Time-Effective Logistics of Project-Based Course Electronic Instrumentation

Samuel Kosolapov
Department of Electronics
ORT Braude Academic college of Engineering
Karmiel 21982, Israel
e-mail: ksamuel@braude.ac.il

***Abstract*—Historically, the classic course Electronic Instrumentation was based on analog electronics - analog sensors, actuators, and amplifiers - and was taught in most colleges and universities as the theoretical course. The appearance of inexpensive micro-controllers revolutionized the usage of sensors and actuators; hence, our days Electronic Instrumentation can be taught as "a classic course in the modern envelope": by using as analog as digital elements, plus by using special programming techniques. In order to make the content of the course closer to modern industry design techniques, most of the assignments were made project-based. It is clear that checking and grading a large number of project-based assignments is time-consuming. To make this process time-effective for the educator, a set of rules and procedures were formulated. This article describes the time-effective logistics which were used during the 7 years to teach this course, as in "regular time", as in "COVID19 time" by using real electronic components, and by using TinkerCad simulations.**

Keywords-project-based learning; time-effective logistics; electronic instrumentation; TINKERCAD.

I. Introduction

Starting from the 80s, electronic analog systems were gradually replaced by digital systems containing “the wonder chip Micro-processor” [1] [2]. Large control panels equipped with analog voltmeters, ammeters, and mechanical switches were gradually replaced by compact digital systems with visual display units. Programming of the Micro-processors has become an important part of electronic engineering education.

In the past, the classic course Electronic Instrumentation was based on analog electronics - analog sensors, actuators, and amplifiers. Hence, in the majority of universities and colleges, this course was taught as a theoretical course – mostly, due to the high cost of the real-life systems utilized then in the industry. The appearance of inexpensive microcontrollers revolutionized the usage of sensors and actuators, hence our days Electronic Instrumentation can be taught as "a classic course in the modern envelope": by using as analog as digital elements, plus using special programming techniques.

Many educators in the field of electronic instrumentation have emphasized that practical training is an essential part of the learning process. In most of the following steps: "conceive, experiment, design, build, test, improve" – practical aspects are critical for understanding the items learned [3]. Leading educational institutions like MIT [4] and others incorporate into their curricula of electrical engineering a substantial amount of 'hands on' lab skills, by using real electronics components and basic electronic equipment.

Alternatively, a number of educators have experimented with online training technologies. Those attempts have become vital because of COVID19 situation. The current situation in education, which is still seriously dependent on the epidemiological situation, makes educators look for new ways and specific platforms as a means of implementing their educational programs [5]. It was necessary to provide a way to carry out electronic experiments and assignments, as in a real laboratory, as in a student’s home. An interesting option was to use the online TinkerCad platform for implementing at least some elements of the Electronics Laboratory activities [6].

An additional idea was to lease to each pair of students a kit containing real electronic components so that students would be able to execute assignments at their homes – by using the kit and PC. Some elements of this idea were partly described in [7]. This article describes additional details and new elements introduced in the recent years.

Section II describes “Elements of the Course” – such as lectures, exercises, non-obligatory “Class Micro Works”, homeworks and MicroProjects including details: how they were provided in “regular times” and in “COVID19” time. Section III describes implementation details of “Logistics of Homeworks and Micro Projects”. Those details are provided in two sub-sections: sub-section “A” – named “Homeworks: Electronic Projects executed by using real components and by using TinkerCad simulations” and in the sub-section “B” - named “Micro-Projects: description of existing designs and TinkerCad simulations”. Important part of any “time-effective” logistics of that kind is time-effective grading. Details are described in Section IV named “Time-Effective logistics of reports checking and grading policies”. Section “V” shortly summarize results of student’ pools (partly published in the previous publications) and provides some ideas to be weighted for the implementation in the future.

II. Elements of the Course

Course Electronic Instrumentation in the new format was provided at the Department of Electronics of ORT Braude Academic College of engineering every semester starting from 2015. Elements of the course are: 13 two-hour frontal in campus lectures, 13 one-hour in campus exercises, three homeworks, two Micro Projects, and 10 non-obligatory “in Class Micro Works” (CMW, - provided during exercise hours). Homeworks and Micro Projects are executed by pair of students at their homes by using specially prepared kits (to be described later). In the process of practical implementation of homework, students compiled reports by using specially designed PowerPoint templates and sent them by Gmail. To make the evaluation and grading of these reports time effective for the educator, special format was developed. The main ideas of this format (albeit for the course “Image Processing”) were described in [8]. After two Micro Projects were executed by pair of students, students sent compiled PowerPoint reports to the lecturer for preliminary evaluation. After corrections, students presented their Micro Projects in class. Micro-exams were individual assignments solved by students on paper. During three semesters starting from March of 2020 to August of 2021, this course was provided under COVID19 restrictions by using online tools: ZOOM, TinkerCad, and Gmail. Specifically: lectures were provided by using remote ZOOM sessions, and assignments were executed by using TinkerCad simulations instead of using real components. Starting from October 2021, the course is provided in a hybrid way: lectures are provided at the campus, but with ZOOM “on”, so that students have a choice: to visit the campus, or listen to the lectures by ZOOM from outside the campus. Homework and Micro Projects are executed by using the kits, but in some situations, students are asked to provide simulations by using TinkerCad and/or MultiSim simulation applications. Grading policies are described at Section IV.

III. Logistics of Homeworks and Micro-Projects

In the subsection “A” logistics of homeworks is described, whereas logistics of Micro-Projects is described in the subsection “B” is described.

A. Homeworks:Electronic Projects executed by using real components and by using TinkerCad simulations

At the beginning of the semester, pairs of students get from the lecturer a specially prepared kit. Specifically, in the frames of the course Electronic Instrumentation, students get: an Arduino UNO R3 board (see item 1 on Figure 1), a small-size breadboard (marked as 2 on Figure 1), a shield with a small breadboard (marked as 3 on Figure 1), a short USB cable, set of wires, and a plastic box (marked as 4, 5 and 6 on Figure 1) and a 37-sensor box (marked as 7).

Electronic modules (sensors and actuators) inside the “37- sensor box" are voltage compatible with the Arduino UNO R3 board. Some modules were extracted from the box – for example, the laser module – in order to prevent possible eye injury in case of reckless usage.

Figure 2 presents simplify flowchart of the steps expected to be executed by educator and by pair of students in the frames of the described logistics. In the frames of homework assignments, students were asked to design, assemble, and test a simple electronic system containing a number of sensors and actuators that are controlled by the Arduino board. Additionally, students were asked to create a program (sketch) for the Arduino board according to the description provided by the educator. It is important to mention, that homework assignments were executed by students at their homes, and thus, the educator could not see how the required design and assembly steps were executed. Hence, students were asked to document the assembly of the system by adding a set of photos to the PowerPoint report. Figure 3 presents exemplary photos taken from the typical student’s report. By exploring those photos, an educator can in a number of seconds validate if students properly put the modules on the breadboard, properly executed interconnections on the breadboard by using colored wires, and properly connected pins of the Arduino board. Additionally, students were asked to fill a number of tables in which they specified all the connections by using special codes and specify colors of wires. It is clear that any discrepancy with the connections specified in the tables and on the photos will be immediately revealed by the educator, hence the requirement to add photos of the assembly steps and the requirement to fill the connections tables is important in the frames of the selected logistics. Yet, additionally, every pair of students were asked to physically demonstrate the operation of their system in the class and answer some questions concerning the report and system operation.

As it was mentioned above, during three semesters starting from March of 2020 to August of 2021, this course was provided under COVID19 restrictions. During those semesters, the distribution of real electronic components became at least problematic, but working in pairs with real components became impossible. The possible solution was to use online TinkerCad simulations. An important feature of this simulation is that it is a free cloud service, so that no installation is needed. However, when COVID19 restrictions were pronounced, it was not immediately apparent that this specific TinkerCad cloud service could be used in the frames of this specific course. Fortunately, in less than 3 days after the pronouncement of COVID19 restrictions it was proved that only minor changes in the requirements for the homework assignments were required. Figure 4 presents screenshots of the TinkerCad screens. The left screenshot demonstrates an exemplary modules layout on the breadboard as it was prepared by the lecturer. This screenshot was given to the students as a slide in order to demonstrate to the students that Homework 01 can be executed by using TinkerCad simulation. During the exercise provided by ZOOM, the lecturer provided a live demonstration of the system operation in full accordance with the description. However, the code of the program (sketch) was not revealed to the students. So, students were asked to do with TinkerCad simulation actually the same steps as with real components: to position modules and to connect them by wires, but, instead of real photos of real components, screenshots of the simulation screens were used. The right part of the Figure 4 presents the layout of the system as prepared by some pair of students. Again, the educator, by exploring the link to the student’s simulation, can very quickly validate that all the blocks were properly connected by color wires. The parts of the student’s report describing the code and testing the system were nearly the same as in the case of real components, so that grading of the report by using a specially prepared list of requirements was fast and simple. Additionally, students were asked to demonstrate operation of the system during exercises by using the “share screen” feature of ZOOM. It is clear that if some pair of students had "copied" photos and "code" from the report of another pair of students, this would be immediately revealed. During 7 years, such "illegal copying" was revealed less than 10 times.

B. Micro-Projects: description of existing designs and TinkerCad simulations

In the frames of the course, students were asked to prepare two Micro-Projects. It is clear that students have limited time to implement full-scale projects containing both theoretical part and implementation of some system with real components. Hence, the name used for this assignment is Micro-Project.

The first micro project was about different types of motors (6V DC, Servo, Stepper, and Brushless). Each pair of students prepared a PowerPoint presentation about a specific type of motor, about a specific type of electronic controller and, present it in the class (in the case of “regular” semester) or by ZOOM (in the case of “COVID19” semester). In these presentations, students were asked to explain the physical principles of the specific motor operation and explain how this motor can be controlled electronically by presenting the exemplary circuit needed to control this motor from a microcontroller.

The second Micro Project was about creating an Automatic Measurement System (AMS). Each pair of students was asked to develop a different type of AMS: an AMS for measuring DC voltage in the different voltage ranges, an AMS for measuring AC voltages in the different voltage ranges, etc. Students were asked to prepare the electric circuit of the AMS, provide relevant calculations, and prepare a TinkerCad simulation (including the analog part, Arduino UNO R3 board, and Arduino sketch). In this case, each pair of students was asked to send a PowerPoint presentation and link to the TinkerCad simulation.

IV. Time-Effective Logistics of Reports Checking and Grading Policies

Considering the limited number of kits, and the typical size of electronic laboratory, the number of students in this course was limited to 24, that is, by 12 pairs of students. It is clear, that checking 12*(3+2) reports is a time-consuming job. Hence, significant efforts were made to develop time-effective logistics (a set of formal rules) describing how exactly students must prepare and send their assignments. Our days it is obvious for most educators that reports must be sent electronically (and not collected physically as reports printed on paper). A number of pedagogic systems (like MOODLE) exist for collecting students' assignments. However, most elements of this logistics were developed nearly 15 years before [9]. Then the logistics were based on using Gmail cloud services. During the years, this service was proved as simple and reliable. Hence, there were no serious reasons to change usage of Gmail cloud services as a proper tool to send and store student’ reports and PowerPoint presentations. It is known that some educational institutions strictly forbid using of Gmail and other Google services. In that case, alternative e-mailing or messaging services can be used, while those services have searchable subject field and support attachments, so that using Gmail is not a critical element of the described logistics. A simple, but really time-saving element of this logistics is the naming rule of the assignment materials. The same “name” was used as the Gmail subject, the name of the attached PowerPoint presentation, and the name of the attached zip file (containing code). This name can be described as a set of tokens divided by the delimiter “-“. In the course Electronic Instrumentation this name was:

“ABCD-EFGH-X-YYYY-MM-DD”

ABCD stands for the last four digits of the ID of the first student. EFGH stands for the last four digits of the ID of the second student. The obvious rule needed to prevent ambiguity was that ABCD < EFGH. X – describes a type of assignment – HW01, HW02, and HW03 – for the homeworks 01, 02, and 03, and P1Z and P2Z for the Micro Project 1 and Micro Project 2, where Z is a number of assignment (typically in the range {1..6}, so that every assignment was typically executed and presented by two pairs of students. YYYY is a year, MM is a month, and DD is the day on which the assignment was sent. This naming rule enables a very fast and simple search for the specific report, for all the reports of a specific group, for all the assignments of a specific type, etc. Figure 5 presents exemplary screenshots of the lecturer's Gmail. On the left screenshot of Figure 5, an exemplary result of search for “all assignments of the specific pair of students” by using their short ID token “1576-7618” is shown. Two items emphasized by BOLD exploits a known feature of Gmail: signaling to the educator that this specific mail was not opened yet, and, thus, this specific report was not graded yet. On the right part of Figure 5, an exemplary result of search for “all students that have sent reports for the homework 01” is shown. In this case, search was executed by using token “-HW01-“.

It is important, that when one student sends the assignment to the lecturer, he/she is asked to send a CC to the email of the second student. This simple rule effectively prevents the non-pleasant claim “lost report”. In the case of a problem, students were asked to send a screenshot of the relevant email page as solid proof that the requested report was sent on the specific date. Actually, during 15, years fewer than 5 claims of “lost report” were raised and none of them was found to be valid after simple search together with students.

In order to provide fast, equal, and fare grading, Excel templates were prepared. Figure 6 presents an Excel template for grading homework 01 in the "COVID19 semester". Rows of the template contain an exact copy of the requirements as they are specified in the description of homework 01. Every row has a special code (for example, HW01.11). Students were requested to type this code in the title of the relevant slide of the PowerPoint presentation. This simple numbering makes grading extremely simple and clear both for the educator and for the students. It is important, that requirements to be executed are written in a short but unambiguous fashion. For example, the requirement in the row HW01.13 on the left part of Figure 6 is “Fill Table 3 of the wire’ connections”. It takes some time and efforts for the students to properly fill this table. They cannot use the work of other students because every pair of students uses a different layout of the modules, and then the connections of wires must be different. While executing and documenting this sub-task takes some time for the students, the time that the educator needs to check if this specific requirement was executed as required is very short – less than one minute. In order to make grading even faster, it is recommended to use a PC with two monitors (or a PC with a wide monitor). The first monitor is used to present the Excel grading template. On the second monitor, the educator opens the PowerPoint presentation of the specific pair of students and compares the content of the slide labeled as, say, HW01.11, with the requirement. Then, by using the maximal grade for this item (specified on the next right column), the educator updates the grade for the specific pair of students. In case it is necessary, educator adds comments to the relevant cell, so that students can see why the grade was reduced. Typically, on the rightmost cell of this row, typical students’ errors are listed, and for every “typical error” a simple number is assigned. In that case, it is enough to use this number in the comment - that is: much less for the educator to type. It is important, that this procedure makes grading more fair – “the same grade for the same error”. The final grade of each pair of students for the specific report is automatically summarized in the row marked as “total”. The template presented at Figure 6 contains “non-final” grades. It can be seen that some pairs of students have already sent PowerPoint presentation, but their simulation did not work as expected. In that case, students were asked to demonstrate their simulation and answer the educator’s questions. The grading policy was that for the homework 01 students were permitted to correct their presentation. (Maximum two times). As for homework 02 and 03, only one version of the Report and simulation were permitted.

Figure 7 presents an Excel template for grading Micro Project 1. The basic structure of this template is the same. While homeworks were the same for all pairs of students, Micro Projects were different for different pairs of students. Considering that in this specific semester six different types of motors were used, typically two pair of students had the same assignment. Again, significant efforts were made to formulate the requirements in a short but unambiguous fashion. For example, row “P1V.13” (V stands for the project number) clearly states that photos of two commercially available motors must contain explanations of the pins of those motors. Again, the grading policy in this assignment was to enable three versions of the PowerPoint presentation. It is clear, that in that case most of the student’s pairs arrived to the maximal grade. The goal of this “trick” was that to force students to understand the level of requirements of the nearly industrial-grade report. Obviously, only one version of the Micro Project 2 presentation was permitted. The final grade was calculated by Excel according to the self-explanatory formula: A=0.05*HW1+0.1*HW2+015*HW3+0.3*MP1+0.4*MP2;

Final Grade = G = MAX (0.2*CMW + 0.8*A , A) ;
Where CMW stands for the grade of non-obligatory “Class Micro Works”. ”.

V. Conclusions and future work

During 10 years, different variants of this time-effective logistics for the different electronic engineering courses were tested. Some results were published before in [7] [8] [9] and reported at a number of international conferences. In the semesters when student’ pools were provided, grades provided by students for this course were in the range {4.23...4.94} (by using 1-5 scale) and was in most cases by 0.5 higher that mean department’ courses grade. In the written comments, most of the students’ remarks were positive, and, median grade for this course in most of the semesters was 5.0.

Currently, management and processing of all the Emails are executed manually, mainly by exploiting email search utilities. Manual management and grading of the student's reports (by using grading templates) was found simple and time-effective, as for the students, as for the educators. While the course is provided for a group of students of limited size (say, up to 24 students), automatization of the above management by creating dedicated software scripts or by creating special software, does not look as important improvement of the logistics. However, for the large groups, such automation may be found instrumental.

An additional automation option is to include elements of the discussed logistics as an additional module to any available ELM. Specifically, in the ORT Braude Academic College of Engineering, a number of ELM were tested. Currently, MOODLE system is used by most of the college lectures. However, in its current implementation, using MOODLE was found as less suited for the goals of this specific course than the proposed Gmail-based logistics.

It is assumed, that by analyzing the results of the last student pools, more conclusions will be drawn, and some modifications in the logistics will be provided.

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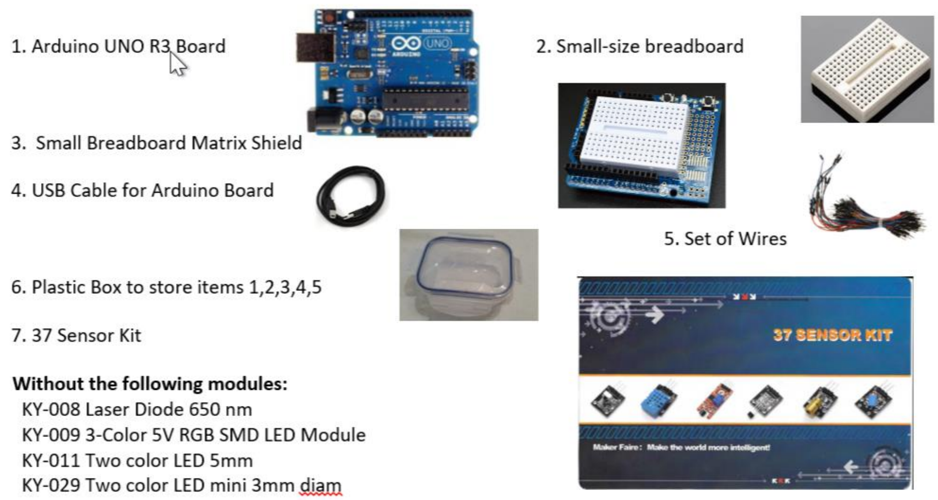

Figure 1. A list of electronic components that were provided to the students for the work at their homes.

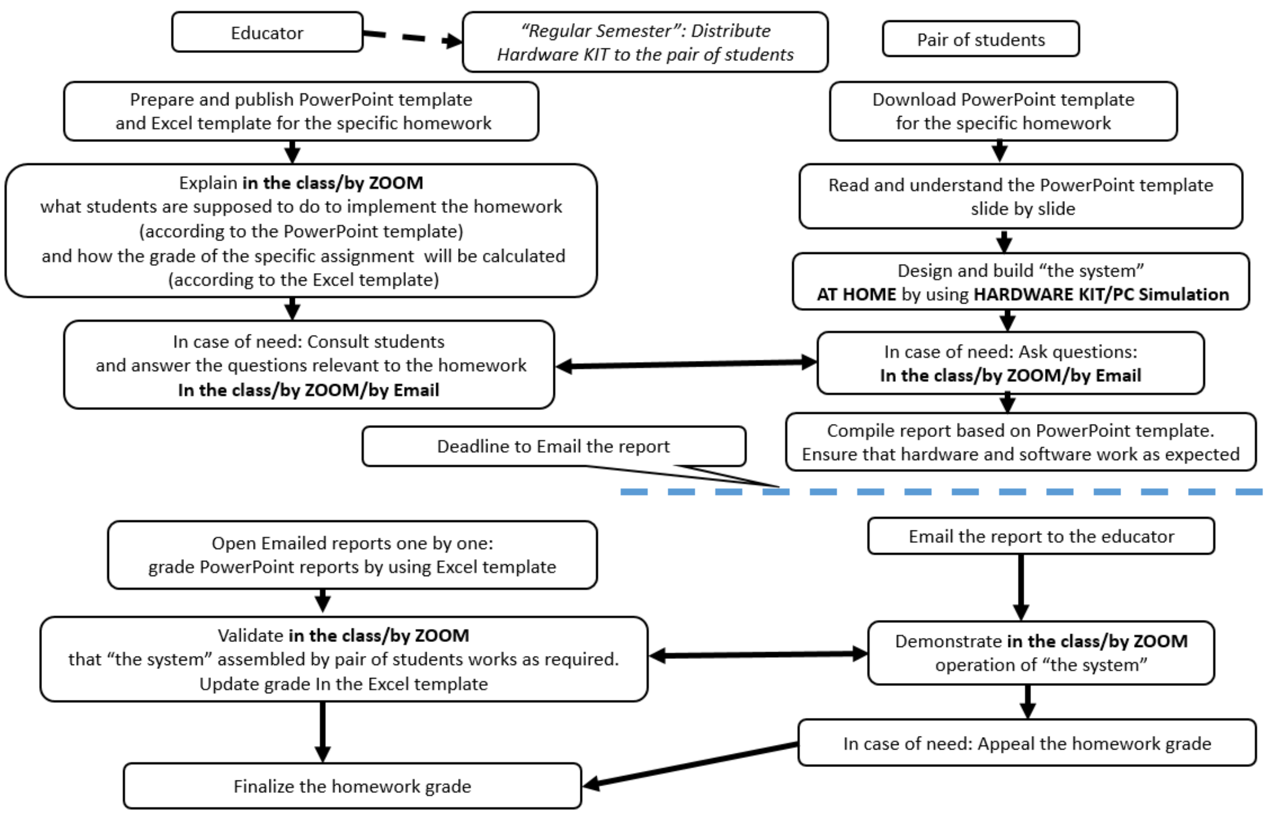

Figure 2. Simplified flowchart of the exemplary homework roadmap.
Left: actions of the educator. Right: actions of pair of students

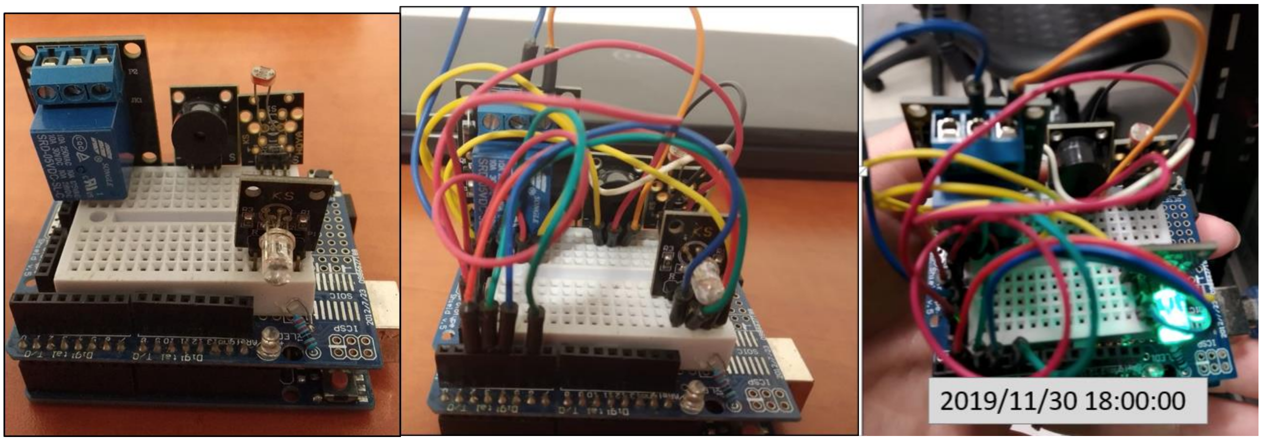

Figure 3. Homework 01 as impmenented by pair of students by using real electronic components.: Left: A photo of the system with four modules positioned on the breadboard. Center: a photo of the system with colored wires added. Right: photo as proof that the system works as required.

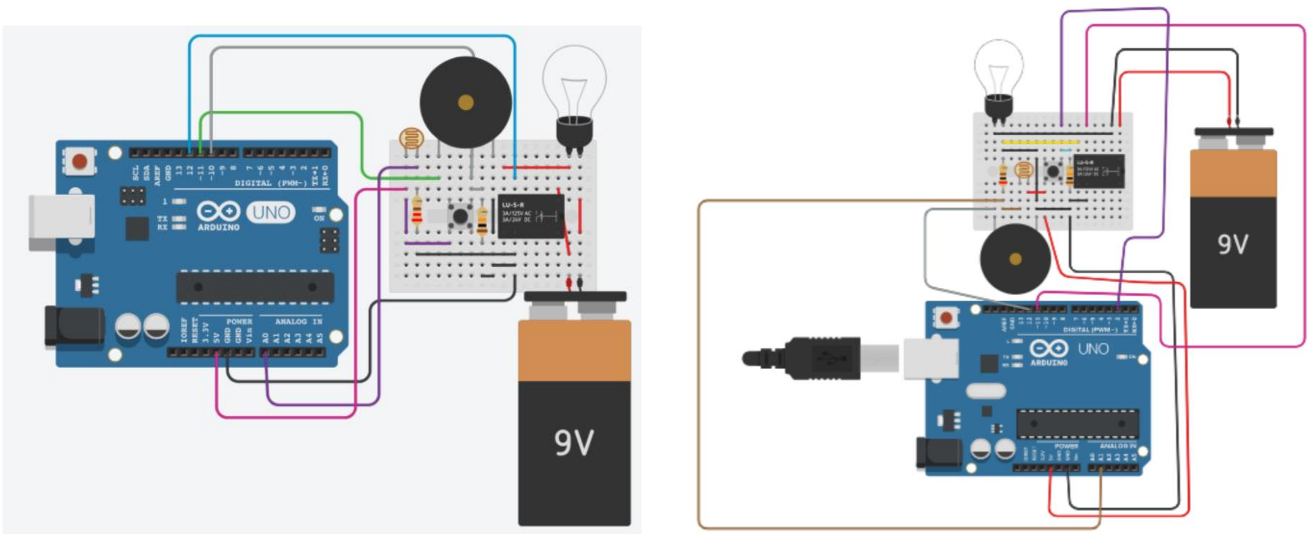

Figure 4. Homework 01 impmenented as a TinkerCad simulation .Left: Exemplary layout of components as proposed by lecturer. Right: layout of components as created by pair of students

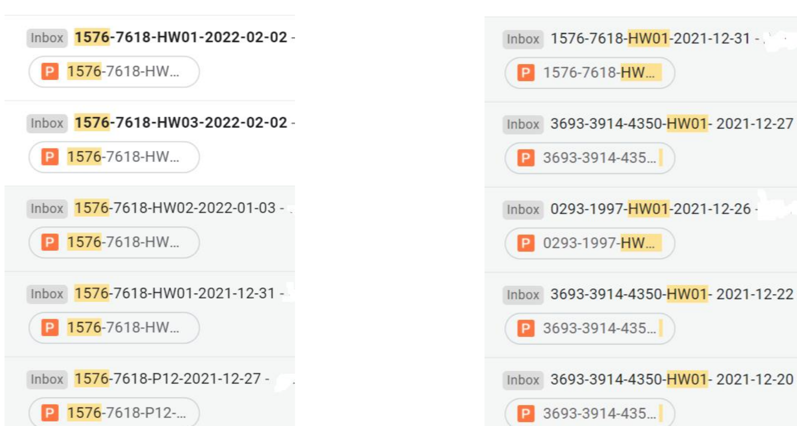

Figure 5. Screenshots of the lecturer's Gmail. Left: Results of search for all assignments of the pair of students by using the short ID token "1576-7618". Marked as Bold : works that have not been checked and graded yet. Right: Search of all reports of the homework 01 by using token "-HW01-"

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	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Num	Item	Max Points	4216-4960	2553-5282-8676	0293-1997	3509-4152	3693-3914-4350	3447-4989	0437-6198	1576-7618	1624-1671-8387	3693-3914-4350	5424-6813
5		Kit Number		11	12	13	14	15	16	17	20	18	?	19
6														
7	HW01.11	Put here at least **SIX** clear screenshots of the modules positioned ONE by ONE on the breadboard WITHOUT WIRES. Put here **FIVE** clear screenshots of the modules positioned on the breadboard: With all wires connecting different holes of the breadboard With all additional wires connecting sensors and/or actuators going to Arduino IO Pins With all additional wires going to the Ground With all additional wires connected to the 5V With all additional wires connected to the 9V battery and to the Light Bulb Lecturer must be able to "reverse engineer" your shield in case of need	1	1	1	1	1	1	1	1	1	1	1	1
8	HW01.12	Fill table of of the Component' position on the mini breadboard For Components use Format: X.Y (X – Number of the component in the Table 1 Y – relevant alpha-numerical descriptor of the pin – invent your STANDARD in case of need) For the mini-breadboard use hole-descriptors like A1-D2	1	1	1	1	1	1	1	1	1	1	1	1
9	HW01.13	Fill Table 3 of the wire' connections	1	1	1	1	1	1	1	1	1	1	1	1
10	HW01.14	System' Electrical Circuit must contain all components and all the connections Pins of all the components must be clearly marked	1	1	1	1	0	1	1	1	0	1	0	1
11	HW01.15	Block-Chart of the System' operation	1	1	1	0	0	0	1	1	0	1	0	1
12	HW01.16	Test Report of System' operation 0 is OK	-5	0	0	0	0	0	0	0	0	0	0	0
13		Simulation 0 is OK	-5	0	0	0	-5	-5	0	0	-5	0	0	0
14		Total:	-5	5	5	4	-2	-1	5	5	-2	5	3	5

Figure 6. Excel template for grading homework 01.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Num	Item	Max Points	4216-4960	2553-5282-8676	0293-1997	~~3509~~-4152	3693-3914-4350	3447-4989	0437-6198	1576-7618	1624-1671-8387	5424-6813
2		Project Num (V)		1	2	3	4	5	6	1	2	3	5
3		First Version Date		12-02	12-02	12-02	NONE	12-02	12-02	11-30	12-02	12-02	12-02
4		Second Version Date		12-21	12-20		12-20	12-02	12-16	12-20	12-13	12-16	12-05
5		Final Version Date			0102		12-27	12-26	12-26		12-27	12-28	
6		Presentation Date and Time		12-21	12-21	12-21	NONE	12-21	12-21	12-21	12-21	12-28	12-28
7									01-08				
8	P1V.11	Mechanical and Electrical Elements of the motor (drawings and explanations)	3	3	3	3	3	3	3	3	3	3	3
9	P1V.12	Physical principle of the motor operation (drawings and explanations)	3	3	3	3	3	3	3	3	3	3	3
10	P1V.13	Photos (from Internet) of at least TWO commercially available motors with pins explanations	2	2	2	2	2	2	2	2	2	2	2
11	P1V.14	Important parameters of above two motors (names and typical values and graphs with VALUES) + explanations & comparisons;	4	4	4	4	4	4	4	4	4	4	4
12	P1V.21	Full Electrical circuit of a motor controller (in case of IC – what exactly is inside IC)	4	4	4	4	4	4	2	4	4	4	4
13	P1V.22	Photos (from Internet) of at least TWO commercially available motors controllers with pins explanations	2	2	2	2	1	2	2	2	2	2	2
14	P1V.23	Full electric circuit containing Arduino, Controller, Motor, External Power supply (if relevant)	4	4	4	4	4	4	2	4	4	4	4
15	P1V.24	Explanation: how speed and direction of a rotation can be changed by Arduino Commands	4	4	4	4	4	4	3	4	4	4	4
16	P1V.25	Evaluation of speed (RPM) limits. Explanation of a typical torque behavior	2	2	2	2	2	2	2	2	2	2	2
17	P1V.3	Numbered list of sources (IEEE Style)	2	2	2	2	1	2	2	2	2	2	2
18		Presented (-5)	0	0	0	0	-5	0	0	0	0	0	0
19		Total	30	30	30	30	23	30	30	30	30	30	30

Figure 7. Excel template for grading Micro Project 1.

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