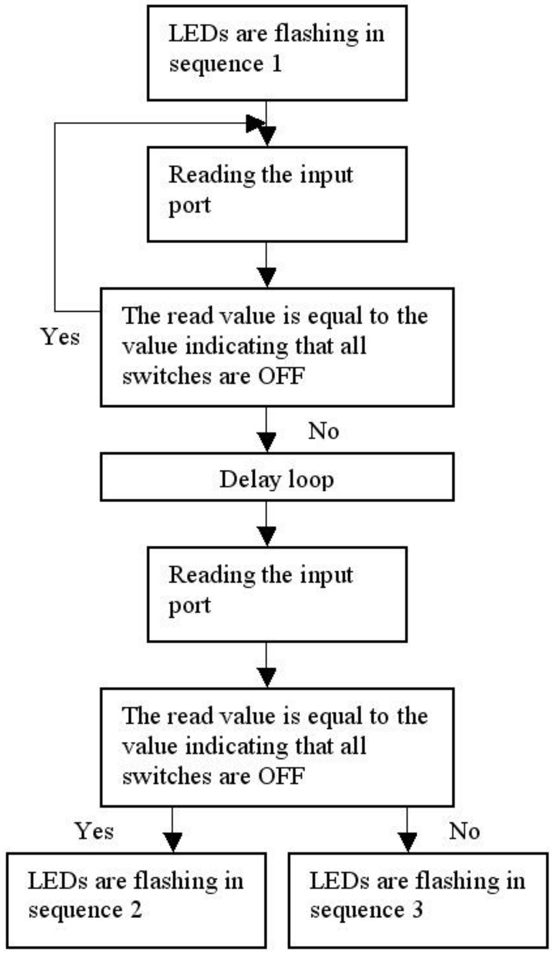

Figure 1. Program Flowchart

Several students asked for advice, in attempting to design more complex programs, for example, a program allowing a gradual increase of the LEDs' brightness. These students were advised to use high-level programming languages (e.g., C language).

3. Evaluation

In recent times there were supported two modern directions in academic education: one involving Distance Learning [2], [3] and another regard PrBL/PjBL(Project Based Learning) [4], the acquired expertise being applied to select the most adequate method for students' training.

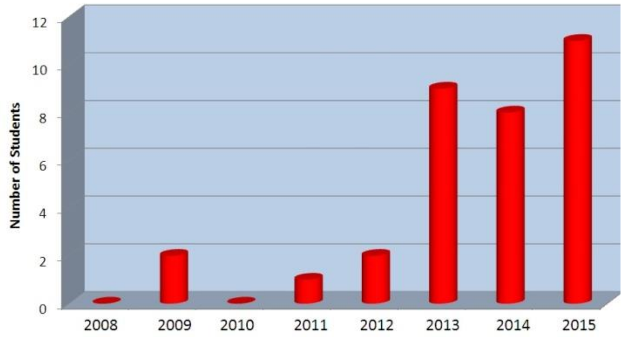

Figure 2. Number of interested students

In 2012, the method proposed herein was introduced, for the first time, in the *Computers* laboratory of the Faculty of Materials Science and Engineering. According to Figure 2., for the first time in academic year 2013-2014, a significant number of students showed interest in practical laboratory work, many asking for teacher advice and support for personal applications. This increase in motivation determined the need to receive relevant student feedback throughout 2013-2014, 2014-2015 and 2015-2016 academic years.

The following two hypotheses were formulated:

1. Using the LED device in the laboratory should increase the level of student satisfaction;
2. The students' satisfaction level, in terms of laboratory layout and applied methods directly correlates with the level of academic performance.

One of the research methods was based on a semi-structured, survey - focused interview. The purpose of this method is to identify the level of student understanding about the use of programming techniques during laboratory sessions, their perceptions on the novelty of the employed method, and to encourage students to hierarchize the different issues according to their importance. The interview was a standardized one based on an interview guide, and includes the following questions:

1. How much of this laboratory is identical with other laboratories?

2. How difficult was it to understand programming during the lab sessions?

3. How clear were the aim of this activity and the working techniques employed?

4. What was the satisfaction level while watching the LEDs flashing?

5. What new and important notions have you learned in this laboratory?

Another research method was focused on quasi-experiment or pre-experiment, since the authors were unable to measure the level of perceived satisfaction before the experiment.

The third research method was intended for document analysis, collecting and analyzing learning performance data from faculty documents such as transcripts of records, summary reports of the received bonuses, and attendance lists.

The research conducted between October 2013 and May 2016 (2013-2014, 2014-2015 and 2015-2016 academic years), included a total of 46 1^{st} year students, from Applied Informatics in Materials Engineering, Faculty of Materials Science and Engineering. Of the total number of students, aged between 20 and 24, 17 were female and 29 male.

The first question invites the students to evaluate their satisfaction level on a scale from 1 to 5; 1 – unsatisfied, 5 – extremely satisfied. With regard to the main purpose, in terms of identifying the declared learning satisfaction level, the results show a considerable amount of overall satisfaction, which is a relevant indicator of the correlating phenomena. The satisfaction level ranges between a minimum of 3 and a maximum of 5, with an average value of 4.6. As can be seen in Figure 3., a significant number of respondents (43 students of a total of 46) expressed high or above average levels of satisfaction, which confirms hypothesis 1.

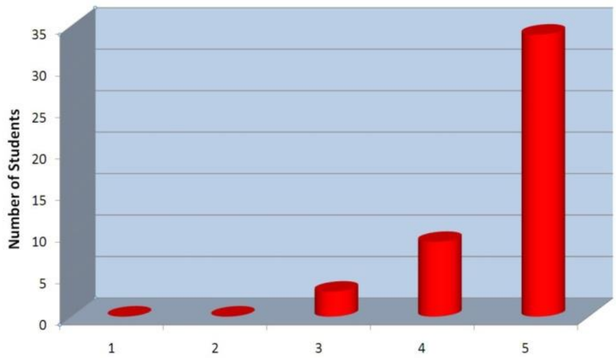

Figure 3. Number of satisfied students

The extent to which students appreciate the clarity of the goals and the way of conducting laboratory activities, can be seen in Figure 4. (S1): 25 students (54.4% of the participants) considered the activities to be very clear, 12 students found it clear, 6 relatively clear. A number of 3 students found that the activities are unsatisfactory. Consequently, 80.4% of the students deem laboratory work to be explicit and clear, in terms of laboratory aims and the way of conducting lab activities.

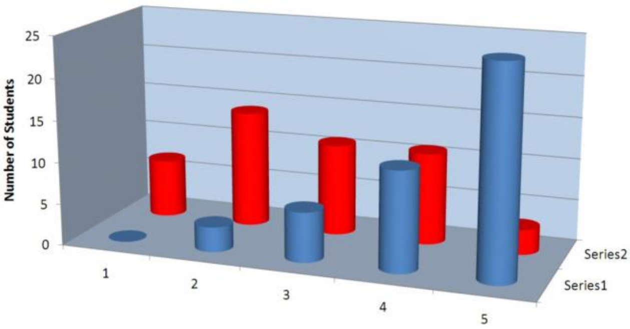

Figure 4. Number of students which appreciate the clarity of the laboratory goals and the number of the students evaluating the difficulty of the lab

With regard to the difficulty of understanding the programming activity, the percent distribution of the respondents showed some interesting results, Figure 4 (S2). Thus, only a percentage of 6.5% of the students (3 students) rated the assigned tasks as having a low difficulty level, 47.8% (22 students) considered a moderate level of difficulty and 45,6% (21 students) considered the tasks to be difficult. It can be assumed that these results illustrate a successful pedagogical intervention, since the students, far from being discouraged by the higher level of difficulty, were actually even more interested in this lab activity obtaining better results and declaring a level of satisfaction above the researchers' expectations.

To the question: "*Which of the learned aspects are new to you?*" the response options were:

1. *LED sequencing software (Fig.5., Series 1);*
2. *The importance of loop delay (Fig.5., Series 2);*
3. *Possibility to read switches (Fig.5., Series 3);*
4. *Understanding the notion of registers (Fig.5., Series 4).*

As it may be seen on the chart (Fig.5), the students from three graduating years (2013-2014, 2014-2015 and 2015-2016) have different views on the novelty of tasks. From one graduating year to the next, the students seem to become a little more familiar with the proposed tasks, yet no relevant trend could be identified. The number of students regarding "at least one aspect as new" decreased from 37 in 2013-2014, to 23 in 2014-2015, then again increased to 28, in 2015-2016.

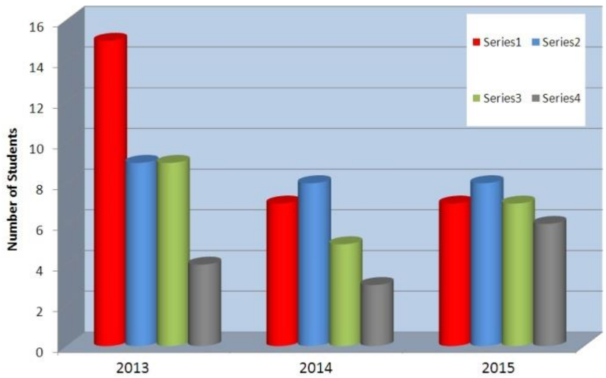

Figure 5. Number of students who appreciate the novelty of the laboratory tasks

Obtaining student feedback about the novelty and importance of the different issues related with the proposed laboratory exercises is intended for better teacher information. Consequently, the teacher has the possibility to reconfigure her/his explanations in accord with the students' previous knowledge, and the perceptions they have about the importance of the envisaged aspects.

The evolution of academic performance following the introduction of these laboratory exercises was assessed by calculating the students' average marks after the final exam. To increase the relevance of the final scores, the final average marks were calculated by considering the marks obtained for the answers to the following questions:

1. *'Define the CPU registers and their functions'*
2. *'Define the IP (Instruction Pointer) and his functions'*
3. *'CPU Speed versus the speed of Input/output Peripherals'.*

The average mark variation between 2008-2009 and 2015-2016 academic years is shown in Figure 6.

Comparing the students' average marks obtained after completing the training in the new laboratories (the average mark in 2013-2014, 2014-2015 and 2015-2016 academic years was 8.75) with the average marks obtained after completing traditional lab classes (with an average mark of 6.07) confirms the increase of students' satisfaction, which is in direct correlation with the level of academic performance in terms of laboratory layout and applied methods.

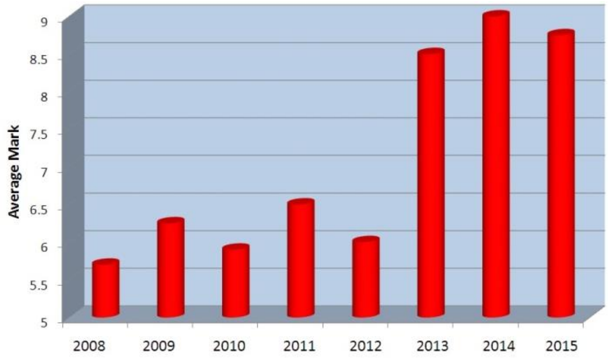

Figure 6. The average mark variation

A further research could be relied to the introduction of mobile phones. Because students check several times their messages from social networks during classes, this can be considered an opportunity. A variant of the use of mobile phones is provided in [12], and a guide to using social media to enhance teaching and learning is presented in [26]. The authors intend to post some short movies including a blinking sequence devised by each student, with the possibility of selecting the most attractive sequence through vote.

Further future research could be aimed at the impact of a professional blog, where the flashing sequences could be submitted. Thus, the students would be able to contribute to the blog content by entering new experiences acquired during university study.

4. Conclusion

The authors have applied and monitored this way of working to three categories of youths:

1. First-year engineering students, for which the timetable of the laboratory activities was previously presented. These are lacking any programming experience and their feedback was obtained through interviews over three successive years.

2. Three or four-year students from different specialties at the Faculty of Electrical Engineering and Computer Science who pursued a course containing assembly language concepts. Their practical activity was condensed into only 3 laboratory sessions, yet allowed them to accomplish all the requested tasks. The activity continued with laboratory exercises about stepper motor drives, DC motor drives and USB interfacing.

3. A contest for assessing the programming abilities of the best high school students was also organized. At high school, students are taught different programming languages, yet assembly language is not studied. Therefore, it was considered that knowing this particular programming technique would ensure equal opportunities for all competitors. The contest included theoretical aspects presented by a teacher during 2 hours, followed by the actual contest extending over 4 hours. All competitors successfully completed their dynamic sequences, which could be changed by pressing two switches.

After completing the set of laboratory exercises, the students were supposed to have gained additional logical and algorithmic thinking capabilities, thus becoming more familiar with the working philosophy of a digital computer. The success of the method was confirmed by the fact that many students constructed their own device with LEDs by continuing their work at home. For those students who lacked opportunities to construct this model or have PCs without parallel ports, a workstation with Internet access equipped with the LED module and a remote controlled web cam was installed at the faculty.

The following are some advantages of this range of laboratory exercises:

1. Enhancing students' understanding of the close relationship between software and hardware, of the physical effects of running a program and hence to comprehend the role of a process computer, as well as the fact that a computer can do a lot more than just display images on a monitor;

2. Increasing students' satisfaction as they watch a simple program working to generate a dynamic flashing sequence, which stimulates their desire to further understand, study and achieve;

3. The originality and the attractiveness of the flashing sequence are rewarded accordingly. This creates a favorable climate encouraging student competition for gaining higher scores and also their fellow students' recognition. Notably, there are frequent cases when low scoring students get the most bonuses.

4. Students are familiarized with several currently widespread techniques, such as producing different effects when pressing the same switch, or using PWM commands. This concept of stimulated learning through visualization was applied to the subject of Embedded Systems attended by the students from Applied Electronics and Computers. E.g., when the students who are constructing microcontroller modules connect their LEDs to an 8-line port, using at least one of its lines, the LEDs will start flashing, thus marking the first step in testing the functionality of the module.

The statistics results were obtained after analyzing a relatively small student sample, because only a fraction of the class participated in the experiment. Due to the encouraging results obtained in the academic year 2013/2014, the initiative was extended in order to include all students from the specialties mentioned in the 'Introduction'.
Finally, the results of this of study will allow the improvement didactical activities, predicated on the premise that the student is our client and must therefore be motivated to pursue and complete university studies. It can be concluded that the

students' academic performances are directly linked with their creativity and motivation.

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