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This is the peer reviewed version of the following article:

Original:

Montalbano, V., Marinelli, C. (2019). A flipped-classroom pilot in a spectroscopy course for undergraduates. In Journal of Physics: Conference Series (pp.1). Dublin, Ireland : Institute of Physics Publishing [10.1088/1742-6596/1286/1/012017].

Availability:

This version is available <http://hdl.handle.net/11365/1086104> since 2019-12-10T10:47:45Z

Publisher:

Institute of Physics Publishing

Published:

DOI:10.1088/1742-6596/1286/1/012017

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To cite this article: V Montalbano and C Marinelli 2019 *J. Phys.: Conf. Ser.* **1286** 012017

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A flipped-classroom pilot in a spectroscopy course for undergraduates

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Abstract. In order to promote problem-based and active learning in the physics laboratory, we designed a flipped classroom focused on the Franck-Hertz experiment. The flipped classroom approach moves course content from the classroom to homework and uses class time for engaging activities and problem solving. This constructivist approach to teaching is an effective means of student-centred collaboration and it can promote active learning, enhance the critical thinking and obtain the maximum use of student-faculty time together. We report preliminary results of the flipped classroom approach to a laboratory and how it worked in the context of a small group of students in a physics course.

1. Introduction

Despite the belief of many physics faculty that students learn best by listening to expert lectures, the literature demonstrates that this is not the case. The evidence for higher conceptual understanding gains in active learning environments over passive ones is hard to overlook [1–3]. Traditional lectures (teacher-focused, with passive students) still remain as the only instructional strategy of choice in many science courses. Adoption of research-based instructional strategies is low or absent, despite a large body of physics education research (PER) spanning over decades, and extensive dissemination efforts by physics education researchers [4–6].

An opportunity for curriculum renewal and developing a more student-centred approach is the flipped model [7–9] which has the potential to enable teachers to cultivate critical and independent thought in their students, building the capacity for lifelong learning and thus preparing future graduates for their workplace contexts. These improvements are becoming increasingly important as we face a shortfall of skilled workers in science-related disciplines.

The instructional strategy is to reverse the traditional learning environment by delivering instructional content outside of the classroom. Thus, the flipped approach moves activities, including those that may have traditionally been considered homework, into the classroom. Interactive engagement techniques enable active learning with many opportunities for formative feedback to the student. Science education literature indicates that students taught interactively have a considerably better conceptual understanding and problem-solving skills than students taught with traditional lecture [1].

Usually, the flipped model is implemented in a large-enrollment physics class like introductory undergraduate physics course. We tested the methodology in a rather different context, namely, a



specialized physics course to enhance modelling skills in the laboratory. In the next section, a previous successful experience with a small group of students which inspired the designing is described. This flipped classroom in a laboratory course with few students, showed the effectiveness of the methodology despite the short time available if a careful choice of materials and activities is done. The context and the realization of the pilot with undergraduate physics students are reported in the following section. Finally, some comments and remarks on the effectiveness of this approach in physics laboratory education are given in the last section.

2. A previous successful experience

The idea of proposing a learning path in laboratory based on physics education research arose from an early experience realized with a small group of graduate students [10]. A flipped classroom was realized in pre-service education in order to promote multimedia (MM) and the quality of their use in the teaching and learning processes in laboratory. The course, Physics Lab Didactics, promoted active learning through the direct experience of young teachers. The flipped classroom approach was presented and discussed with the aim of clarifying the teaching process; in-training teachers were invited to explore how to implement this methodology in a class after their experience. This pilot study showed great potentiality for flipped classrooms in pre-service education and it indicated that the use of MM in the laboratory learning process can be improved by following this approach.

2.1. The flipped classroom

The main purpose was to promote the use of MM in physics education through direct involvement of young teachers in specific tasks. The idea was to show them that learning by themselves how an MM tool works and then designing and developing new effective materials for the use in class was possible even with little time. For the flipped classroom, four open-source software (*Audacity*, *GeoGebra*, *Algodoo*, and *Tracker*) were proposed. A few words were spent introducing them (where they could be downloaded, how each software could be useful, and so on) and presenting the proposed materials (one or two examples in PER for each tool).

2.2. Tasks

The goal of maximizing the exploration with the proposed MM tools was achieved by assigning the following tasks to each student:

- Choose a different MM tool (promote cooperation in organizing the tasks);
- Learn to use the MM tool (require active learning);
- Design a learning path related to a physics lab topic where the MM tool can demonstrate effective assistance in the learning process and implement it in details (promote active learning in teaching skills);
- Share his/her learning path with peers with explicit remarks on methodological choices, and the strengths and weaknesses of the use of the software (maximum dissemination of MM and learning paths).

2.3. Results

Each teacher presented and discussed a different and richly documented learning path. The main goal achieved with the flipped classroom was the excellent engagement and the active response from teachers. Their full involvement led to animated and interesting insights into the use of the programs in the classroom and in the laboratory. A direct assessment was performed during lesson time, laboratory and MM products were shared together with new ideas and educational materials, maximizing the available time. The success of the teaching experience relied on a careful choice of the initial materials proposed for the flipped classroom and a well-established student-teacher relationship.

3. Designing and realization for undergraduate physics students

In order to improve the effectiveness of the learning process in the laboratory context, we decided to test the methodology in an undergraduate course. We used a flipped model approach for designing an introductory laboratory in the course of Laser Spectroscopy and Applied Optics for students enrolled in the third year of Physics and Advanced Technologies degree course. The aim was to develop problem-solving skills in laboratory and to improve physics learning by modelling, i.e. by engaging students in activities that help them to organize concepts into viable scientific models. The context was a very small class (about 10 students) where all other courses utilized very traditional methodologies (frontal lessons, detailed recipes in lab, etc.).

3.1. Contents and methodology

The learning path was focused on the Franck-Hertz experiment as a laboratory for introducing the light-matter interaction. The Franck-Hertz experiment was the first electrical measurement to clearly show the quantum nature of atoms but it is not commonly displayed in laboratory courses for physics students. Sometimes, it can be utilized for introducing the students to fundamental aspects of QM and finding the most suitable teaching approach to develop a deeper understanding and comprehension of the QM concepts (see [11] for an inquiry-based experience with engineering students).

The introductory laboratory was realized by:

- proposing a plain task which seems easily achievable by using classical physics;
- discussing students' solutions and give gradual hints toward the experimental device available in lab;
- direct discovery in lab of an unexpected behaviour;
- discussing with students what can be the new phenomenon;
- confirming the quantum description of the phenomenon by measuring the frequency of emitted light by using a monochromator.

3.2. From theory to practice

After the designing, it took a few months to acquire the instrumentation for the Franck-Hertz experiment. Meanwhile, the first regular course would have been in the following academic year. Thus, we decided to test the introductory laboratory in a pilot internship on matter-light interaction (not mandatory for students). Internships in a research laboratory are foreseen in the degree course and allow to acquire additional training credits. The internship on matter-light interaction was chosen by 5 students (at the end of the 2nd year with all related examination like the one on electromagnetism just acquired).

The task was to identify a stable source of electrons and to characterize their velocity distribution. The activities took about 13 hours in the laboratory and were as follows:

- presentation, what we do and how to assign the task (1 h);
- discussion about solutions proposed by students (2 h);
- discussion about other experimental situations (2 h);
- exploring the experiment, qualitative and quantitative observation, visual documentation (2 h);
- presenting software for video analysis (*Tracker*) and give some hints about a series of measures (1 h);
- measures in lab and data analysis (2 h in lab and homework), with teacher support only on demand;
- presentation of the second activity in lab (1 h and homework), documentation on monochromator is given;
- the measure of frequencies of emitted light (2 h).

The assessment was carried out on the basis of discussions between students and the instructor during the activities and the final report required for obtaining the academic credits.

4. Results, remarks and conclusion

Students were resistant, in the beginning, to new instructional techniques. Moreover, they underestimated some relevant aspect in the task. For example, in the first discussion, they were ready to propose an evaluation of the electron velocity distribution by studying trajectories in a constant magnetic field but no source for electrons was given, and any kind of modelling or relation between the distribution and measurable physical quantities was missing. After a little discussion, a cathode ray tube was proposed but they have no idea about how electron emission can occur. At this point, some hint was given by the instructor (thermionic emission) with other open question (the metal cathode is usually in tungsten, why?). A schematic diagram of the Franck-Hertz tube was given (figure 1) with the suggestion of studying it in order to understand what happened in the case of a vacuum tube when the electrical potentials U , U_F , U_{CS} and U_{GA} change.

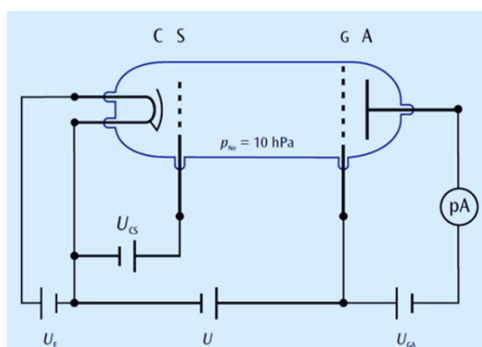


Figure 1. A schematic diagram of the Franck-Hertz experiment. The tube is fitted with four electrodes: an electron-emitting, hot cathode C; two metal mesh grid S and G; and an anode A. The grid's voltage is positive relative to the cathode so that electrons emitted from the hot cathode are drawn to it. The electric current measured in the experiment is due to electrons that pass through the grid and reach the anode.

In the second discussion, students were able to link the Joule effect to the choice of the metal cathode but their understanding of the thermionic effect still remained at a very superficial level (no reference to Richardson's law that links temperature and extraction work from the metal or to the Schottky effect that justifies the presence of the potential U_{CS}). The role of potential U_{GA} remained unclear. Finally, students evaluated the order of magnitude for velocity and how it changes with different U (monotone function). A new hint was: what happens if there is a gas inside the tube (low pressure)?

4.1. In laboratory

The next step was exploring what really happens with a tube filled with a low pressure of a gas. The students could explore the phenomena, decide what measurements were useful and propose other measures for checking their modelling of the electron collisions with atoms.

Initially, the tube was powered with a saw-tooth voltage U and the signal was displayed on the screen of an oscilloscope (see figure 2).

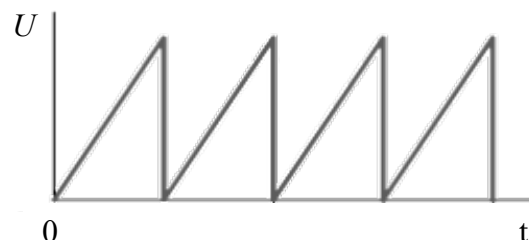
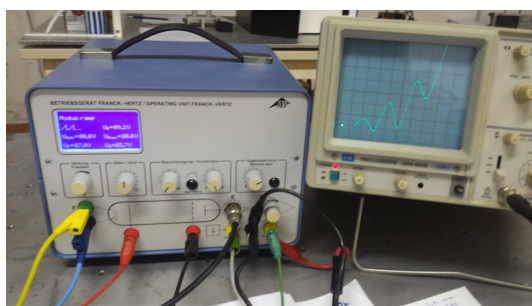


Figure 2. The Franck-Hertz device, showed on the left, allows to visualize the transmitted current directly on the screen of an oscilloscope if the tube was powered by a voltage U varying as a sawtooth wave (on the right).

The result was in complete disagreement with the prevision of classical physics and showed until to three peaks. Thus, the students' prediction of a monotone increasing with the increase of the voltage U , even in the case of both elastic and inelastic scattering with the atoms, resulted completely in contrast with the experimental evidence.

The cognitive conflict led to a discussion in which emerged the need to introduce quantum physics for describing the interactions between charged particles and atoms.

For a better understanding of the phenomenon, the tube was supplied with a fixed voltage U . In this condition, the weak pulsing light in the tube observed with the variable supply disappears for values of U lower than 19 V. For higher U values the atoms emitted light in one or more well-defined spatial regions where electrons have gained enough kinetic energy for allowing inelastic scattering as shown in figure 3.

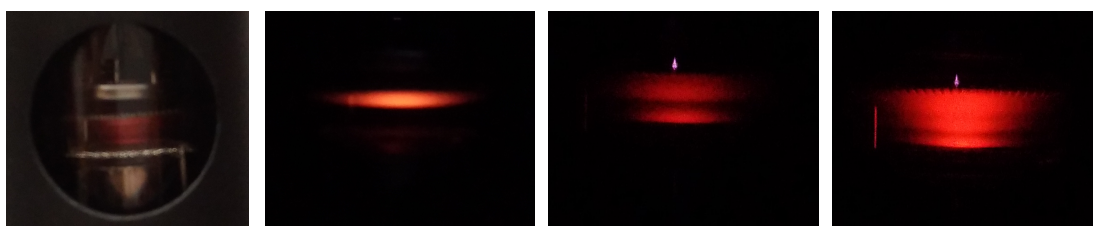


Figure 3. The Franck-Hertz tube is shown on the left (a), where it is possible to recognize cathode, anode and the metal grids with inside 3 regions in which atoms are emitting light. By varying slowly, the voltage U it is possible to observe no light emission until a narrow light emission zone near the anode appears (b). For a further increase of U , the light emission zone moves toward the cathode until a second light emission zone appears near the anode (c) and so on (d).

In the following, students revised their modelling for the motion of electrons and checked what happens by varying the other electrical potentials in the light emission zone, guessing a relation between the initial velocity distribution with which the electrons are emitted and the spatial light distribution.

At this point, the instructor suggested a technique for measuring the spatial light distribution by using an open source software (*Tracker* [12]). Some measurements, realized by using images acquired by students, are shown in figure 4. The group designed and realized a series of measurements for further data analysis.

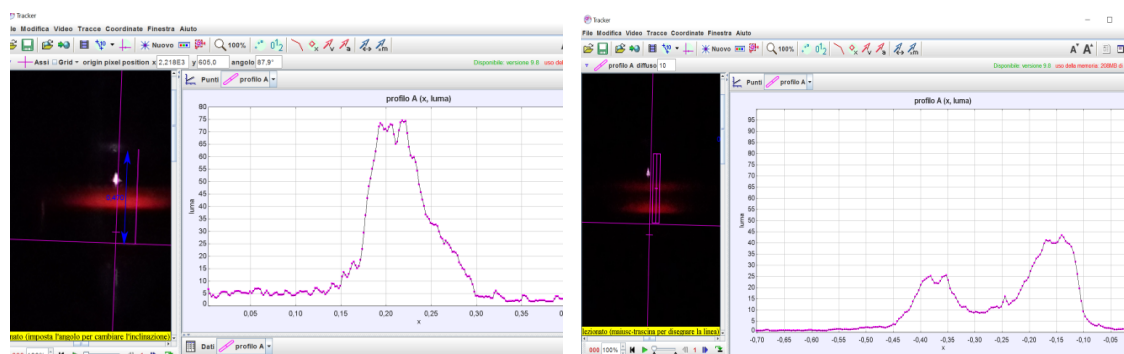


Figure 4. Examples of data analysis with *Tracker* realized on images taken by students' smartphone by using a line profile track, i.e. a tool for measuring brightness and RGB data along a line on an image. The profiles of a single and a double fluorescence emission zone are shown on the left and on the right side respectively.

The final step in the laboratory was to acquire a spectrum of the emitted light (see figure 5) in order to discover which gas interacts with electrons in the tube and to confirm the quantum description of the

phenomena. The light emitted by the Franck-Hertz tube was analysed by a monochromator and the main lines can belong to neon spectrum.

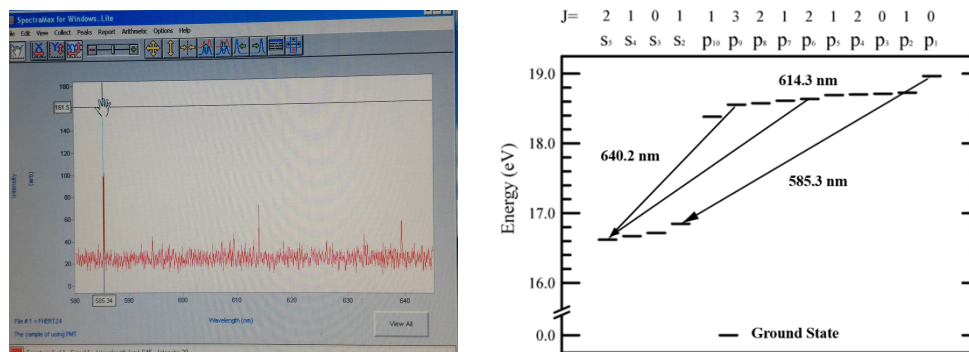


Figure 5. The analysis of the light spectrum by the monochromator is shown on the left side, where the neon principal spectral lines with wavelengths of 585.3, 614.3 and 640.2 nm respectively. On the right side, a schematic representation of the energy levels for neon is given.

4.2. Remarks and conclusion

The flipped model tested in the reported pilot seems to be effective in engaging students in active learning in the class time more than the traditional approach but some relevant problem emerged.

Students persisted in underestimating the relevance of the homework and in lacking a deeper learning approach. This attitude culminated in avoiding to conclude the task assigned by delivering the final report. Thus, the assessment of research-based instructional strategies can be only partial.

Nevertheless, it is possible that encouraging students to read materials and answer questions before class gives students a conceptual basis to better absorb material during class time and approach problem sets more efficiently. In fact, the face-to-face classroom time was used for peer collaboration, inquiry, and modelling and students became more and more active and collaborative.

We think that the decision of testing the learning path in an optional internship was crucial. Inclusion, as initially planned, in a regular course should prevent students from escaping evaluation and encourage them to a deeper learning approach even in homework.

Another relevant remark is the need for a careful choice of materials to be proposed for home study because they can be of help and stimulus in active learning. Finally, we must report that the inverted model realized in laboratory activities requires almost twice the time spent in a traditional approach.

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