# Increasing Students' Interest by Encouraging them to Create Original Lab Projects

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***Abstract*** **– Sometimes traditional lab projects based on standard kits and modules fail to stimulate students' interest and creativity. This paper presents a novel laboratory concept which allows students to develop their own lab projects using open-source resources. The lab experiment includes competition aspects allowing every student to come up with ideas of which the best are selected. The lab projects include both hard and software components using Arduino-compatible systems and interfaces. Before starting the practical activities as well as after the completion of the lab session, the students were asked to fill in an anonymous questionnaire.**

***Keywords*** **– Engineering education, open-source, Arduino, creativity**

## 1. Introduction

Worldwide many universities experience increasing disinterest of engineering ICT students' especially at the beginning of the study period [1], due to various reasons [2]. In [3] the authors maintain that "student disengagement was conceptualized as a multi-faceted, complex yet fluid state that has a combination of behavioral, emotional and cognitive domains influenced by intrinsic (psychological factors, low motivation, inadequate preparation for higher education and unmet or unrealistic expectations) or extrinsic (competing demands, institutional structure and processes, teaching quality and online teaching and learning)"

In order to cope with ever increasing employer demands and the growing students' dropout rate the classical education paradigm needs to be changed. Two most important changes consider encouraging student creativity and increasing attractiveness of educational activities. Creativity is defined [4] by two necessary characteristics, the first one being originality and the second necessary characteristic is utility. Academic engineering education institutions responded to this challenge by introducing the concept of *gamification* [5].

Encouraging creativity and increasing attractiveness are assumed goals at the Faculty of Electrical Engineering and Computer Science of Brasov, Romania. Several actions were organized to increase student motivation including meetings with employers, student scientific conferences, professional contests. Educational processes especially laboratory activity [6,7] and distance learning [8] were also upgraded.

This paper presents one successful initiative regarding the replacement of the classical Computer Interfacing laboratory attended by Computer Engineering students with a PBL (Project-Based Learning) system in accord with the directions presented in [9]. The classical version of laboratory activity attended by 4$^{th}$ year graduate students, which was based on modules connected to the ports of a PC, failed to stimulate student creativity. To implement the improved laboratory version we opted for open-source resources in order to minimize costs.

Lately, applications based on open-source resources have become increasingly popular, especially in the field of education. One of the most popular open-source hardware – software combinations is Arduino [10]. The Arduino solution uses microcontroller-based development systems and software for various applications and is available to a large user community. Open-source solutions provide

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many advantages that will be examined in this paper, among which cost efficiency [11].

The novelty in developing this lab project set consisted in the fact that the content of the practical experiments were proposed by the students. Next, a contest of ideas was organized to select 4 most interesting ideas to be implemented. In the second phase were devised 4 groups of 4 students each in order to physically accomplish the proposed ideas using Arduino modules. In the final lab session the achievements were presented and tested. This novel lab procedure has established a competitive and at the same time collaborative environment which stimulates student imagination and creativity. The outcome was surprisingly favourable since many students adopted original ideas engendered by the lab projects and implemented them into their diploma dissertation.

## 2. State of the art – educational applications of Arduino systems

One of the first papers highlighting the importance of Arduino systems applications in education [12] appeared in 2011. The paper emphasizes the interest shown by the students using Arduino systems, their achievements but also the difficulties of assessing the students' original achievements, given the large number of open-source applications.

Ease of programming and the diversity of Arduino-compatible devices makes them useful for both beginner and advanced ICT students and even to those from other engineering specialties. Below are given several initiatives of introducing lab projects based on Arduino systems to beginner IT students:

- In [13] with the title "Building a Doorbell for Deaf People" the results show the interest of the students for this kind of projects. "Reported scores of 'agree' or 'strongly agree' Likert-scale options are 77%, 62%, 56%, and 76%, respectively, for 'Content', 'User Interface', 'Ease of Use' and 'Enthusiasm and Motivation' dimensions. "
- Introducing lab projects based on Arduino systems into the course in Introduction to Computer Engineering at the University of Mato Grosso do Sul, Brazil [14] has increased the attractiveness of the activity. Thus "After a statistical analysis and validation of the answers, 28% of the students have pointed out that the activities have been determinant to increase their motivation to study computer engineering. The impacts on students' motivation, since the first semester, have been observed in the students' evasion rate. The percentage of evasions in the computer engineering is less than with other engineering programs"
- The lab projects proposed in [15] are designed to encourage students to build a robot based on an Arduino system. The activity is subdivided into several steps including the digital outputs, the serial port, and the PWM port. In the next phase the Arduino board is interfaced with a LCD and wireless transmission modules.

The importance of programming knowledge in present-day technologies has spurred the introduction of Arduino-based lab projects to those engineering specialties which traditionally focused on the mere utilization of computer technology.

- For chemistry students in [16] is proposed a laboratory designed to provide programming skills using Arduino systems in chemical processes control. The paper maintains that "The implementation of such technology in training students can further assist the development of a range of complementary skills, which can readily be combined with chemistry-specific skills".
- For physics students from Goucher College Baltimore were introduced Arduino-based lab projects [17]. In this laboratory the students without any previous microcontroller or software knowledge can develop applications which stimulate motivation. Thus, "Several students began extending the projects beyond the requirements by the third week of the class".

Mechatronics, which is considered a multidisciplinary field, also responded to the trend of introducing Arduino systems for educational purposes:

- In [18] it is maintained that "It can be difficult to retain modern students in an engineering programme given their demand for instant gratification." The authors propose Arduino-based lab projects in Mechatronics for the Data acquisition course in very new and attractive field (Sonic Engineering). The initiative was a successful one; all students passed the exam.
- The Faculty of Engineering of Bangkok has developed a set of lab projects where students work in groups to build a plotter [19]. The plotter structure helps

understanding the concept of mechatronics as a combination of mechanical, electronic, control and computer systems. The electronic control module was implemented with Arduino systems.

Arduino development systems are used not only for beginner-level lab projects. Some Arduino-based applications, which are designed for final-year graduate students are presented below:

- At the University of Tsukuba, Life Science Center of TARA Japan, the students developed projects in the field of brain-computer interface using Arduino systems. The projects were granted the BCI Research Award 2014 [20].
- At the San Marcos University Lima, Peru, were developed Robotics and IoT (Internet of Things) lab projects using Arduino systems for the Research in Computer Science course, with good results [21].
- In [22] are proposed lab projects in the field of Embedded Systems using higher performance development systems (ARM microcontrollers) that are programmed at a higher level of abstraction. The lab projects are designed for IoT and robot control.

The popularity of Arduino systems and the availability of open-source information provide numerous opportunities of cooperation. In [23] starting with the premise "there is a widely noted gap between industry needs and the education that new engineers receive" is presented an initiative of collaboration between companies and universities wherein 250 projects were achieved in just 2 years, many of them using Arduino systems.

## 3. Performing the lab experiments

In the first lab session in Computer Interfacing the students were notified about the objectives of the laboratory, which consisted in the achievement of 4 lab projects using Arduino systems selected after a competition. The criteria used to select the lab projects involved conditions like interfacing possibilities, attractiveness, and feasibility of the practical experiment. During the second lab session every student proposed a lab project and after discussions 4 ideas were selected which the group considered to ensure optimum compliance with the selection criteria. The students that proposed the winner lab projects are appointed team leaders and can build their team in order to accomplish the lab project. Assessment of lab activity is based on marks derived from the points granted by the teacher to the team. In turn, the team leader distributes the obtained scores to each team member according to the contribution of the latter. This procedure was applied for the first time in the academic year 2016-2017 and the selected projects were:

1. Temperature measurement using a temperature sensor and PWM controlled dc fan motor in order to keep the temperature between 2 thresholds;
2. Connecting a 16–button keypad over the parallel ports and a LCD to indicate which key is depressed;
3. Connecting a tri-axial gyroscope and a tilt display using 4 LEDs connected to a parallel port;
4. Connecting an analogue joystick to the analogue-to-digital converter of the microcontroller displaying the position with LEDs.

Figure 1. presents the lab project with a tri-axial gyroscope and tilt display using 4 LEDs connected to an Arduino Uno developed by the group of students who obtained the highest mark. In the third lab session the students have set up a list, installed the IDE (Integrated Development Environment) Arduino environment on their PCs, and started to familiarize with writing programs in C. From the fourth session onwards the modules are operable, therefore the students can write their application software and verify the results. Before achieving the physical setup the students were asked to create a Proteus simulation of the application and test their program.

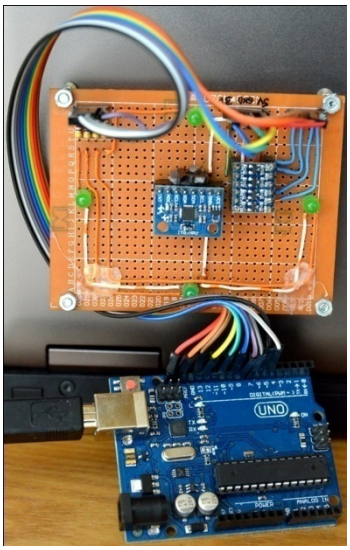


*Figure 1. Interfacing a gyroscope with an Arduino Uno system*

In the final lab session, in the 14th week, the students made a Power Point presentation of the achieved lab project and provided a demonstration test describing its functionality. The lab projects are intended to train the students how to build an interface between the microcontroller and the

connected devices and, after having understood the data transfer protocol mechanism, to write the transfer software. Due to the large number of open-source programs that are available for Arduino-based modules, the students have downloaded adequate programs and pre-tested the functionality of the connected modules. After ascertaining hardware functionality of the interface, the actual software design became a more straightforward approach. One of the requirements imposed to the students' achievements refers to their usability in terms of functional lab projects, i.e. the latter must be appropriately described and documented in order to be integrated into the classical laboratory activity. After the first 6 weeks, the students came to the conclusion that any of the achieved lab projects are too difficult to be completed by the average student during one single lab session. After a period of intense brainstorming trying to solve the problem ,the best solutions proposed by the students were:

- Introducing a preliminary lab project focused on the Arduino system presentation to familiarize the students with the module and the IDE development environment, wherein the students are requested to write a program designed to light up a LED on the circuit board;
- Distributing the more complex lab projects over several lab sessions; e.g. one lab session dealing with keyboard interfacing and another with displaying the code of the depressed key on the LCD;
- For even more complex lab projects, such as interfacing the tri-axial gyroscope, certain program sequences were made available from the open-source software.

One of the issues affecting the laboratory activity consisted in the differences between students in terms of knowledge level. Performing the experimental procedure was a routine task for some of the students who had previous programming knowledge above average, due to their internship position with IT companies. However, choosing Arduino shields for specific functions, understanding their mode of operation, and programming them was a real challenge for most of the students who considered this activity a very useful learning opportunity. By organizing work groups, we created a collaborative atmosphere allowing the students to distribute the tasks, discuss, and solve together the arising problems. Moreover, by using scores to assess each group's performance in terms of quality and complexity of the identified solutions, a competitive environment was created, as well. A photo with the experimental procedure during a lab session with one of the teams debating after achieving the proposed module is given in Figure 2.:

*Figure 2. Photo showing a sequence of the experimental lab procedure*

## 4. The achieved outcomes

In the academic year 2015-2016, a certain indifference and lack of interest was observed among students as regards the classical lab projects in Computer interfacing using modules connected with PCs via USB, parallel port, and serial port UART. A questionnaire distributed among students in the final session with a 5-point Likert scale showed an average of 3.69 (5 = very useful) to the question about how useful the laboratory activity was considered to be. The average to the question about how much did they learn from the lab projects was 3.57 (5 = very much). The global degree of satisfaction attained an average of 3.65 (5 = very satisfied). All of the scores showed a degree of relative satisfaction. An average of 4.11 was obtained to the question "How do you appreciate the concept of developing lab projects based on ideas proposed by the students and selected through a contest of ideas? "(1=bad, 5=very good). A number of 26 students responded to the questionnaire. The questionnaire was anonymous and voluntary. Based on these considerations it was decided to adopt the modified lab experimental procedures.

*Table 1. Statements and the averages of the responses before the lab activity*

| Question | Average |
|---|---|
| 1. My knowledge about microcontrollers has improved significantly. | 4.05 |
| 2. The idea to design and build one's own lab is a very good one. | 4.52 |
| 3. It was easy for me to design and achieve the lab projects | 3 |
| 4. The proposed scores have compensated the effort required by the achievement of the lab projects | 4.47 |
| 5. The idea of introducing competition during the lab activity was a very good one | 4.05 |
| 6. I am satisfied with this way of achieving the lab activity | 4.47 |
| 7. This way of achieving the lab activity seems to be more useful than the classical one | 4.63 |

In the academic year 2016-2017 the modified procedures for the laboratory classes presented in this paper were implemented. In order to identify the outcomes of this initiative we conducted a statistical study with the following goals:

1. Determining student satisfaction as regards these changes
2. Determining the effectiveness of the method by analyzing the outcomes

The conducted study was a quasi-experimental one based on anonymous questionnaires that were distributed both at the beginning as well as at the end of the lab activity period. The study was approved by the Department of Electronics and Computers.

The study was based upon following hypotheses:

1. Student satisfaction degree will be higher compared with the classical lab activity
2. The quantity and quality of the acquired knowledge has improved
3. The academic results reflected in the obtained marks will be better.

The students had the possibility to choose among following answering options as regards the statements of the questionnaire 1-strongly disagree, 2-disagree, 3-neutral, 4-agree, 5- strongly agree. The statements made at the beginning of the semester and the average response scores are given in Table 1.

According to the results, the students appreciate their knowledge degree on microcontrollers as rather low. They anticipate future difficulties, bad results, are reticent to the idea of competition yet consider that the allotted scores are correct. A number of 19 students responded to the questionnaire.

Table 2. presents the questionnaire statements after completing the lab activity and score allotment.

*Table 2. Questions and the average of the responses after completing the lab activity*

| Statements | Average |
|---|---|
| 1. I have advanced knowledge about microcontrollers. | 1.73 |
| 2.The idea of designing and building one's own lab project is a very good one | 4 |
| 3.It will be easy for me to design and achieve the lab projects | 2 |
| 4. The proposed scores compensate for the effort required by the achievement of the lab projects | 4.42 |
| 5.The idea of competition (since only the 4 best solutions will be implemented) seems very good | 2.63 |
| 6.I will score very good in this subject with the new experimental lab procedures | 2 |

The questionnaire was voluntary and anonymous. A comparative graph of the student responses to the first 5 questions *before* and *after* the lab activities (Table 1. and 2.) is given in Figure 3.

Series 2 (red) represents the average of the responses before performing the lab activities and Series 1 (blue) afterwards. A significant improvement could be ascertained as regards the knowledge on microcontrollers (from 1.73 to 4.05) (statement 1) as well as an improvement of the students' perception about the ideas of competition (from 2.63 to 4.05) (statement 5). The idea of building one's own laboratory enjoys higher appreciation and at the same time the assigned task is considered a bit less difficult. The scores are considered to be equally good before and after the lab activity.

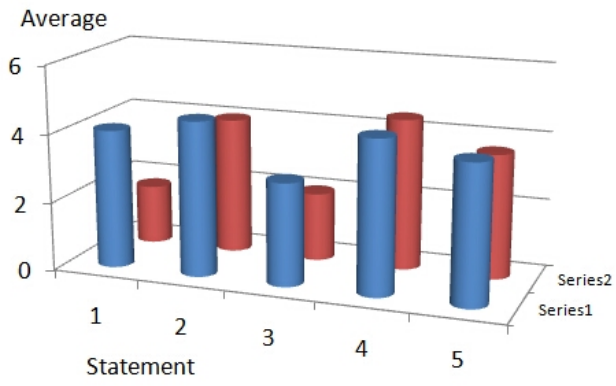


*Figure 3. Average of the responses to the 5 statements before and after performing the lab activities*

Figure 4. presents a significant graph showing the distribution of the students' responses relating to the degree of satisfaction, after performing the classical lab activity in 2015-2016, as well as the modified lab activity in 2016-2017.

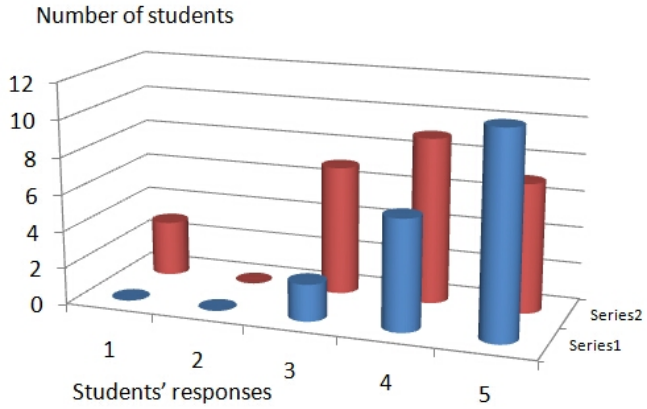


*Figure 4. Distribution of responses about the degree of satisfaction with regard to the classical lab procedures (S2) and the proposed procedures (S1), (from 1= unsatisfied to 5 = very satisfied).*

The proposed modified experimental procedures (S1series, blue) were appreciated by the students with a high degree of satisfaction (4.47), whereas a year before the degree of satisfaction as regards the former classical lab procedures was 3.65 (S2 series, red). A percentage of 89% of the students considered the lab procedures introduced in 2016-2017 as "good" and "very good", in contrast to 61% for the case of the classical lab procedures of 2015-2016.

From the perspective of the academic results in 2015-2016, the overall average mark obtained after completing the classical lab projects was 6.68 in contrast with 7.71 in 2016-2017. In 2015-2016, 4 of a total of 28 students failed to pass the final exam while the average mark was 5.50. In the academic year 2016-2017 all students passed the final exam with an average mark of 6.21.

## 5. Conclusion

Proposing the new experimental lab procedures designed to replace the classical procedures proved to be a surprise and, initially, the students were fairly reticent. The classical lab activity, with predictable operations, where each student knew precisely what he was supposed to do, is a convenient set of procedures, which poses no challenges. Although the students are not very happy with the classical lab activity (an average of 3.65) they fear a change that would include competition (they expect mediocre marks, question 6 in the questionnaire, at the beginning of the semester).

Over time, the students got more and more involved in the new lab activities becoming more interested by discussing various ideas and proposals while erroneous or whimsical application concepts were gradually ruled out. The most interesting lab session was the one in which the students selected the winning solutions after spirited discussions and controversies. A delicate situation was created after selecting the 4 winning ideas, in the process of forming the teams and assigning specific tasks. A few students with lesser expertise failed to be included into these teams. Together, they proposed to develop a simple application software devised to light up 8 LEDs connected to a parallel output port.

Once the needed components and circuits became available, the students started to work on their modules. During their activity they reported a few drawbacks and shortcomings:

- The students started to work without a clear concept so that they discussed the V model of achieving a project based on the information provided by the Wikipedia
- Over time they realized that the software needed for their application was too complex and the solution was to use open-source Arduino libraries to achieve certain software sequences
- Documenting the achieved applications was a difficult task.

The main advantages ascertained by the students with regard to this new set of lab procedures are:

- Due to open-source software libraries the students can test the functionality of the application before writing their own software
- The various applications cover a range from simple to complex ones, which makes them more adaptable to the students' knowledge level
- The lab projects based on Arduino systems can be extended, increasing complexity and turning them into dissertation projects

Advantages identified by the organizers:

- Arduino modules, components, and shields are cheap and readily available due to a multitude of suppliers.
- The experimental procedures ensure competition during theme selection and create a collaborative environment during the achievement phase. Therefore, the working atmosphere becomes creative and has a high education potential.
- Orienting the activity towards individual effort has increased the amount and the quality of the students' knowledge about microcontrollers and interfacing

One disadvantage consists in the organizers' increased logistic effort along with the higher material expenses.

The statistical study confirmed the initial hypotheses, the increase of student satisfaction towards these new lab procedures, their knowledge improvement and slightly better academic results.

Both the students and the staff ascertained that these new experimental procedures are qualitatively superior to the classical ones. Therefore, we proposed to expand this initiative to other groups of students in order to monitor the results of a larger number of students.

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