International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 7
July 2017

PB LEARNING-- A Project-Based Physics Lab Learning Using Low Cost Open Source Hardware Based on IOT

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ABSTRACT

Laboratory experiments take place in controlled environments and are the main method used in the natural sciences such as PHYSICS, CHEMISTRY & BIOLOGY. There are numerous experiments which have been designed to test numerous scientific theories in the field of physics, chemistry & biology.

The logic of the experiment method is that it is a controlled environment which enables the students to measure precisely the effects of independent variables on dependent variable, thus establishing cause and effect relationships. This in turn enables them to make predictions about how the dependent variable will act in future.

The artificial environment of the laboratory is so far removed from real life that most of us will agree that the results gained from such experiments tell us very little how respondents would actually act in real field.

As we are living in a technology rich world, Science & Technology are extremely popular with learners of today, they are also pathways to career opportunities in the future. It is widely accepted among world wide educationists that to do work and operate in the learning environments of today , our learners need to be technology fluent and develop real life skills such as cooperation, self confidence, teamwork ,creativity and innovation.

Therefore in order to explore the practical aspect especially in the field of PHYSICS at a student platform & to build a creative and an innovative runway among their minds it is important to develop a framework comprising a practical learning approach based on IOT.

This will further lead to :-

- *ENERGIZED CLASSROOMS.*
- *PROBLEM SOLVING & TRAINING FOR FUTURE CAREERS.*
- *LOGIC BUILDING & ENGANGEMENT.*
- *HANDS ON LEARNING & ENGANGEMENT.*
- *FUN LEARNING.*

PB LEARNING-- A Project-Based Physics Lab Learning Using Low Cost Open Source Hardware.

Traditionally student's labs are used in physics curricula to let the students discover and measure phenomena they are otherwise studying. Experimental setups can range from very low tech to elaborate high tech, but a key parameter for a successful learning is student engagement.Recently, the use of microcontrollers has been much simplified by the development of the famous ARDUINO microcontroller. This open source low-cost microcontroller is widely used by the maker community. From a technical point of view, these boards can be used as a low cost acquisition card. Arduino boards allows students to build low cost setups such as computerized mirror system for optical setups or a giant stopwatch or a data logger.The low cost and flexibility of Arduino are not its only advantages : its open source fablab nature can encourage sharing of ideas , tinkering and creativity among students. In terms of pedagogy such an engaging environment is idealy suited to a Project Based Learning (PB LEARNING) FRAMEWORK. Many PBL examples reported in the literature were implemented in university level, why can't it be integrated at the school level? Several parameters reduce the appeal of a project-based approach in physics curricula at school level, it generally requires a large set up of a versatile and often expensive equipment , it requires more time than traditional teachings, and for the instructors PBL can be destabilizing. Several strategies can be used to downsize the cost of the equipment such as the use of a cheap electronic equipment, or building up a stock of used lab equipment over the years. It gives students an easy way to acquire data with a large flexibility in terms of set-up design. However, the technical specifications of the Arduino boards present strong limitations compared to more specialized data acquisition cards, in terms of digitalization and sampling rate. In this report, a project –based student lab using Arduino boards has been described to acquire data, where students build their own experimental set-up from scratch. These labs are part of a broader endeavor to renew physics teaching in schools. The main aim is to present a detailed description of this course so that it can inspire other teachers, especially those interested in the PBL approach but unsure of its technical feasibility.

This project includes a technical description of the acquisition material for physics experiment, its sensitivity and its cost. Student's projects are then described with an emphasis on some examples and student's results. Finally, we report on the students and teachers perceptions of these projects through a survey.

DESCRIPTION OF THE "OPEN-PROJECT" STUDENT-LAB TEACHING UNIT

Most of them have been following a physics curriculum that relies heavily on theoretical and calculation skills with a low emphasis on student labs at middle wing. In the senior wing the amount of time dedicated to lab work increases. During their lab visit students have to use an elaborate experimental setup. The setups are very specialized and focus on a single experiment and physics topic for example a setup to measure the resistance of a conductor or to measure the blackbody radiation. Students use a top-equipment experimental setup, study complicated physics phenomena, and discover the difficulties of experimental work. However no freedom is given to the students as far as the experimental setup (and the underlying physics) is concerned.The organization of student labs was rethought for the whole fundamental physics section. In the course of this reorganization a new project-based student labs mirroring the organization of the focused labs. The main pedagogical objective of the open projects is to be a realistic introduction to experimental physics even though understanding the phenomena that is studied is important, the focus is more on how to perform a scientific study and the skills it requires, from the conception of the experiment to the analysis of the results. Students are given a complete experimental autonomy and can choose which physics topic they want to study, their task is to build an experimental setup from scratch and to carry experiments in whatever direction they think is best. In other words they have to lead their own research project. This project corresponds to the "discipline project" PBL. This lab course is divided in two parts. Before the project itself, a first two-day period is dedicated to student's training on the acquisition material (ARDUINO board & sensors). The approach is learning –by-doing; after some simple exercises to master arbitrary constraints and type of measurements such as " build game using two different kinds of sensors". The objective of these two days is to let students learn how to use Arduino boards and sensors to measure physical quantities, but also to let them realize how easy it is to build things. No physics is involved at that level, except basic electronics: the main goal of this first period is to engage students with an open and active approach.

Near the end of these training days, the students spend a couple of hours on a collective brainstorming session in which they list as many potential physics projects as possible. Based on this list, the students working in pairs, define their project themselves: they choose the physics topic and begin to work out how to investigate it. Note that no pre-made topic list is proposed by teachers, contrary to many project-based lab teaching. The teachers only role is to validate the project in term of feasibility and check with the students for special needs (for example if a specific material is required).

The project itself takes place in a second period of five consecutive days. The students have at their disposal the same material than during the training days plus some other useful material (metallic wires and plates, plastic foils, multi meters). The students' objectives are very ambitious for only five days: they have to conceive the experimental setup, build it, test it, and measure whatever physical phenomenon they chose. They must also analyze properly their data and interpret their results. As in any project, tries and errors are expected, and the students are told to await some delays or changes in their original project. Teachers regularly come and discuss the progress of the project, mentoring the students. Except when there is a security issue (such as using a 10 A / 20 V power source without supervision), the students are free to explore any direction they want; however they have to justify their choices.

The teachers provide a more extensive help for some specific technical skills (how to solder a wire, how to use the fitting software, etc.). Changes in the original project are accepted, but the students are expected to produce some measurements at the end of the five days, to be able to explain what they did and why, and to discuss the physics they measured. The assessment consists of a 15-minute oral exam and a written report.

ACQUISITION MATERIALS: ARDUINO BOARDS AND SENSORS FOR PHYSICS

Letting the students decide their own research topic is in line with our objective to provide an introduction to experimental physics. A consequence of this is that a large set of diverse materials should be available. The choice of Arduino boards as the backbone of the open projects is deliberate. The use of a low-cost multi-purpose microcontroller to pilot data acquisition limits the total cost (an Arduino Uno board is about $20 and the coding interface software is open source and free). Arduino is not the only low-cost microcontroller, 23 but it is recognized as very user-friendly and its user community is large. Only basic coding skill is required to operate the Arduino board as many code snippets for various sensors are available on the Internet. In terms of connectivity, it just needs an USB port, so that students can use their own laptop and can even bring their project outside of the lab rooms if needed.

Table 1: list of sensors and their specifications.This list gives an idea of the physics phenomena that can be studied. This list is given as an example: numerous other sensors exist.

Physical parameter	sensor	range	resolution
Voltage	Arduino board analog input	0 V – 5 V	5mV
	voltage amplifier for thermocouple MAX31855	Typical -10mV to 40mV	10 µV
	Arduino board analog output	0 V – 5 V , limited at 40 mA	20 mV, pulse-width modula-tion.

Table 1 shows the specifications of the various (low-cost) sensors our students had at their disposal for their projects and the corresponding physics measurements that can be performed.The diversity of the projects is obviously linked to the variety of sensors available. These sensors don't have the sensitivity of lab-quality equipment, but they offer a wide range of physics phenomena that can be measured, and studied. All in all, not counting the computers used for data analysis, the total cost of the material used in each student's project was less than $100. So with a total budget under $2000 and some computers, it is possible to successfully organize a physics project-based students' lab for about 20 students. At first, the Arduino and sensors presented here were chosen mostly because of their low cost, allowing us to test this teaching with no financial risk. However, it was realized that using low-cost hardware had also an influence on our pedagogy: instructors can encourage students to experiment in whatever they think is interesting, even at the risk of damaging the equipment. One or two Arduino boards were fried during the projects, which is a very small price for complete student autonomy.

STUDENT'S PROJECTS

Prior to the project week, the question of whether Arduino boards and low-cost sensors would allow students to perform studies of interest for a junior and a senior wing physics curriculum was open. After completion of the projects, all eleven pairs of students succeeded in producing a working experimental setup and physical measurements, even though some projects have been reoriented along their course and their ambition downsized.

We present three typical student projects that explore different fields of physics.

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ISSN 2394 – 3386
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A. ELECTRICAL PROPERTIES OF MATTER

With its analog inputs and outputs, the Arduino board can be used directly to study the electrical conductivity. A simple voltage-divider circuit with a reference resistor in series al-lows the measurement of a sample resistor through the analog input of the board. Changing the reference resistor of the voltage divider allows scanning a large range of sample resistance, from 150 Ω to 60 kΩ in this case. The temperature can be determined with the same electrical circuit, measuring the resistance of a standard Pt100 thermistor. Current-voltage curves can also be obtained if the voltage-divider circuit is driven by the analog output of the Arduino board: varying the output voltage thus varies the current flowing through the sample. A simple low-pass RC filter should be added, since the analog output is actually 0-5 V pulse-width modulated at 980 Hz and needs to be averaged to produce a real DC voltage.1,24 The value of the current is measured by the voltage drop across the reference resistor, and the value of the voltage is read directly. The students developed and carefully tested the measurement circuits. They also worked on the sample-thermometer thermalization and built a setup with a large thermal inertia to control the rate of temperature variations: the sample was embedded in a beaker full of glass beads and liquid nitrogen was used to provide cooling power. The students used their setup to study different properties of a semi-conductor. They could clearly measure the exponential de-crease of resistance with temperature and extract the electronic gap of their sample, a NTC thermistor. They found the reasonable value of 0.22 +/- 0.01 eV. After verifying Ohm's law on a resistor, they performed I-V curves on LED's p-n junction and showed that the value of the threshold voltage presents a temperature dependence of - 2 mV/K consistent with the literature,25 as shown in Figure 1

Figure 1: (adapted from a student report) current-voltage dependence of a LED at two different temperatures. The noise in the low temperature data is probably due to a degradation of the LED after being cooled down rapidly with liquid nitrogen. Insert: temperature dependence of the threshold voltage.

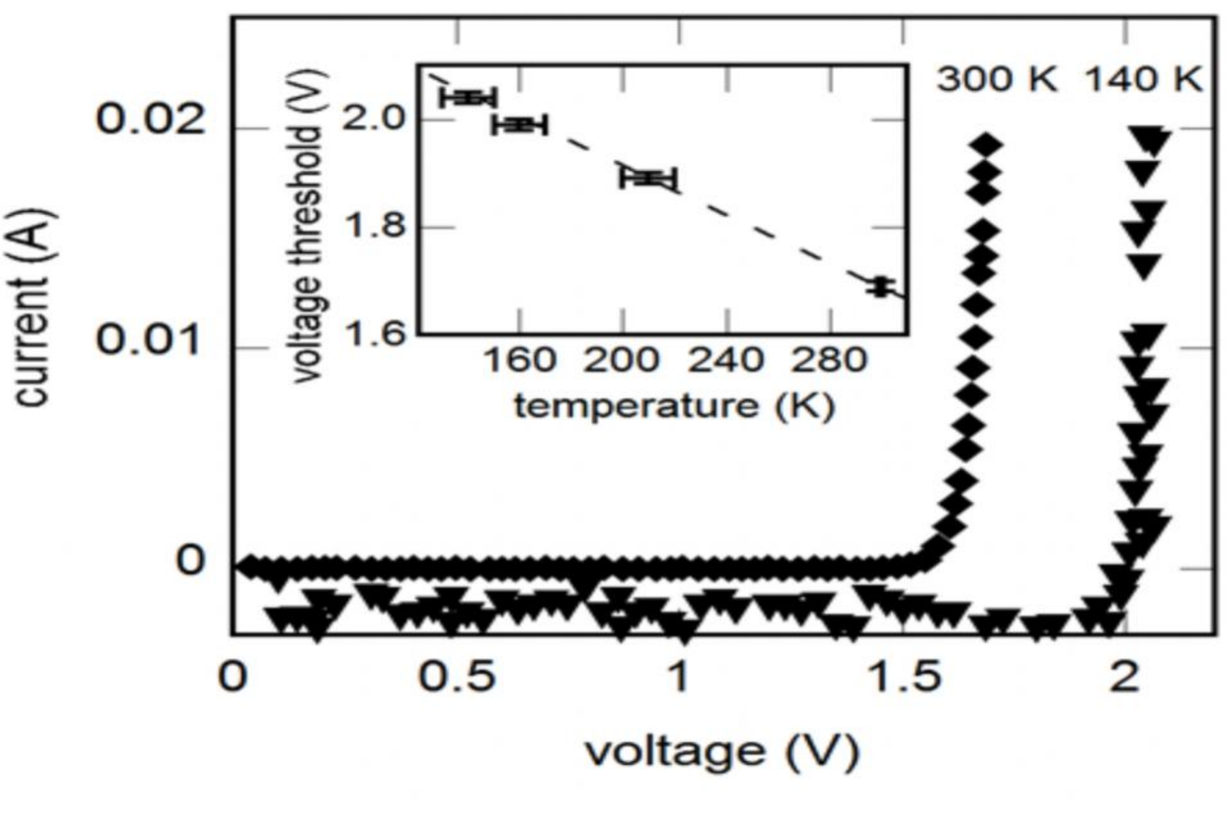

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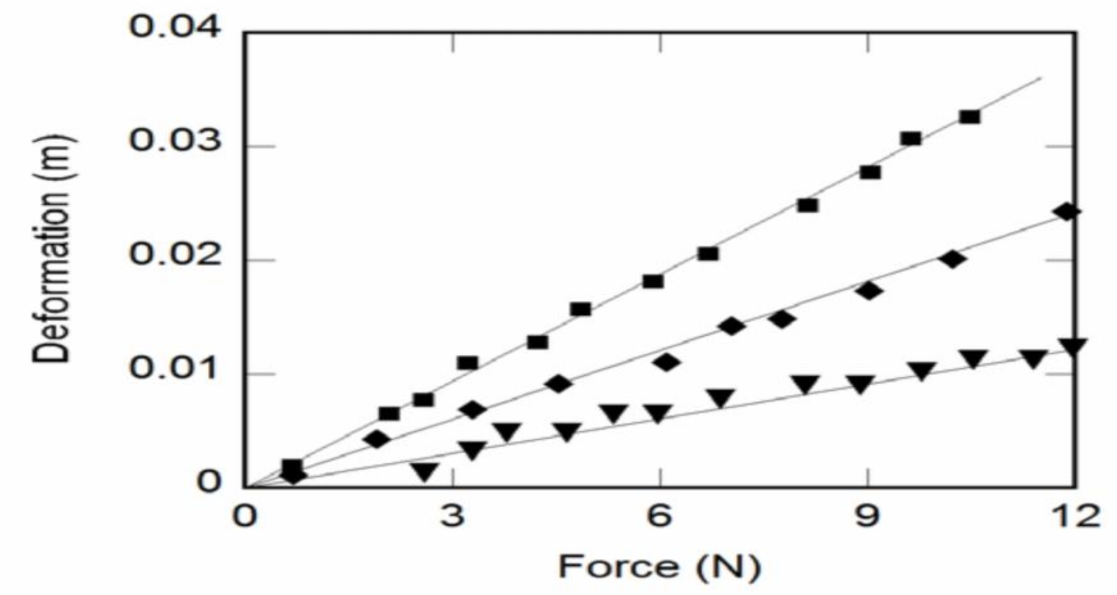
Figure 3: (adapted from a student report) deformation of a copper rod vs applied force at the middle of the rod. Different rod lengths are represented. The slope of the linear fits is related to the Young modulus.



THE IMPACT OF THE OPEN LABS ON STUDENTS AND TEACHERS

As we wanted to have a first feedback from the students to gauge their reception of these projects, a survey was send consisting of a series of open-ended questions. The goal was not to assess student's knowledge improvement, but to see how their perceptions compare with our objectives. Before the project week, at the beginning of the year, the open projects were proposed as an alternative choice to the more standard focused labs. Among 103 students, 50 chose to follow the open projects, but a limit was set to 24 because of practical constraints. Both open and focused projects were held in parallel with a similar schedule with the same instructors, and for similar students, allowing us to compare the perception and opinions of students following the open projects to those following focused labs. Not all students answered the survey, so we compared 17 students for the open projects and 21 for the focused ones.

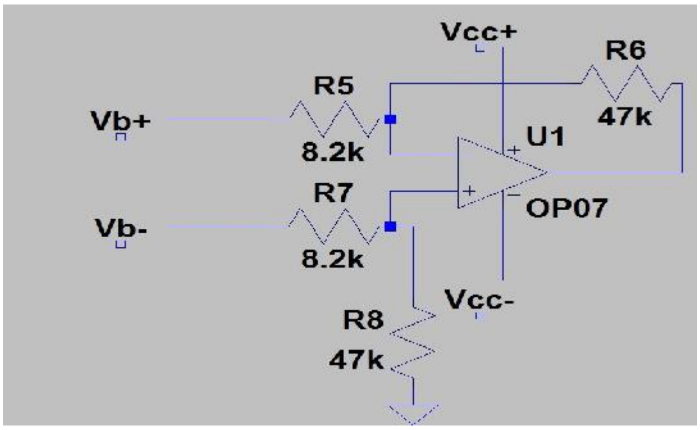
Table 3 presents the questions and the answers classified in categories.

		open-project students	focused-lab students
"What is the contribution of this lab week to your scientific formation?"			
experimental capacities	*"the most important thing I learned is how to interpret data". "I learned to perform experimental work"*	65%	24%
academic knowledge	*"knowledge on transition phases", "a better understanding of super-conductivity"*	30%	57%
difficulty of doing an experiment	*"doing a proper measurement is not easy"*	29%	14%
"What was the impact of this lab week on you, on a personal basis?"			
autonomy, patience and perseverance	*"I grew in autonomy", "patience, and not giving up"*	18%	57%
team work	*"team work [...] communication, sharing of ideas and point of view"*	53%	24%
work organization	*"organization and a better capacity for team work"*	24%	0%
"What did you particularly appreciate in this lab week?"			
autonomy and liberty	*the total liberty we had: we had our own room, our own setup, our own topic", "the liberty, being able to try things and fail"*	59%	38%
interaction with teachers	*"I appreciated the teachers' trust", "the exchanges with the teachers"*	41%	19%
team work	*"group work"*	24%	19%
having five full days	*"having a lengthy student lab gives a different point of view"*	0%	24%
"According to you, what was lacking in this lab week?"			
time	*"Time?", "more time", "Time. It is a pity that it is so short. I wouldn't have mind having a week more"*	59%	38%
better equipment	*"more precise equipment", "better equipment"*	35%	24%

Due to the relatively small number of participants, we will only use these survey results to discuss general trends among student'sanswers.To the question "What is the contribution of this lab week to your scientific formation?" the open-project student answers put more emphasis on the experimental process (65%), whereas a majority of focused-lab student answers enters into the theoretical concepts category (57%). This significant difference mirrors the emphasis put on experimental methods rather than theoretical concepts by the open labs. To the question "What was the impact of this lab week on you, on a personal basis?", team work and work organization is much more often quoted by open-project students than by focused labs ones (53% vs 24% and 24% vs 0%). More surprising is the low mention of autonomy by the open-project students (18%), especially compared to the focused-lab students (57%). However, to the question "What did you particularly appreciate in this lab week?, more than half (59%) of the open-project students enjoyed being autonomous (com-pared to 39% for the focused-lab students). It is interesting to note that the students appreciated the autonomy during these projects, but did not acknowledge it as an important factor in the previous question.The interactions with the teachers were also often mentioned: in 41% of their answers, compared to 19% for the focused lab students, whereas the teachers spent as much time with both type of students. In a PBL the role of a teacher is more about mentoring, helping students to reach their own decisions, than teaching in the traditional sense. In the open projects every setup is as new to the teachers as to the students, and it seems that the students were sensible to the different dynamic it creates.To the question "According to you, what was lacking in this lab week?", time was cited by 59% of the open-project students (compared to 38% for the focused-lab students). The need for better equipment was mentioned in a similar fashion by the open-project (35%) and focused-lab students (24%). This latter result is surprising since the equipment used in the focused labs is often of laboratory quality, and the budget for these labs is in the 10000-euro per-setup ballpark. Finally and most important, to the question "Would you like to have a similar lab week again?" only a marginal number of students answered "no". No difference could be observed between open-project and focused-lab students. The five instructors who mentored these labs (among which two authors of the article) were also asked about their teaching experience. All teachers consider that the main upside of these projects is that they constitute a good introduction to the experiment, that it gives students "a better understanding of what measuring means". Among other upsides, autonomy and the fact that students can choose and accomplish their own projects are often quoted. As downsides, it was noted that the students often focus on the experiment itself to the detriment of the physics at play and the analysis of the data, which could have been lead further in many projects ("students did not push enough their experiment"). Some students seemed to consider that obtaining data was enough to complete a study, and failed to analyze their results as thoroughly as possible to obtain more physical information. Last but not least, all teachers enjoyed mentoring the open projects, and are willing to do it again the coming year. They appreciated the variety of the projects, the pleasure of the challenge for the teacher, and of discovering new thing. PBL is known to engage students and to increase their motivation; it can also be engaging for the teachers.

CIRCUIT DIAGRAM:-

Figure4: illustrating the simple experiment based on electrical properties via arduino.



CONCLUSION

New low-cost technology, such as the open-source Arduino microcontrollers and associated sensors, opens the route to simple implementation of project-based physics student labs. This report describes a practical framework for such labs. Within this framework, students can perform pertinent studies of physical phenomena at the level of their senior wing curricula even with this low-cost equipment. Our survey on students' and teachers' perceptions suggests that students felt engaged by their projects, discovered experimental physics, and appreciated this intense lab week. The majority of the students mentioned better experimental methods as contribution to their scientific formation. Even though a quantitative assessment of the student's knowledge and skills improvements during these labs was not done, our study suggests that the knowledge gained by the students is less conceptual than in a traditional student lab and more centered on soft skills, such as autonomy and team work.

Beyond this particular PBL framework, the possibility to do physics experiments with a low-cost hardware opens some interesting possibilities. It could be used to develop institutions physics curricula in emerging countries where limited funding is available to build new labs. It could also be used to let the students perform experiments outside of the institutions walls. One could imagine a physics curriculum that includes home-work with "do-it-yourself" experiments using Arduino boards and simple electronic sensors that could be lent to students, with tasks or challenges corresponding to the lesson of the day. It could also be particularly useful in the case of an online education curriculum and MOOC type of approach. Finally, the development of similar Arduino teachings in other universities could encourage new types of exchanges among physics teachers and students all around the world.

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