PART I –

THE PROJECT OF THE MULTIMODAL NARRATIVE COLLECTION OF S&T TEACHING PRACTICES.
1. Introduction

Multimodal Narratives (http://multimodal.narratives.utad.pt) is a portal, available online since October 2017, that shows how Science and Technology (S&T) teaching practices can be public and shared, preserving their holistic, complex, and multimodal nature using an innovative Instrument – Multimodal Narratives (MN). The portal includes: (a) an MN collection; (b) information about the research projects on which it is based; and (c) information about the own MN instrument. It is targeted at S&T Teachers in all educational levels, S&T education researchers and other professionals.

This publication organizes the NMs available in the collection on this date (2017), presenting and explaining what they are, how they are done and what they are for.

There is a long history of research and work with teachers around the MNs. Since 2014 the MNs have been the object of academic recognition (international publications and PhD theses) and culminated in the creation of this portal and this publication.

The MN, as an Instrument, refers to a protocol to make an MN (data collection, elaboration and validation) that guarantees characteristics and structure common to any MN, as well as a document (linked to independent data) with a multimodal, self-contained, validated, verifiable and public description of professional practices in real work context (e.g. classroom teaching). The characteristics and structure of MN allow comparability (even from different contexts) between them, in order to meet objectives related to the improvement of S&T teaching, research and professional development.

The relevance of MN’ is justified:

a) by an OPEN SCIENCE PERSPECTIVE, since professionals can elaborate MNs of their professional practices, based on data, thus participating in the research process and gradually increasing the available collection of MNs;

b) through POTENTIAL RESEARCH, as MNs allow the study and comparison of teaching practices at different educational levels, countries, and contexts, and even professional profiles, allowing a deeper understanding of professional practices;

c) the VALUE for teacher education and professional development because research and sharing professional practices can influence the quality of teaching practices of the teachers involved.

In this portal, we provide a set of information related to MN, including the protocol with the steps for the development of an MN, a MN example of complete MN and a template. Are presented real reports of people who used the MN in various contexts (professional, research
and training) where they explain the usefulness, usability, and experience they had in the exploration of the MN.

At the moment, around 100 MN of S&T classes of different professionals, from different teaching levels and learning contexts and different countries, namely from Portugal, Brazil and Angola, are organized in a collection. The NM collection is constantly being updated and available for online consultation on the above-mentioned portal (free access, but you will have to create a profile account).

We intend to involve and grow the community of teachers, trainers and researchers around the MN by sharing ideas and knowledge in the various forums available on the site and through the contacts provided.
2. The importance of the quality of S&T teaching practices: in search of solutions

2.1. How to obtain data on teaching practices

Improving the quality of S&T teaching practices with an impact on the quality of learning is a concern for teachers, researchers and society in general. In this context, it is essential to articulate S&T teaching practices with educational research in this field in order to explore viable solutions. One of the difficulties is to penetrate into classrooms and obtain teaching practice data that can be used and compared, both by teachers and researchers, and that retain the holistic, complex and multimodal nature of such environments.

Although there are various instruments for collecting data on teaching practices, namely video or audio recordings (Kung, Kung & Linder, 2005), diaries (Hundhausen, 2002), reports (Alsop, Bencze, & Pedretti, 2005; Mason, 2002), narratives (Craig, 2011), structured daily records with information about events or classroom interactions (Rowan, Camburn & Correnti, 2004), our team missed something that combined all these characteristics. On the other hand, several approaches were identified to access the teacher’s teaching practice in the classroom: (a) teaching characteristics linking them to school culture, curricular material, teachers' knowledge and beliefs and students' learning (Tytler, 2003); (b) collection of indicators on the classroom environment (Borko, Stecher and Kuffner, 2007), or artefacts used in the classroom combined with self-report (Martínez, Borko, & Stecher, 2012).

In this way, we identified the need for an instrument that, not limited to the collection of data about the lesson, could bring together in a document as complete as possible, the contextualisation of the lesson, the teacher's intentions and perceptions, the reactions of students and the own teacher, the work proposed and actually carried out by students, etc. In summary, an instrument that would help to collect genuine and useful data on teaching practices, capturing the teachers' intentionality and that would be translated into a single document that would preserve the complex, holistic and ecological nature of teaching and learning that occurred in an unrepeatable situation.
2.2. How Multimodal Narrations were developed

Since 2007, a team of researchers coordinated by Joaquim Bernardino Lopes has been developing and improving an instrument that allows the collection of relevant and detailed data on teaching practices in the classroom, within the framework of research on teacher mediation in the classroom.

In 2008, the book "Researching Your Own Practice: The Discipline of Noticing" (Mason, 2002) emerges as a source of inspiration for a new conception of data collection in a broad, diverse and complete way of teaching practices. In the same year, the first reference to this approach is made, namely in the article by Lopes et al. (2008).

Later, the first narratives began to appear but still without multimodal elements. These first narratives were subject to a systematic process of analysis by several teachers and researchers, in order to solve problems that were detected (e.g.: focus, objectivity) and to establish criteria for an elaboration protocol, explicit integrating elements and characteristics.

It was in 2010 that the expression Multimodal Narrative appeared for the first time (Lopes et al., 2010) and in 2011 the expression Multimodal Narrative was used for the first time in international literature (Lopes et al., 2011).

In the meantime, several Multimodal Narratives (MNs) from different authors were created, which allowed the development of a protocol for the development of MNs, explaining indications for the structuring, focus, characteristics, reliability and comparability of each MN. The MN is elaborated in three essential phases: data collection; the elaboration of the MN; and the validation of the MN. For each phase there is a set of procedures.

The Protocol was validated by external consultants (national and international researchers) and finally published (Lopes et al., 2014).

Presently, several professionals, researchers and teachers have used and developed MN, according to the published protocol of elaboration and validation.
3. Multimodal Narratives: Conceptualization, elaboration and usefulness

3.1. What are Multimodal Narratives?

The term Multimodal Narrative (MN) refers to two different entities:

(i) A protocol to make an MN (detailed in section 4) that proposes:

a) a set of indications on the collection of classroom data, its context and the use of multimodal records;

b) A set of steps for the narrator to make a single document describing the course of action and discourse among the characters in the classroom, which aggregates and transforms the data collected and incorporates the teacher's point of view in a descriptive way;

c) A set of steps to validate an MN that includes verification of the essential MN characteristics as well as its internal structure.

(ii) A document (linked to independent data) with a multimodal, self-contained, validated, public and shareable description of a teaching practice.

The Multimodal Narrative (MN), as a document, is a chronological, self-contained and multimodal description of what teachers and students do and say in a particular teaching context, aggregating and transforming all the data collected (data independent of the teacher and data that depend on his point of view) following a previously defined and published protocol (Lopes et al., 2014). In this way, an MN aggregates and organises data of teaching practices in a single document and has a first treatment of the data, taking advantage of the teacher’s perspective on what is happening in the classroom (Lopes et al., 2014). In other words, an MN is an autonomous and concise document that can be further analysed, avoiding the difficulty of dealing with multiple data sources (Lopes et al., 2014). It incorporates excerpts of collected data and the description of intentions, decisions, attitudes, silences or gestures of the teacher and students. Once developed by the narrator, an MN is designed and validated by independent researchers to ensure that it is readable, self-contained, reliable and consistent with the data collected (Lopes et al., 2014). Once validated, an MN is not changed, can be made public and
can be used for various purposes. Note the difference between a video or audio recording of a class or other type of data, which if viewed in isolation, do not represent an integrated, intersubjective and articulated description of what happened in the classroom.

3.2. How Multimodal Narratives are done?

The process of building an MN, although complex, allows the data collected to be structured, helping to reflect on the teaching practice and improving the teacher's own perception of his or her class. With some practice, the assimilation of the process turns its construction into a methodical and useful system, allowing a (self) reflection on educational practices. This process goes through three essential stages established in a protocol with indications for:

(a) the collection of classroom data;
(b) the narrator builds the MN, making a single document;
(c) validating the MN.


3.3. The purpose of Multimodal Narratives?

MNs can be used in research, training and professional development in educational and other professional contexts that involve human interaction.

In the field of research, MNs are presented as an instrument that allows the organization and systematization of relevant and diverse data, both in the volume of data and in the diverse nature of the data itself, related to processes and contexts of science and technology teaching.

MNs preserve the complexity of professional environments and allow comparability between them. These two characteristics make it possible to carry out research on teaching practices in extension and/or in depth.

Within the scope of teacher professional development, the MN assumes a double potentiality: the first consists in the deepening of knowledge that allows for the improvement of the quality of teaching and learning practices; and the second in the development of
collaborative practical communities among teachers, where teachers share experiences, visions and teaching practices, among other dynamics, contributing to the improvement of essential skills for professional development, both in initial training and in the continuous training of teachers.

Finally, MNs can be used in other professional contexts, both in the previous training period and throughout the professional career.
4. Project of Multimodal Narrative Collection

The Collection of Multimodal Narratives was created within the scope of the dissemination of an instrument of professional development and research: the "Multimodal Narrative" (MN).

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4.1. Goals

The project of the Multimodal Narrative Collection has the following goals:

1) The dissemination and expansion of MNs as a tool for professional development and research;
2) Sharing the MN Collection for academic, scientific and professional purposes;
3) The creation of a community of teachers, researchers and professionals around the MNs, promoting the interaction of community members through the sharing of knowledge and ideas about the MNs in the forums of the website http://multimodal.narratives.utad.pt dedicated for this purpose;
4) Promote the sharing of projects and publications related to MNs in order to establish new lines of research or to establish contacts with researchers and teachers interested in the use of MNs in their practices or research projects;
5) And arouse interest so that there are submissions of new MNs to add to the Collection.

4.2. Functionalities of the collection
The Multimodal Narrative (MN) collection is also available at http://multimodal.narratives.utad.pt. The collection includes about 100 MN that have been validated and kindly authorized to be made available by the narrators (authors) of the same.

The first functionality is effectively sharing this MN collection in an accessible, public and open way.

The MN collection is extensive in terms of the diversity of educational contexts, teaching practices, the countries in which they were developed (Angola, Brazil and Portugal), and the profile of who narrates MNs (prepared by the teacher himself or by a researcher).

We can also find MN that were elaborated in different types of Teaching, namely:
- In Elementary Education and in various areas such as: Natural Sciences, Mathematics, Physical and Chemical Sciences, Information and Communication Technologies (ICT);
- In High School, in the areas of Physics and Chemistry, ICT;
- Within the scope of Professional Courses in the areas of ICT and Informatics;
- In Higher Education, namely in the areas of Physical Sciences and Mathematics;
- And also in other contexts, such as Adult Education and Training.

The second feature of this collection is the possibility of receiving new MN of teaching practices and professionals from teachers, from other professionals related to education in Science and Technology. It is also open to other professionals from other areas who base their professional practices on interaction with people (such as doctors, nurses, caregivers, etc.). The submission of new MN is done through the platform available on the website http://multimodal.narratives.utad.pt.

After the validation of the new MNs, and with the due authorization of their authors, the MNs will become part of the new edition of the MN collection. In this sense, it is intended that every year there will be the publication of a new edition of the collection in PDF format, in addition to the website.

The third functionality of the MN collection is its use for research or training purposes in various contexts and areas, provided that users are properly registered on the site http://multimodal.narratives.utad.pt and that they correctly reference the MN collection.

The collection in this publication is organized into 10 chapters, according to the level of Education (Elementary, High School, Higher Education, other contexts), area of study (Physical and Chemical Sciences, Mathematics, Informatics, etc.), level of education and chronologically from the oldest to the most recent MN. Each chapter is divided into subchapters, according to the type of narrator (the teacher himself as narrator and lessons narrated by a researcher).
The collection can be consulted in this publication or through the online database where you can consult only a collection of MN or a specific MN, available on the website http://multimodal.narratives.utad.pt.
5. Ethical considerations

The data collected for the development of MNs followed the authorisation procedures in force in the respective institutions. In order to safeguard the confidentiality and anonymity of the participants (students, teachers, institutions), the names were changed to fictitious names in the MNs and the faces of the participants were hidden in illustrative figures/images.

All narrators authorised the inclusion of their Multimodal Narratives in this collection and their availability on the http://multimodal.narratives.utad.pt portal, by means of a declaration of informed consent.
PART II –

MULTIMODAL NARRATIVE COLLECTION
Example 1 of Multimodal Narrative

**Context:** Formal Education  
**Country:** Portugal  
**Professional Code:** Sofia  
**Professional activity:** Teacher

**Narrator:** Teacher who taught the lesson  
**Narrator's code:** Sofia

**Teaching context:** Physical-Chemical Sciences  
  - **Discipline:** Chemistry  
**Education Level:** Middle School – 8th grade  
  - **Age group:** 13 years old  
**School year:** 2007/2008  
  - **Topics:** Acid-based chemical reactions; Atmospheric pollution.

**Multimodal narratives related to this one:**
  Multimodal Narrative 2 – Chemistry Class of the 8th grade (2008)

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**Lesson n.º 1 (05/05/2008)**

**Total lesson time:** 90min

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**Contextual Information:**

This is a group of students aged between 13 and 16 years, who attend the 8th grade for the first time and only 5 have retentions during their school journey.

The school has little availability of classrooms and, for this reason, there is no deployment of classes for practical classes.
As I needed the students to come to the lab, I switched rooms with another classmate. This was the first class in this environment and with this organization of work, which motivated some excitement and deconcentration in the students. In the room where I worked with the class in previous trimesters, the students never sat in groups because there wasn’t enough space to move around the room (it was a room that was part of a prefabricated improvised by the school to deal with the problem of excess of students, which is designated as "the haystacks" given the manifest lack of conditions of these rooms). Previously the students worked almost always in pairs.

Another fact that seems relevant to me is the little contact these students had with the material, equipment and reagents normally used in chemistry. The students in the 7th grade made few practical activities (they didn’t have classes in the laboratory and the class was larger) and in the 1st and 2nd trimesters they only studied Physics.

These students have a 90-minute weekly workload for Physical Chemistry and there is no shift deployment, so there are always 22 students in the class.

The classroom doesn’t offer many possibilities for the organization of the space, once it is a laboratory with 3 fixed workbenches (with great dimension), in which I asked for extra tables to be placed to be able to organize more work groups.

In this way, the 22 students were distributed in working groups with 4 or 5 elements each, as can be seen in the classroom layout shown in figure 1.

![Classroom layout](image-url)
The free top on the central bench was used by me to place and organize the material to distribute to the students.

**Synthetic narration of the entire lesson:**

I started by organizing the students into five working groups (see figure 1) and drew attention to the need to keep the working tables organized, which took about 8 minutes.

Then, I distribute the grid relative to the self-evaluation of the students' performance in the tasks, one per group, making a brief synthesis about its fulfillment and emphasizing the importance of their correct execution.

Next, I showed a photograph with dead fish floating in a lake as a result of water acidification (Physical Situation) and questioned the students, based on the knowledge already acquired in the discipline of Natural Sciences, about this phenomenon. Almost all the students tried to answer at the same time: pollution, says one student; acid rain, says another; acidification, adds another. As all the students wanted to answer, I asked them to try to answer one at a time. Taking advantage of these answers, I asked them if they knew how acid rain formed. Only one student mentioned that acid rain is formed through carbon dioxide.

After 9 minutes from the beginning of the lesson, I distributed a questionnaire to the groups about the physical situation with five questions on this topic, in strips of paper. While I was distributing, I asked the students to pass all the questions they had to answer on to the notebook. I emphasized the importance of reading the question well, discussing it in a group, and together giving the answer that would then be presented by the group spokesperson. While the students were trying to answer, I moved around the room trying to ensure that they had understood the task and checked if there were any doubts, encouraging collective participation and the exchange of ideas within the groups. During this task, two students showed little engagement: Sandro, who manifests difficulty in remaining seated in the respective group, and Pedro, who tends to discuss other issues, having been called to attention several times.

During the completion of the questionnaire task, I wasn’t very requested by the students, since they all demonstrated sufficient knowledge to answer the questions. In general, all the students were engaged and working, even though each group showed different rhythms.
When all the students indicated that they had finished (after 15 minutes) I started by calling a member of the first group to the board to write down their response. I did this successively with everyone for all the questions, which in the end were supplemented with the answers from the other groups, iteratively. The students were helped by me in the final synthesis of each question.

After the students had finished writing the answers on the board and in the notebooks, I placed on the work desks the material needed to perform the 2nd task, which consisted of neutralizing an aqueous solution of sodium hydroxide, through the action of the \( \text{CO}_2 \) released by the students, while they talked inside the Erlenmeyer that contained the solution. This task was presented in a paper strip that contained the explanation of the task (exemplary type) and questions related to the interpretation of the phenomenon in question. Once again I asked the students to pass the questions to the notebook. I explained the task they were going to perform and exemplified it by speaking into the Erlenmeyer.

During the execution of the task by the students, there was some confusion due to the failure to achieve the desired results. The previously prepared solution was very concentrated and the students couldn’t see the change of color, despite several attempts. As such, I needed to dilute the solution and ask the students to repeat the procedure. Even so, the students still had difficulty completing the task. As a result, they often called me and I had to move between the groups, questioning them and removing the doubts that arose in the meantime. At the end, I asked the students to record all the observations in their notebooks and to answer the question in groups: "Why has the solution changed color?". The registration of the observations and their understanding were always monitored by me, as I was asking questions, in order to lead the students to identify the reagents in order to elaborate the word scheme that translated the chemical reaction. In almost all the groups, the students showed some difficulty in understanding that the initial solution was basic and, as such, in identifying the phenomenon observed as a neutralization reaction. I explained several times what 'neutralizing' means and had to refer to the name of the reaction products myself, as no group could write the word equation. In some groups I found that the students referred to phenolphthalein as a reagent. In general, all groups concluded that there was a chemical reaction, although they couldn’t identify it. Thus, based on the students’ responses, I had to present the word equation for this reaction on the board, because the students weren’t able to get there alone.
As there were only about 20 minutes left until the end of the class, the 3rd task, initially thought to be executed by the students, had to be demonstrated by me. Using universal indicator paper and three acid solutions (carbonic, sulphuric and nitric acid) and with the help of the students, we verified the pH of these solutions, using the respective colour code. I asked the students to record the pH values of these 3 solutions in a table and explained that the increase in rainfall acidity was due to the presence of carbonic acid, sulphuric acid and nitric acid in the atmosphere.

At the end, I showed the figure that appears in the 4th task and remembered the pH values obtained in the previous solutions. I also mentioned the influence of these acids in the atmosphere, regarding the formation of acid rains. However, as there wasn't more time, I asked the students to finish task 4 at home, or in the Accompanied Study.

At the end of the lesson, I asked the students to don't forget to complete the form distributed at the beginning concerning the evaluation of the performance of the tasks.

**Episode(s) related to this lesson:**
All the episodes of this lesson will be presented below, since in all of them there are aspects related to research on mediation, namely regarding the choice, presentation and management of tasks. These three aspects were decisive for the events reported in the episodes. With regard to the use of aspects related to graphic language, the students were presented with images and schematics and asked to prepare representations (tables, word schemes). Therefore, there was no choice or selection of episodes for this multimodal narrative.

<table>
<thead>
<tr>
<th>1st Episode</th>
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<tbody>
<tr>
<td><strong>Beginning</strong>: 8min 42s</td>
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</table>
After the students in each group had observed an image (figure 2) on A4 paper (one copy for each group and one that I held in my hand) with dead fish floating in a lake as a result of water acidification (physical situation), I told the students that this was a phenomenon that they had already studied in Natural Sciences and asked if they knew what it was about.

![Figure 2: Image provided to students on A4 paper.](image)

After observing the image, the students began to give their answers without respecting their turn and trying to speak at the same time:

- Pollution - said Joel, Manuel, Ruben, Pedro and Miguel talking over each other and at the same time.
- Aquatic - added Manuel.

And I continued:
- But this pollution has a specific name... and it causes acidity... of the waters?!
- Acid rain - says Ruben.
- Acidification! - says Miguel.
- Pollution of rivers. - adds Joel.
- Acidification of aquifers - insists Miguel.

Everyone tried to respond at the same time, arguing with each other, while Miguel insisted on acidification. At this point, colleagues wanted to "beat" Miguel, but he insisted...

- River acidification!
- One at a time, please! - I added in an attempt to maintain order in the speeches.
- Acidification of aquifers - continued Miguel.
- And how does that happen, Paulo? - and now I'm going to one of the students who stubbornly said acid rain.
- It's from the acid rain. - answered the student.
And how is acid rain formed? Does anyone know? I questioned the class by looking around.

Once again the students answered at the same time.

- Through carbon dioxide. answered Rita and Ruben.

- My friends, one at a time!

At this point I was "brusque" with Ruben because he had always spoken at the same time as his colleagues in all their speeches. As a matter of fact, this student has great difficulty in respecting his colleagues' turn to speak and has an old "bad habit" of intervening in their turn, so he said that it was Rita’s turn to speak.

- Oh, “Stora”! (abbreviation for teacher) - Ruben reacts by showing himself to be sullen at the fact that he didn’t’ let her speak.

Rita there followed up with the answer:

- The gases released by cars and industries go into the atmosphere and in contact with water acidify and then precipitate.

- Okay. More... Does anyone else know anything about it? - I tried to get some more students to add some more ideas. But Rita's answer left her classmates without much more to add. Besides, Ruben was still sulking...

- That's what I wanted to say!

- Exactly... or in other words?! Tell me, what did you have to say? - I tried to smile, but Ruben remained silent.

From this moment on, given the incident with Ruben, the debate of ideas was interrupted and I proceeded to the task of the questionnaire.

The excess of disorderly interventions and the noise that was generated brought the discussion to the end. By giving Rita a turn to respond, having calmly exposed the causes of the acid rain, she allowed the dispute with her colleague for the best response to end, but prevented the other colleagues from continuing to explore her ideas. The dialogue was cut abruptly and I closed the question, moving on to the distribution of the questions (figure 3), in small pieces of paper, among the different groups.

**Task 1:** Based on your knowledge of acid rain and its effects, discuss with your colleagues in order to be able to answer the following questions:

a) What is the effect of acid rain on living beings?
b) How does acid rain affect aquatic ecosystems?
c) How can acid rain affect the life of terrestrial plants?
d) How can acid rain affect animal life?

Figure 3: Questions presented to students

I gave one strip of paper to every two students as it was a way to save paper and photocopies, since there is a limit to how much we can do at school. I didn’t choose to project the issues in an acetate, or through a multimedia projector because this room faces south in one corner of the building and has two glazed walls, without blinds (only curtains), which prevents it from being possible to view with quality any projection that is made on the whiteboard, given the excess of luminosity. In addition, the class starts at 1:30 in the afternoon, which aggravates the problem.

I started distributing the strips of paper to the groups and in the meantime I was saying:
- So, you’ve heard so much about it... you’re already in a position to answer these questions...
- Pass to the notebook what’s there... pass to the notebook...

However, Miguel asked:
- All of them?
- You all pass to the notebook, so you can read it well... - I replied.
- Since you were so excited to talk about it... you know perfectly well what’s there! - I insisted.

I showed once again the grid that allows self-evaluation of the students' performance during the execution of the tasks. I had already explained how to fill it in, but since they are using it for the first time I decided to show them where to put the cross in this case:
- That is, in relation to this form.... you have heard about it - I said as I was showing the grid.

In the meantime, Manuel called me to ask what the date was, as he was starting to organize the notebook to write the questions.

I noticed that there were students who hadn’t yet started passing the questions to the notebook.....
- Kids, everyone should pass the questions to the notebook.
The idea is to read the question, talk to each other and try to give an answer that is from the group. Be aware that now I don't want individual answers. You will talk to each other and the answer you write is the group's answer.

I have tried to ensure that this question about the need to exchange ideas with each other has been understood by everyone. In the meantime, I went around the room and found that in group V only two students were trying to answer the first question and the boys were distracted. So I went to that group:

- The answer is in group.... you have to talk about it, see what you already know and don't know and try to give an answer in group. At the end, a student spokesperson presents the group's response to the board.

I circulated around the room again to see how the students were working and stressed the need for them to work in groups.

- So I don't want individual answers. Any doubts you may have...

I tried to assure that each group wasn’t doubt about the task.

As it was a small set of questions, the students easily achieved what they were supposed to do. Soon, some students started passing only the first question into the notebook and trying to answer it. Other students (more female students) started by passing all the questions to the notebook and only then began trying to answer them. Anyway, I noticed that the task itself wasn’t a problem.....

I let them work.... but I quickly found that the students barely spoke to each other. After 1 min 30 s, some students called me individually to ask questions of the kind:

- Do I have to give a big answer? - Miguel asked.
- No, it has to be complete. Try to answer based on what you already know.

I stressed that they would have to talk to each other to get the answers.

In group I they called for help to clarify the meaning of the questions. This group showed some commitment to what I went there for...

- I don’t understand question a) - Miguel and Rita asked.

I got closer and just read the question out loud.
- What is the effect of acid rain on living beings?
- Death...- replied Miguel with an air of astonishment.
- Of the living beings..... - I insisted.

But Miguel kept repeating it:
- Death!
- Now they are dead, but they were alive! - I replied smiling when I reached the sense of the true doubt of the students.

All the students in the group laughed and began to write in their notebooks without saying anything more. Apparently they managed to move forward.

I've decided to move around the room and remain silent. I noticed that the students seemed to be working on the answers to the questions, except for Sandro's occasional attempts to distract colleagues from the other groups, as he got up to sharpen his pencil. After 4 minutes, I had to call his attention and for this reason, I was no longer silent. However, I indicated to Sandro and Daniel that it would be better to sit on the other side of the table to be closer to the group colleagues. However, my real intention was that Sandro would sit with his back to his colleagues from the other groups and there would be less cross talk!

After that I just watched.....

I noticed that group III works very well, even though I placed one of the students with a complicated behavior there (Manuel). It is a group with a student (Joana) who shows great maturity for her age and who manages to involve her colleagues in working with her, although she is a student who interferes little in the discussions that extend to the class. They didn't call me once and I found, in the phase that followed (presentation and discussion) that I was the group with the best answers (figure 4). I also noticed that she didn't limit herself to dictate the answers to her colleagues, because she tried to talk to them and asked what they thought of their answers.

Figure 4: Answers from Group V

The students were working and it was only 2 minutes after the call to attention to Sandro that the two students of group IV, who worked in a committed way, but without much collaboration from their colleagues (Sandro and Bruno),
called for me. At that moment, the two boys tried to pay attention to the dialogue I had with their colleagues, pretending to be committed.

- The effect of acid rain on the plants corrodes them? - asked Irene.
- And not only that! Those who died in the meantime, but in relation to all the others...? - I said, trying don’t answer the question.
- No more plants will be born in those places! - Irene concluded.
- Why? - I asked.
- Acid rain affects the soil... - replied Irene and Cátia.

As additional information, I indicated to the group that there are plants that don’t like acidic soils and that if the acidity is high, few plants develop there.

The students seemed to have understood what was intended and I left them alone. However, I noticed that Bruno and Sandro only copied what the two colleagues (Irene and Cátia) were trying to do together. Sandro is a critical case... and distracts Bruno.

In the meantime, I was asked by group II about the same question.

Joel, pointing to the paper says:
- The c)?

I just read the question out loud:
- How can acid rain affect the life of terrestrial plants?
- They affect their development..... - answered Telmo.
- How?

The students looked at each other, but said nothing. In the meantime Telmo started writing and I watched. Then he dictated to his colleagues what he had written in his notebook.

The students continued to work, but in this final phase (about 3 min) there was already a greater buzz in the room which indicated that some groups were already finishing, namely group III which was the first (about 4 minutes before the others).

Group IV was the one that took the most time. Although this group seemed committed while I was in the room, it didn’t work as hard as it seemed at first sight. With the exception of student Pedro (who I called twice because was talking to Sandro) all the others seemed to be working and talking about the issues. Only when they had to come and explain their answers to the board I realize that they had worked less.
At this stage, while waiting for colleagues who were finishing the task, I suggested that they complete the self-evaluation grid.

The execution phase of this task took about 15 minutes.

*(Intermediate time: 27min 10s)*

After having answered all the questions that were included in the task, the students were able to understand the effects of acid rain on living beings and on the abiotic world. As such, after everyone had answered the questions, one student from each group came to the board to present an answer to a question. Colleagues from the other groups made their contributions in order to improve and/or clarify them iteratively. In this way, the contributions of each group helped to enrich the final answer to each question.

Miguel first came to the board and presented the group I’s answer to the question about the effects of acid rain on living beings:

- Then, Miguel will say what is the effect of acid rain on living beings, according to the opinion of his group. You will hear everyone and if there are different things to add... it will be added at the end! So, come on!
- I think it can cause death and it can cause disease. - Miguel said before he started writing on the board.

As the student wrote on the board I repeated so that everyone could hear what Miguel had said. Then I went to group II:

- What did you say?

Ruben and Telmo tried to talk at the same time. Once again Ruben can’t resist speaking in his turn!

- One at a time, so no one understands each other...- I said, trying to keep order in the room. Then I suggested:

- Start there...one of you! - said, looking at Telmo and Paul.
- It can cause the death of ecosystems. - answered Telmo.

Then I went to group III:

- Here? What did you say?
- It can cause the destruction of terrestrial and aquatic ecosystems, causing the death of living beings. - replied Manuel.

- All right.....there? - I asked the next group, looking at them.

In this group, no student answered immediately, because they hadn’t yet defined the spokesman..... there was agitation in the room because in the other groups they urged Peter to answer. But he wasn’t sure of the answer, since his colleagues in the group had different answers than his own. This was indicative of the fact that the group members worked on their own. I also found this in the answers to the following questions.

- One of you.... we’re not going to raise a question about it now! It doesn't hurt at all, come on! - I said, urging Peter don’t hesitate in answering.

- Acid rain can cause the death of living beings and the acidification of aquifers. - Peter finally answered.

Then I went to the last group:

- Acid rain can cause the death of living beings. - replied Bruno.

Addressing the student who was on the board, I said that we could complete with the answer given by group III.

- There’s no need to erase the answer... let's add what our colleagues said. Complete your answers so that they look like this (the one on the board) - I mentioned that.

The answer has been corrected on the board by Miguel and in everyone’s notebooks.

This was followed by a speech by the spokesman for Group II, Paul having written on the board:

"They acidify the aquifers".

When I questioned the students, I noticed that practically all of them had given the same answer. However, when I questioned Sandra (group IV), she answered:

- Acid rains pollute aquatic ecosystems and cause the death of living beings.

I then ask the student to go to the board to complete the answer that was, which she did by adding:

"Causing the death of ecosystems."

The answer to the third question by Manuel (group III) was immediately interrupted by Sandro, who was having difficulty sitting.....
While Manuel was giving his answer, he was interrupted by me and I had to ask colleagues to listen carefully.

- The acid rains polluting the soil.... - Manuel said until he was interrupted.
- Listen to Manuel.... if you don't hear him, nothing will happen.....

In the meantime, I had to remind Sandro again to don't interrupt his colleagues' work. Manuel then resumed his reply:

- Acid rain by polluting the soil makes it infertile, hindering the development of plants.
- Does anyone give any reason why they should become infertile? - I asked, addressing the class.
- Soil acidification - adds Miguel.

I questioned the other groups. In the end I suggest:
- Your answer is fine. I would only add: 'make soils infertile due to their acidification'. Can you come and write, Manuel? You add only in your answer "make soils infertile due to their acidification."
- Next question... here... someone.... - I continued... going to group IV
- Who's on the board?

It was Carolina's turn:
- When animals eat and drink, they can catch diseases and cause death.

However, I had to draw attention to the fact that they should listen to Carolina. Once again, I had to ask Sandro to don't bother his colleagues.

Groups I and III, Miguel and Joana, respectively, have the same answer. I therefore suggested simply that they replace the expression 'when eating and drinking' with 'through food and water'.

Irene had to give the answer to the last question, but since the class is a little agitated at the moment and the student speaks very quietly, they can't hear what she says very well. Moreover, since my attention was focused on what Irene was saying and I was situated next to her, the students sitting in the farthest places took the opportunity to talk about extra matters and weren't attentive to the response of their colleague.

I had to ask the students to shut up to hear what Irene says:
- Acid rain can cause deforestation, respiratory diseases and skin cancer.
Yeah, except this is about... skin cancer is about living beings, deforestation on plants.... The question was: "In addition to the effects that we have already mentioned, the previous questions, what other effects can acid rain have?" - I tried to help understand what was at stake in the issue, since this group seemed doesn't have understood well.

- Material damage - says Miguel.

I tried to involve the whole class in the question and I looked at the various groups waiting for more answers:

- Material damage, namely....? - I asked.
- Buildings, cars ... - tries Joana.
- More...? Basically everything that is metal structures, rock structures ... - I tried to conclude, with some difficulty due to the agitation of the class.

As the students had made reference, in their answers, mostly to the effects on living beings, I ended up dictating to Irene that she writes on the board:

"They cause material damage to structures, statues and buildings, etc."

In the meantime, Rita adds:

- In cars!

Then we hear Peter say:

- The stone melts!
- It doesn't melt! - I answered Peter.

Then I went to the class and I asked:

- What happens to the stone?
- It destroys - some students answered in a chorus.
- It suffers from degradation. She is attacked by acids. - I completed.

This presentation and discussion of responses was very lengthy (about 15 minutes), since it was necessary to interrupt many times with calls for attention to students who were disrupting the work of colleagues. In addition, the students took a long time to write on the board and to copy the answers.

During this presentation of the answers, in order to improve them, I had the concern to guide the interventions of each one, because I had verified by the incident of the beginning of the lesson that the oral interventions became more difficult because of the newness of being seated in groups of 4 or 5 elements and facing each other, which promotes cross comments on subjects extra class. In the case of students such as Sandro and Bruno, this causes them to constantly...
challenge colleagues from other groups through gestures and facial expressions, which deconcentrate and disrupt the progress of the lesson.

*(End of the 1st Episode: 42min 28s)*
Example 2 of Multimodal Narrative

Context: Formal Education
Country: Portugal
Professional Code: Rafael
Professional activity: Teacher

Narrator: Teacher who taught the class
Narrator’s code: Rafael

Teaching context: Degree in Electrical Engineering (1st year) - Discrete Mathematics and Linear Algebra
  Discipline: Linear Algebra
Education Level: Higher Education
  Age group: Adults (> 18 years)
School year: 2011/2012
  Topics: Matrices language; operations with matrices.

Multimodal narratives related to this one:
  Multimodal Narrative 2 – Linear Algebra Lesson (2011)
  Multimodal Narrative 3 – Linear Algebra Lesson (2011)
  Multimodal Narrative 4 – Linear Algebra Lesson (2011)
  Multimodal Narrative 5 – Linear Algebra Lesson (2012)

Lesson n.º 2 (03/11/2011)
Total lesson time: 95min

Contextual Information:

This is a class of Discrete Mathematics and Linear Algebra curricular unit, in a public institution of polytechnic higher education, with students of the first year of the
Electrical Engineering course. Until now, the Discrete Mathematics component has been taught, having taken place during the first eight classes, as well as one class of the Linear Algebra component. It is important to point out that this class precedes the intermediate moment of the written evaluation.

Thirty-one students are registered, of which sixteen are attending for the first time the curricular unit. Few repeat students attend the classes, so they are almost entirely the group of students who attend the classes assiduously. Nineteen students attended this class.

The classes take place alternately in two classrooms, one of which is an electronics laboratory with a capacity of 25 students, with individual tables, grouped together and arranged on line. On each side, there are two benches, with various equipment and materials. The board is near the door and the room has only small windows at the back, with opaque glass. Figure 1 shows the classroom layout and the disposition of the students that are present.

In the room there is a video projector, which is placed on the teacher's desk, and the image is projected to the wall next to the board. It is used in all classes to project the slides of the support text and to show how to use the software involved at certain times and their exploration.

In the context of the exploration sequence of the subjects, this class continued the presentation and exemplification of basic definitions about matrices initiated in the previous class and evolved to the introduction of algebraic operations with matrices. A methodological innovation focused on the resolution of a task as an introduction to the multiplication of matrices, this being the first moment in which students made a work of this nature.

![Figure 1: Classroom layout](image)

**Characterization of the group of students**

**Characterization of the environment provided in the classroom - Description of the organization of space**

**Description of available resources**

**Characterization of the context of the lesson**

**Enrichment - Multimodal elements (classroom layout)**
Synthetic narrative of the entire lesson:

I began the lesson by announcing the construction of a scheme as a way to review the concepts about matrices covered in the previous lesson. I also informed that the scheme would continue on the board throughout the lesson, not erasing it, in order to be completed with two new concepts that would be introduced in this lesson.

Then, I added to the scheme the various concepts about matrices, sometimes talking about their meaning and relationships between the concepts, sometimes requiring information from students about what they remembered in relation to a certain concept. In the end, as transversal to all concepts, I added to the scheme the reference to the Scilab software.

The lesson continued with the introduction of the concepts of staggered matrices and matrices in canonical form reduced by lines. Projecting an example of the support text, containing matrices written in staggered and canonical form reduced by lines, I established a dialogue with the students about the necessary requirements to reach those concepts. Meanwhile, I used the computer to show the Scilab rref command, which reduces a matrix to the canonical form reduced by lines, and inform that this software doesn’t reduce a matrix to the staggered form. I then wrote some more matrices on the board for the students to conclude on their writing in the staggered or canonical form reduced by lines and clarified some doubts.

Having already passed around 28 minutes since the beginning of the lesson, I proposed the resolution of two exercises related to the various definitions of matrices already seen. I ended up not giving the students time to try the resolution on their own. As the first exercise presupposed the filling of spaces, I continuously asked the answer in each case and, once accepted, the students would put the answers in their notebooks. Also by questioning the students, we found together the answer to the second proposed exercise. Focusing again on the previously constructed scheme, I completed it with a reference to the two new concepts on matrices, which were addressed in the meantime.

Approximately 39 minutes after the beginning of the lesson, I introduced the study of subchapter 1.2 - Operations with matrices - starting with the algebraic operation of adding matrices. The approach I outlined involved transposing students' knowledge about vector operations, already studied by students in previous teaching cycles, towards algebraic operations with matrices. The objective was to show that the subject in hand wasn’t completely new and disconnected from what they already knew.
Using GeoGebra software, I represented two vectors in the plane and asked students about their coordinates. Based on the sum of the vectors I executed in the software and the mention I made of the parallelogram rule, the students advanced that the sum vector resulted from the addition of the respective coordinates of the vectors, including already talking about the sum of the elements of the corresponding lines. I then wrote on the board the addition of the two vectors and the result, using the language of the matrices. I told the students that after all they already knew how to add matrices, since it was processed as the addition of vectors. Then, around a proposal to add two matrices that I wrote on the board, the students were able to establish that to add two matrices it was necessary that they had the same dimension and proceeded individually to their sum. To close this topic, I also designed an example of the supporting text and, using gestures to mark the homologous terms, repeated the example of the addition of matrices.

Similarly, returning to GeoGebra, I explored the multiplication of a scalar by a plane vector. The students were able to indicate the coordinates of the resulting vector in each case that I proposed, and I recorded one of the cases in the board, using the matrix notation. Then I wrote a matrix and the proposal of its multiplication by a scalar, through which the students established that the multiplication was done "one by one", that is, the scalar by each element of the matrix.

Already in the second half of the class, announcing the study of the multiplication of matrices, I started by mentioning that I would propose "something different". I projected task 1 of the support text, indicating that before knowing how to multiply matrices and without presenting any algorithm, the students would perform two subtasks and whose final discussion would conduce to the formalization of an algorithm. I also took the opportunity to point out that the first subtask wasn't relevant for those who already knew the matrix multiplication algorithm. I then proposed that the students organize themselves in groups of two or three elements and distribute the enunciation of the task to those who didn't have the support text.

In view of the difficulty that I observed in the students in starting to solve the task, I tried to help them interpret the enunciation. I added that they had information about a multiplication of two matrices performed in Scilab and that the challenge was to interpret and apply the information provided in each subtask. I even established that the multiplication of an element by the homologous element wouldn't be translated into the result presented. I also briefly reviewed the concept of internal product.
Then I followed the work of the different groups, encouraging and continuing to clarify the students, when requested. As time passed, the questions about the statement began to give place to questions about possible answers, which I was accepting or identifying the error and suggesting its reformulation. About 12 minutes after the start of the task response, I proposed that we discuss the results, although I found that the students hadn't yet made much progress in responding to subtask 2.

When I asked for an answer to subtask 1, the students remained silent. The impasse was unblocked when Filipe, at my request, proposed to multiply each element of the first line of the first matrix with each element of the first column of the second matrix. Then I continued to describe the process, using the signage of the elements I was considering, and the students were interacting more and more naturally. At this moment I took the opportunity to approach the basic requirement for the possibility of multiplying two matrices, in light of the dimension of the matrices. I concluded this subtask, doing the calculations until confronting with the result presented at the beginning.

As for the second subtask, and given that no one group was able to find an answer, I then proposed to exemplify another possibility for the multiplication of matrices, highlighting the choice for the rows and columns that the students should have considered and the operations with previously learned matrices that followed. Until Cátia and Filipe began to say that it was "so much work". I emphasized the importance of the comments, because this was an indication for the choice of an algorithm for the multiplication of matrices that we would make in the end. After we got to the desired result for subtask 2, I posed the question: "What is the best algorithm in terms of time savings?". The answers weren't unanimous, which for me was a surprise, because I thought everyone would think that the algorithm underlying subtask 1 would lead to the product of the matrices being obtained more quickly. Either way, I left it open that they could then multiply matrices by the algorithm they preferred.

At this point the students were already embarrassed by the short time left until the end of the class (about 15 minutes), because they were already asking if we were still practicing and if the subject was still coming out for the test. I continued the lesson, formalizing an algorithm for the multiplication of matrices, the one underlying subtask 1, from an image that I projected and that was in the support text.

Next, presenting an example with two matrices, I started by reviewing the criteria for the possibility of multiplying the matrices and continued with the suggestion for the students to mentally perform the intermediate calculations. Then, listening to the
students, I wrote the result of multiplying each row by each column. Adding another matrix, I took the opportunity to ask for the resolution of an exercise involving the operations learned throughout the lesson.

I ended the lesson with information about the contents I would contemplate for the written evaluation and some exercises that the students should solve as training. In the final minute, I structured the resolution of an exercise that I thought was important and related to the resolution of a matrix equation and the application of algebraic operations with matrices.

**Episode(s) related to this lesson:**

<table>
<thead>
<tr>
<th>Episode</th>
<th>Duration</th>
<th>Actions of the teacher and students complementary to the registered record of the lesson</th>
</tr>
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<tbody>
<tr>
<td>1st</td>
<td></td>
<td>In the construction of the scheme, I initially placed the term vector and referred to it as underlying the language of the matrices. Next, I added the terms square matrix, row matrix and column matrix to the scheme. Regarding the last one, I emphasized again that it corresponds to an alternative writing of the coordinates of a vector. I continued with the reference to the null matrix and the notation $0_{m \times n}$, this matrix that has &quot;all zeros&quot;, as Joana said. Continuing the scheme, Filipe advanced with a designation:</td>
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<td>- Diagonal matrix!</td>
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<td>- Very well! And what is a diagonal matrix? - I asked, directing the question to him.</td>
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<td>- When above and below the line gives zero - anticipated Hugo.</td>
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<td></td>
<td>- They are all null elements - I added, referring to the elements that were above and below the diagonal.</td>
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<td></td>
<td>- What if by chance all the elements of that main diagonal are all equal is called matrix as? - I continued.</td>
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<td>- Identity - answered Joana.</td>
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<td>- Not exactly ... Identity is more in particular - I corrected.</td>
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<td>- Scaling - suggested Joel.</td>
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<td></td>
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<td>- Scaling! - I immediately corroborated.</td>
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<td></td>
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<td>I continued:</td>
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**3rd main section – Detailed narrative of each episode**

**Duration of the episode**

**Actions of the teacher and students**

**Enrichment with excerpts from the dialogues**

**Teacher Actions**
- When the diagonal elements are all the same. And now yes ... if they are all one is that we can already call matrix ... are seeing the arrows going from the most general to the most particular - I said, pointing to the sequence that had just put in the scheme (matrix diagonal → matrix scalar → matrix identity).

After talking about the notation of the identity matrix, having even referred to the case of matrix $I_2$, I continued the scheme with reference to the transposed matrix and the symmetric matrix, as being related concepts. In the end, Pedro recalled that the concept of the triangular matrix was still missing and advanced with its definition, given my request to do so. I concluded the scheme with the reference to the Scilab software, given the commands that allow writing or the calculations associated with most of those concepts and that were addressed in the previous lesson. After 6 minutes, I finished the construction of the scheme (Figure 2), saying that it would continue in the board and that it would be completed with the concepts that would be addressed below (those that are marked in color).

For the study of the concepts of staggered matrix and matrix in canonical form reduced by lines, I began by writing these designations as a title on the board. Next, I projected Example 1.9 of the supporting text (Figure 3) and questioned the students about what they saw and what they thought was the colored stain on each of the matrices.
Faced with the suggestions of being diagonal or triangular matrices, I had to remember that these would also have to be square matrices, which was not the case. Hugo even added the occurrence of zeros before me, without giving any more time, to introduce the intuitive designation "in stairs". Then, marking the case of the matrices in the staggered form, I advanced with the search of requirements for the identification of matrices of this nature. I started by asking if any of the four matrices contained null lines and, after the students had answered in the affirmative, I indicated that they were the last two. However, the students remained silent when I asked them about the position of the null lines. I then played with them saying that I would have to enlarge the image and repeated the question between smiles. The students still hesitated to answer, until Hugo talked about being "always on the stairs" and Pedro said "on the last (line)".

So I continued:

- Can I say that they are at the bottom of the matrix? That's a requirement! To be an matrix in staggered form, if there are rows of null elements ... all null ... they have to be ... they have to be the last rows of the matrix.

Looking for another requirement, I pointed to the third matrix of the example and tried to interact with students about the position of the first non-null element of the second line. But I was observing that the students weren't very spontaneous with their contributions, although they were correct. I said that it had to be element 2, before which it was all null and void. I also said that the next line was null. I then transcribed the matrix in the board (Figure 4), while at the same time recapitulating the intuitive idea of a stairs and the requirements:
If there are null lines, they are at the base of the matrix ... and then the first non-null entry of the next line ... has to be on the right - I went ahead.

It doesn't say anything about having to be zero, but I know or deduce that if the first non-null entry has to be on the right, then all these elements have to be ... zero - I concluded by pointing to the element below the pivot and the null elements that followed this line.

Following, Filipe asked if "it could be only a zero on the right", alluding to the circumstance that in one line only the element below the pivot was null. This question perhaps arose from the fact that a situation of this kind hadn't been explored. Now, in this context, I could have taken advantage of the first matrix of the example, but I decided to write another matrix on the board. I placed a matrix with two lines, with the second pivot immediately to the right of the first (Figure 5):

![Figure 5: Extract from a student's notebook from the matrix written on the board, initially with only the first two lines.]

By identifying the pivots, Filipe intervened again:

- But because there's zero ... because zero is below 2 ... if there were another number could no longer ...

I immediately validated the observation, recalling one of the requirements previously reported. Then I asked the students to help me to add a third line (Figure 5), so that the matrix would continue in the staggered form, having here the students showed spontaneity and understanding of the subject. Then I repeated the requirements according to what was written in the projected support text and also clarified Hugo's doubt about the possible positions of the pivot in the last line of the matrix that the students had helped to complete. It was in this class situation that for the first time I referred to the designation "pivot". I also decided, finally, to put an example in the negative, writing on the board a matrix that was not written in staggered form (Figure 6).
Easily, the students identified that there couldn't be two pivots in the same column. Representing the staircase that bounded the position of the pivots, it occurred to me to say more informally "it's hard to climb the step", as an allusion to the fault pointed out, and even though "if the steps are by levels in all the lines, we can climb".

Moving on to the concept of matrix in the canonical form reduced by lines, I established at the outset that the two requirements for obtaining a matrix in the staggered form seen above were still valid and that we would have to look for other complementary requirements. To this end, I took advantage of a staggered matrix that I had previously written on the board (Figure 4) to introduce such requirements:

- Continuing from a staggered matrix, to be reduced by lines, the pivots have to be 1 - I informed exemplifying this substitution in the matrix.
- If there are some ... as pivots ... in this column, everything else is zero - I continued, referring to the second requirement and again exemplifying the necessary change in some elements of the matrix.

Then, using Scilab, I showed the students how to find the canonical form reduced by lines of this matrix and warned that this program didn't have a command to find the staggered form of a matrix (Figure 7). I informed the students that at the moment they could only recognize if a certain matrix was written in the staggered form or in the canonical form reduced by lines and that in a later moment they would learn how to execute the calculations, just like Scilab did it. I argued that such a procedure was nuclear in the learning of the subjects of linear algebra.
Then I corroborated Abel’s observation about paying attention to the columns and not to the lines to verify if a matrix is written in one of the two forms studied. I continued, writing on the board and discussing with the students two more examples of matrices in canonical form reduced by rows, having among them pointed again to the matrices of Example 1.9 allusive to this topic (Figure 3).

In the second matrix that I wrote on the board, I tried to recreate a difficulty by placing element 1 in the last column (Figure 8), questioning the students if this matrix was also written in canonical form reduced by lines.

The students answered affirmatively, but somewhat fearful and didn't provide justifications. After a few seconds, António answered:

- The element of the first row and first column is 1.
- Well done! We call this a pivot - I added.
- Then we have ... so ... the one on the right, which is also 1, isn't it?
- Another pivot. Very well ... and the fact that we have here a 1 and there a 3 - I asked, interrupting the reasoning of Antonio.
- That 1 is not pivotal - said Filipe immediately.
- That’s wrong - said Cátia at the same time.
- It is a requirement not to be in canonical form reduced by lines or is not not being a pivot - I continued, ignoring the answers of Filipe and Cátia and addressing myself to António.
- He’s not a pivot, no ... - he continued António.
- That’s it! - I said.

As I am summarizing this last example, Daniel still interrupts me to ask if the matrix was then written in canonical form reduced by lines. I told him that he could only have been distracted. However, I repeated everything again, with Daniel interacting with me and wondering about the effect of changing the values of some elements.

Closing on that, I pointed to the scheme built at the beginning of the lesson and said that it was now possible to add other designations of matrices, which we would do in the future.

**Intermediate time: 27 min 22 s**

In order to apply the knowledge on the definitions of the matrices seen so far, I proposed the joint resolution of Exercise 1.2 (fill out a frame indicating whether each matrix presented was square, null, diagonal, triangular, scalar and/or symmetrical) and Exercise 1.6 (Figure 9). While the students were looking for the page of the exercises and starting to solve them, I took the opportunity to reiterate that the solutions of the exercises presented in the support text were at the end of each chapter, a fact that the students were unaware of. I also mentioned that it wouldn’t be convenient to consult the solutions immediately, without first thinking about the exercise to be solved.

Almost without giving the students time, I pointed to the Exercise 1.2 chart that was projected and questioned the students about their choices in each case. In this way, we solved this exercise together. Adopting the same strategy, I also guided the collaborative resolution of Exercise 1.6.
When, in the first paragraph, Cátia said that the matrix was simultaneously written in both staggered and canonical forms reduced by lines, I joked with her saying that she hadn't learned that. In that case, the matrix was only written in the staggered form. The suggestions made by the colleagues weren't in agreement, so I again insisted on referring to the requirements discussed above. Moving on to the paragraphs, I asked if I was being too quick, having received feedback from Filipe, saying yes. This student, who is the most joker, said that he was from Alentejo, but I devalued the comment. When in the answer to the second paragraph I heard Cátia say that the matrix wasn't written in any of the forms because "it has a very large step", I immediately focused attention on this circumstance and repeated to the rest of the class what the colleague had said. It was a way of highlighting the informal idea that I had launched a few minutes ago and I appreciated how it was used by the student to get the right answer.

In the next three minutes, we responded together to two more paragraphs and explained to what extent the last paragraph was different, as it involved discussing unknown parameters, but leaving it to the students to solve as homework. Some students started right away with questions and suggestions, and I ended up giving some clues about it:

- They wonder what values they attribute to $a$ and $b$ for the matrix to be written in staggered form and canonical form reduced by lines.

And I added, giving some examples:

- If $a$ and $b$ are equivalent to 1, it becomes a matrix in canonical form reduced by lines. What if it is, for example, all zero?

- It's nothing anymore! They have to be bigger than zero! - promptly indicated Filipe.
- What if one of them is one and the other zero? - I kept problematizing, not paying attention to the comments that were emerging.

- There are several possibilities! - I finished.

At the end I completed the scheme built at the beginning of the lesson, purposely left on the board, with the two new designations of matrices, however studied, using a different color (Figure 2).
Example 3 of Multimodal Narrative

Context: Formal Education
Country: Portugal
Professional Code: Isabel
Professional activity: Teacher

Narrator: Teacher who taught the lesson
Narrator’s code: Isabel

Teaching context: Physics and Chemistry
  Discipline: Physics
Education Level: High School - 10\textsuperscript{th} grade
  Age group: 15 years old
School year: 2011/2012
  Topics: Photometric effect; ionization energy, electron removal energy, current production. Simulation.

Multimodal narratives related to this one:
  Multimodal Narrative 2 – 10\textsuperscript{th} grade physics lesson (2012)
  Multimodal Narrative 3 – 10\textsuperscript{th} grade physics lesson (2012)
  Multimodal Narrative 4 – 10\textsuperscript{th} grade physics lesson (2012)

Lesson n.º 1 (23/11/2011)
Total lesson time: 135min
Lesson start time: 15h 47min
End of lesson time: 18h 15min 00s
Contextual Information:

The intervention took place in a class of 25 students aged between 14 and 15 with a medium/high socio-economic level. These students attend the 10th grade of High School in the discipline Physics and Chemistry. The lesson falls under the chapter of spectra and radiation.

The lesson takes place in a classroom where the teacher organizes according to the layout presented, because she finds it more useful for discussion among all.

This lesson was intended for practical/experimental work because it is only half of the class and the lesson has 135 minutes. The room organized in U where they had class was 3B.

These students are not very used to working on challenging tasks and alone so there has been an effort on the part of the teacher to improve the development of these skills.

Classroom layout:

![Classroom Layout](image)

Figure 1: Classroom layout.

Group 1- 3, 8, 9 e 12 – Looking at the picture of the layout of the room, this is the group on the left.

Américo, Cristina, Célia and Edgar

Group 2- 2, 4, 6, 10 e 13 – Looking at the figure of the layout of the room, this is the group that is in front (bottom of the room).

Rosário, Andreia, Bruno, Daniel, Filipe
Group 3- 1, 5, 7 e 11 - Looking at the picture of the layout of the room, this is the group on the right.
Angelina, Bárbara, Camila, Delfim

Synthetic narration of the entire lesson:

The teacher begins the lesson by questioning the students about the subject they had studied in the last lesson, taking them to make a brief summary of it and jumping to what she intends to approach in this lesson.

- Clarifies doubts to the students, when they present them or are distracted.
- Distribute students into three working groups to make them as uniform as possible.
- Next, tell them that in this lesson they will do a simulation of the photoelectric effect.
- Ask them to open the computers previously requested by other colleagues.
- Try to check if all laptops have internet or not, install in each one the simulation program.
In some situations she also had to install the JAVA a necessary program for the simulation. She distributes the pages of the worksheet for orientation and reflection on the simulation.
She now invites the students to try to do the simulation and to follow the worksheet distributed answering the questions formulated there.
While the students are experimenting with the simulation, the teacher goes from place to place to verify what the students do, they test and write, and she clarifies their doubts. If she finds that students are going the other way or doing things at random, she recommends that they read the worksheet again so that they know exactly what to do.

Episode(s) related to this lesson:

<table>
<thead>
<tr>
<th>1st Episode</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beginning:</strong> 15h 45min  <strong>End:</strong> 18h 10min</td>
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</tbody>
</table>

**15h 45 min** – Students switch shifts with other classmates, a new shift of students arrives. I asked the students to sit in a group and I helped in this task because they don’t make the groups well distributed.

**15h 55 min**
Teacher: I’ll give you the worksheet and as the simulation progresses you have to check and register what you’re observing and explain why.
Before the end of the lesson you should pick up the cards of your colleagues who requested these laptops.

**Teacher** - So the computers are already connected?
**Student** - Yes... Do I need to go to the internet?...

**Teacher** - Yes. Turn on the internet and go to Google and do PhET simulations.

**Student** - Physics simulations?

**Teacher** - Not in chemistry. We are in chemistry. Meanwhile in another group...

And in another group she helped to open the simulations.

**In another group:** Try to open and see if you can get to the PhET simulations.

**Teacher** - Don't you have a flash drive?

**Student** - I have a flash drive.

The teacher explains the need to have a flash drive to save the working documents to be carried out by the students, because after a while these computers automatically turn off and lose everything that was there in the workplace or elsewhere. To avoid losing that work and having to go back to the beginning, it is saved in advance in the flash drive of each one.

**Teacher** - This computer has JAVA 6. I'll want that you print screen the images obtained in each step you take.

16h 10min

**Teacher** - Does everyone see what happens and what doesn't? Apparently not. You have to read the protocol sheet to know what you're going to do and it's not asking every time what I do now and what I'm doing right away. You have to read the first sheet of the protocol to know what you are going to do.

The teacher went to explain to other groups how to open the simulation or find it on the Internet and check if they had java or not.

**Student** - Teacher how do you collect each image?

**Teacher** - Making the Print Screen.

**Student** - I don't know how to do this...

**Teacher** - Select the image and press the button of the print screen, open a word document and make it paste into this document and is pasted.

The teacher needed to explain to the class the whole issue of the print screen and then in particular in each working group. Ask them to do this whenever they get different images. She also asked them to identify this word document with the names of the group members doing that work, as the teacher will collect this data for evaluation.

She also recalled that they should record the observations and the reasons for each.

She was helping in one or other working group until they arrived at the simulation.
**Teacher** - The first image has already given you and is to make the print screen, said addressing to Américo (Group 1).

![Image of a simulation interface](image1.png)

Figure 2: Image obtained in the 1st option and the 1st print screen made by students.

However, the students are manipulating the simulation and observing images obtained for each option they execute, as well as simultaneously registering the observed in the protocol.

![Image of digitized answers](image2.png)

Figure 3: Image obtained by digitizing of the answers given by students in the experimental form (Américo group - Group 1).

There is one group that is still late to get the simulation (Daniel - Group 2). The Teacher let them try until they get it on their own.

**Teacher** - Register in the protocol of each step and make the print screen. And she called attention to the flash drive recording because everything is lost without having been previously recorded on a flash drive.

There were groups that didn’t have a flash drive and the teacher lent hers.

The teacher circulated to everyone and made recommendations to each group.

**16h 16min**

**Student** - In this first hypothesis, nothing was seen.
Teacher - So that's what you're going to put that you don't see any special effect and why?

Student - Wasn't this image the first? (Angelina – Group 3)

Teacher - Yes, you have to save them and answer why that image appears. Again she called attention to the flash drive.

Student - Can I take the flash drive? (Delfim - Gr3) - The student meant to take the flash drive out of the computer.

Teacher - No because if you don't record everything then it was swept and we have to go back to the beginning.

(Delfim - Gr3) - Does nothing....- Referring to the first image obtained with the simulation.

Teacher - Okay and from there you will get an important relation because it doesn't have any effect and what it takes to do.

Teacher Listen everyone (for the whole class), your colleague (Angelina Gr3) no longer remembers how much is the value of the speed of light in the vacuum.

(Student – Gr2) It's 3x10^8.

Teacher - What??

(Student – Gr2) m/s

Teacher And what does it take the C for? Speed of light in the vacuum

Student - To relate λ to the frequency.

Teacher - What is the relationship between λ and energy?

How does energy vary with λ???? You starting with a big λ are decreasing until you reach even the smallest.
Student - Bruno (Gr. 2) replied that it varied inversely and explained that by reducing \( \lambda \) there is higher emission of electrons, which means that the energy emitted is higher.

Teacher - In the case of \( \lambda \), how does it vary in energy? Varying the energy increases intensity what is verified?

Student - They increase more photons. More electrons circulate and the current increases.

Teacher - How does energy vary with \( \lambda \)?

Teacher - Here is the relationship between energy and \( \lambda \) or frequency \( E=hf \) or \( E=hC/\lambda \). - relations written by the teacher on the board.

Student - Thus, the \( \lambda \) varies inversely with frequency and frequency directly with energy, so the higher the \( \lambda \) reduces the energy supplied and consequently there will not be so much photometric effect and the current will be lower.

![Image obtained and recorded in print screen by Bruno (Gr. 2) to explain the variation of \( E \) with \( \lambda \).](image)

Bruno was talking to his group colleagues and asking them to put the image of the first option on and they found that there was no photometric effect.

16h 20min

Teacher - Now increase the intensity and visualize the photons, what happens??

Student - You can already see the photons and there are electrons moving from side to side and there is already electric current with some value.
Teacher - Now it increases the intensity and there are already more photons and some electrons already jump from one plate to another and so there is already a photometric effect. For now there is already a photoelectric effect.

(Edgar Gr1) The incident energy is higher than the removal energy.

Teacher - Is it higher or lower? Is the energy we are providing more than the removal energy? Is it higher?

(Daniel Gr2) - No, it is not. It is smaller.

(Bruno Gr2) - Oh, no, it's not! It's smaller than ... there's not enough energy to remove electrons.

Teacher - Do you think so? So there is no removal of electrons ... how is it equal?? I don't see the little electrolytes passing by, it means that it is smaller and therefore provides a very low energy. So go ahead and write, come on.

The teacher went to Camila's group to observe what the students were doing. The teacher found that these students had drawn conclusions from the observations made in the simulation but were afraid to record this in the worksheet, so she told them:

Teacher - If you have already drawn this conclusion and write it down (Camila - Gr.3).....
Figure 7: Image obtained by digitizing the answers given by students in the experimental form (Camila group - Gr. 3).

16h 25min

The teacher warned about the recordings of the documents and the print screen because it will give the exit sound soon and may lose everything.

Edgar (Gr. 1) - What are the materials that allow for a photometric effect for a $\lambda$ like the previous one? - remembering the pre-test form.

Tomorrow I will put this form back to you and you will be able to answer me well because today you have already learned it (talk about the post test) - The teacher told them this because she did not want to give them the answer, because this was a question made in the skills test and how the post test would be asked again, and wanted the students to get there on their own.

The students asked if the teacher did not strike tomorrow, which she answered in the negative.

The students discussed what to put into the simulation for each variable to be performed.

Break time

16h 48min – They’re back in the classroom.

The employee went to look for the logbook and I told her I was already upstairs. And she went to talk about the computers and the request for them and the need to send students to bring other laptops or not.

(Gr. 1)

Student - Prof. We could do this more often... Can we do this at home??.

Teacher - Of course you can. You google, look for simulations and PhET, and you do the simulation and train as many times as you want.
The teacher addressing the other group (Gr3) to check what the students were doing and exclaimed:

16h 52min- Teacher - There are more electrons there. And what do you see when the intensity increases?

Teacher - Did you already know that?

Student - The colors are violet, blue and green. What....?? - questions the student referring to what it meant.

The group mates tried to show that from the green she doesn't do anything, in the green she still does, "look here", says Angelina!!!

In the meantime, the students experience successively what is asked of them in the protocol. And commenting with each other.

Barbara (Gr. 3) asked her classmates to put on the violet and see what was happening..... There is!

Teacher - Then it increased, didn't it? - the teacher told them in a way of consolidation of observation and interpretation of the phenomenon. As she saw that they were on the right way, the teacher went to another group.

Figure 8: Image obtained and recorded in print screen by Angelina's group, Barbara to explain with the violet radiation is verified the emission of electrons.
Figure 9: Image obtained and recorded in print screen by Angelina’s group, Barbara to explain with the green radiation is still verified the emission of electrons.

Figure 10: Image obtained and recorded in print screen by Angelina’s group, Barbara to explain with the orange radiation, besides the green one does not verify the emission of electrons.
Figure 11: Image obtained by digitizing the answers given by the students in the experimental form (Angelina group, Barbara, Camila - Gr.3) with regard to the observation of the previous images.

**Student** - The higher the power, the more electrons jump! (Edgar Gr1)

**Teacher** - So it's so hard.

**Student** - No, it's cool (Edgar- Gr1).

The Teacher drew the attention of a student who was distracted by doing other things and copying for the girls.

**Teacher** - So, you have to do for yourself and not what the girls do... (to Delphi - Gr.3) Go to your little place, son, you are always out of place.

**Edgar** (Gr1) - If it was the zinc does not pass, or passes little, but the energy is the same and it is used but it is different materials.

**Bruno** (Gr.2) - In Zinc almost not, because it needs more energy to release electrons than sodium. In Zinc it does not and in sodium it does. Edgar corroborated. That passes less in spite of using the same nm.
The teacher agrees with the discussion of the students answers of this group and reinforces the idea of the conclusion reached.

Américo (Gr.1) asked the teacher why different energy is needed in different materials. Teacher, but why? I think it's because in zinc it only allows to go up to 300 and so on and in sodium it allows to go up to 500 and so on. That's why... zinc doesn't pass much.

**Teacher** - The energy you're applying is exactly the same.

In order to better elucidate the answer of group 1, the teacher addressed herself to everyone:

So how do frequency and wavelength vary?

To which Bruno replied:
Figure 14: Image obtained by digitizing the answers given by the students in the experimental form (Bruno’s group - Gr.2) regarding the comparison of sodium and zinc for the same emission energy.

17h 35min

Teacher - The higher the energy, the shorter the wavelength. The minimum removal energy corresponds to a maximum wavelength.

Teacher - The energy is directly proportional to the frequency. The wavelength and frequency are inversely proportional. The frequency is \( C \) over \( \lambda \). If you have less \( \lambda \) you have more energy and more frequency, so the photoelectric effect is higher.

Student - Higher and have more current.

Teacher - What is the doubt here, in this one?

Student - The Américo (Gr.1) in way of doubt and affirmation said: There are some that allow more and others that allow less, with the same emission of energy. It can be seen that for Sodium it is necessary to have less energy (higher \( \lambda \)) in order to start having the emission of electrons and for Zinc it is necessary to have more (lower \( \lambda \)).

17h 48min

It was necessary to deliver the laptops earlier (school rules of functioning).

The Teacher asked them to deliver the computers and complete what they were recording on the worksheet. However, he promised to resubmit the worksheets the next day, which would allow them to complete the simulation and its conclusions.

18h 10min
**Teacher** - Those who have finished recording everything for today on the pages, hand them in and I will return them tomorrow.

As the laptops had to be delivered, the teacher proposed the resolution to exercise the book on the photometric effect.

The students no longer have much desire to work and insist that the teacher let them pack or do nothing. She insists and demands that they solve the exercises.

Some students were solving, especially Daniel, Bruno and the girls, others insist on doing nothing.

However, the teacher collected the documents made of print screen of the groups she did not yet have and asked them to deliver the computers.

**18h 15min**

- The bell rang to get out and I asked the students to set the tables and leave the room clean before they left.
Example 4 of Multimodal Narrative

**Context:** Formal Education

**Country:** Portugal

**Professional Code:** Priscila

**Professional activity:** Teacher

**Narrator:** Teacher who taught the lesson

**Narrator’s code:** Priscila

**Teaching context:** Mathematics

  **Discipline:** Mathematics

**Education Level:** Elementary School - 6th grade

  **Age group:** 12 years old

**School year:** 2016/2017

  **Topics:** Polygons and circles.

**Multimodal narratives related to this one:**

  n.a.

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**Lesson n.º93, 94 e 95 (22/02/2017)**

**Total lesson time:** 40min

**Time to start lesson:** 10h 40min ou 15h 30min ou 8h15min

**Contextual Information:**

The class has 17 students aged between 11 and 13 who attend the 6th grade of school. One of the students has previous retentions. The mathematics classes take place in a normal classroom such as the one in Figure 1, with a frequency of four or five weekly classes, two of which are consecutive.
The domain being taught was "Geometry and Measurement", the subdomain "Measure - Area" and the contents were as follows: (i) Approximation by perimeters of inscribed and circumscribed regular polygons, and (ii) Approximation by areas of inscribed regular polygons. The notions of circle, circumference, radius, rope and diameter had already been reviewed, and the formula for the perimeter of the circle, the notions of angle to the center and circular sector were taught.

This class and this task, in particular, had the didactic objective of teaching and distinguishing polygons inscribed on a circumference and polygons circumscribed on a circumference through the exploration of the artifact "visual representation" in preparation for the teaching of the formula for the circle area, scheduled for March 7. Before that, they would also learn how to calculate the area of a regular polygon using the decomposition (visual treatment) of the regular polygon into geometrically equal triangles and with one of the vertices in the center of the circumference and its rearrangement in a figure (parallelogram) whose formula for calculating the area was known from the previous school year.

The interval of time of approximately 15 days was intentional, to identify the knowledge and procedures that the students would use when exploring the formula of the circle area. It was intended to allow students to explore the use of visual treatments in visual representations and other types of representations and to perceive the effectiveness of this use in the transmission of their thinking and in the search for a solution. For this purpose, I developed the task "Polygons and circles" (Annex 1), as it served these objectives.

I proposed to them their individual resolution, but coordinated by me in order to keep all the students answering the same questions at the same time. The resolution of this task took 20 minutes of one lesson and the next two lessons. In the second lesson I had the support of a teacher from my disciplinary group. The students took their usual places.
in space as shown in Figure 1, which allowed me to move quickly between them. The space where I circulated during the activity is dashed in the figure. All the names of the students are fictitious.

**Synthetic narration of the entire lesson:**

The first minutes of the lesson were used in the classroom entrance and the respective usual positioning of each one of us, and in the brief review of the previous lesson with the writing of the respective summary. I turned on the recorder during this time of reviewing and writing the summary. From the dialogue during the writing of the summary, I felt the need to consolidate various notions such as circular sector, angle to the centre, and straight tangent to a circumference. Next, we characterize a polygon circumscribed on a circumference by drawing some examples. This was followed by an indication of the work to be done, distributing to each student the enunciation of the poly-copied task, asking them to paste it into the notebook. I designed the task in such a way that the students would acquire the notions of polygon inscribed on a circumference and polygon circumscribed on a circumference, and would compare the perimeters and areas of all the figures (including the circle) by approximation. In order for them to do so, I induced the realization of visual treatments. The work was ongoing and the students solved the task without major difficulties, except in the mathematical communication of definitions of the concepts involved.

**Episode(s) related to this lesson:**

<table>
<thead>
<tr>
<th>Episode – Lesson n.º 93 (part) and 94</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning: 32min 15s</td>
</tr>
<tr>
<td>Duration: 93min 14s</td>
</tr>
</tbody>
</table>

Teresa read the first question of the task (*Highlights the figures that represent polygons inscribed and circumscribed on a circumference and pastes them into the notebook.*) Next, I gave a sheet of paper with the figures to each student. I asked Teresa to tell me again what we needed to do. As she was able to reproduce accurately, I asked her to read the paragraphs of Q1. She read them. While I finished distributing the pictures to the students (Figure 2).
Teresa identified the figures in question (A, B and C), cut them out and pasted them into the notebook. They identified the polygons (triangle, pentagon and octagon) and justified that they were regular (Figure 3).

![Figure 3: answers to questions 1(a) and 1(b).](image)

They began by misjustifying, but Fausto remembered the correct justification. The sound was played for the exit and we interrupted.

In the next lesson there was the support of another teacher and we continued where we left off. Rui read the second question (Compare the perimeter of polygon A with the perimeter of the circle inside it. What do you see? Compare the perimeter of polygon C with the perimeter of the circle inside it. Do you see the same?). Before they answered, I made sure they knew what I meant by comparison and they wrote the answer to the question on the blackboard and in the notebooks. Then, Fausto read the Q3, made the comparison between the figures and the same student elaborated the answer.

At this point we realized that we had not answered Q2(a), so we answered him before writing this answer (Figure 4).

![Figure 4: Answers to questions 2 and 2(a).](image)

I've been asking some questions assuming the same situation for polygons with a larger number of sides. Jorge read paragraph a) of Q3 and answered (Figure 5).

![Figure 5: Answers to questions 3 and 3(a).](image)
We proceeded to the Q4 that Anaisa read. (53'34’). I emphasized the fact that we now speak of registered polygons.

We went over the definition of polygon circumscribed on a circumference again, before we defined polygon inscribed on a circumference. I took the circular geoplane to concretize the figure in question. Then I moved the elastic that represented the circumscribed polygon and inscribed it on a circumference. I drew the students' attention to the vertices of the polygon and quickly identified that the vertices of the polygon are points on a circumference. Then, with the help of the geoplane, we distinguish between a polygon circumscribed on a circumference of a polygon inscribed on a circumference. I changed the inscribed polygon to a triangle (scalene) and asked them if it was still an inscribed polygon. Then I changed it to a seven-sided polygon and asked them for their name. They solved Q4. Although I thought it was important for the students to divide the circumferences into equal parts, I decided not to do so at this point to make the task easier and save time. So I marked the vertices of all polygons (three to 12 sides) on the respective circumference. During this work the support teacher and I circulated around the room supporting the students in this work (example in Figure 6) and asking some consolidation questions. During this dialogue, the students defined polygon inscribed as being inside the circumference, which is not a sufficient condition for it to be inscribed. I gave an example on the blackboard with a counterexample.

Figure 6: Part of the answer to question 4.

The students remained in this activity of construction, painting, cutting, gluing (in ascending order of number of sides of the polygon) and respective nomenclature, until the end of the lesson.

Despite being very agitated because it was the last class of the day, I made sure that all the students glued the figures in their notebooks so that they would not compromise the work in the next class.
The first four minutes of the lesson were used to write the summary of the previous lesson and to prepare for further resolution of the task. We waited a while for those who were late to start again together. Celeste read question 5, which asked for a comparison between the perimeters of figures I, D, and M and the perimeter of the circle. The polygon in Figure I is an octagon, the polygon in Figure D is a triangle and the polygon in Figure M is a dodecagon.

Duarte: The perimeter of I is smaller than that of M.
Prof.: And it's only in I? And in D?
Duarte: Also.
Prof.: Also, what about M?
Duarte: Also. All the figures behind the M are smaller than the circle.
Belmira: But the M is the one closest to the perimeter of the circle.

I took Belmira and Duarte's participation and generalized to all the figures since the circles are all the same. I gave reason to Duarte and also to Belmira asking her to elaborate and write the answer to question 5 and 5(a) on the blackboard (Figure 7).

In question 6 they would have to do an analogous reasoning for the area. I took advantage of these two questions to once again lead the students to distinguish between these two dimensions, both defined. They made a similar reasoning and elaborated the answer they would write on the blackboard and in the notebooks. I decided to ask them not to erase it completely but to replace the necessary terms in the sentence that was already written on the blackboard for the perimeter, adapting it to the area. Finally, they defined inscribed polygon and circumscribed polygon. Both definitions are found in Figure 8.
Again, they made the same mistake of defining a polygon inscribed on a circumference as a polygon inside the circumference. I drew a counterexample to make them aware of the inaccuracies in language. To consolidate, I also drew seven figures on the board so that they would identify those that represented, or did not represent, inscribed polygons. In this activity, it was clear that some students had difficulty in drawing the geometric figures, even in sketch mode. We proceeded to the last question: draw an octagon inscribed in figure C and compare the perimeters and areas of the two octagons and the circle between them. I circulated all over the place to make sure that everyone built the octagon correctly. In the meantime it rang for the exit and there was no time to answer the question. I decided not to do it in the next lesson, as it could be conditioning the future task of the circle area.
ANNEX 1
Polygons and circles

1) Highlight the figures representing polygons circumscribed on a circumference and glue them to the notebook.
   a) Identify each of these polygons.
   b) Are these polygons regular? Why?

2) Compare the perimeter of polygon A with the perimeter of the circle inside it. What do you see? Compare the perimeter of polygon C with the perimeter of the circle inside it. Do you see the same?
   a) On which of these will the perimeter measurement of the circle and the perimeter measurement of the polygon be approximated?

3) Compare the area of polygon A with the area of the circle inside it. What do you see? Compare the area of polygon C with the area of the circle inside it. Do you see the same?
   a) In which of them will the circle area measurement and the polygon area measurement be approximated?

4) On the remaining figures, draw the polygon inscribed on a circumference, cut them out, glue them to the notebook and identify them.

5) Compare the perimeter of polygons D, I and M with the perimeter of the circle. What do you see?
   a) On which of these will the perimeter of the circle and the perimeter of the polygon be approximated?

6) Compare the area of polygons D, I and M with the area of the circle. What do you observe?

7) Defines polygon inscribed on a circumference and polygon circumscribed to a circumference.

8) In figure C, draws an octagon inscribed on the circumference. What can you say about the perimeter and area of the two octagons and the circle together?
Example 5 of Multimodal Narrative

<table>
<thead>
<tr>
<th>Context: Formal Education</th>
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</thead>
<tbody>
<tr>
<td>Country: Portugal</td>
</tr>
<tr>
<td>Professional Code: Joana</td>
</tr>
<tr>
<td>Professional activity: Teacher</td>
</tr>
</tbody>
</table>

Narrator: Researcher in interaction with the Teacher
Narrator's code: Diana

Teaching context: Physical-Chemical Sciences
   Discipline: Chemistry

Education Level: Basic Education - 9th grade
   Age group: 14 years old

School year: 2008/2009
   Topics: Atomic structure; Evolution of the atomic model.

Multimodal narratives related to this one:
   Multimodal Narrative 2 – Chemistry Class of the 9th grade (2009)
   Multimodal Narrative 3 – Chemistry Class of the 9th grade (2009)
   Multimodal Narrative 4 – Chemistry Class of the 9th grade (2009)
   Multimodal Narrative 5 – Chemistry Class of the 9th grade (2009)
   Multimodal Narrative 6 – Chemistry Class of the 9th grade (2009)

<table>
<thead>
<tr>
<th>Lesson n.º 1 and 2 (20/04/2009)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total lesson time: 90 min</td>
</tr>
</tbody>
</table>

Contextual Information:

The class consists of 24 students, of which 10 are female and 14 are male, aged between 13 and 17 years. The average age is 14.5 years. The Physical and Chemical Sciences (CFQ) classes are divided with the Natural Sciences classes. As a result, students of the 1st round, i.e. 12 students of the class with an average age identical to the whole class,
participated in this study. In this shift, there are three students who have a retention in their school career and one student who has two retentions.

According to the analysis performed by the Class Director, these students present a very heterogeneous behavior. If, on the one hand, the class consists of students who stand out in a positive way, complying with all the rules to be taken into account in the classroom, on the other hand, there are also some students who show, punctually, a behavior inappropriate to the classroom situation.

In general, the main difficulties diagnosed in this class are at the level of: oral and written expression; interpretation of messages in different graphic supports; understanding and application of knowledge; recognition of essential information; evaluation of results; logical reasoning and information relationship. However, there are still some students who present additional difficulties:

Bernardo has been proposed to benefit from curricular adaptations and special assessment conditions. Minimum competences to be achieved for various subjects have been drawn up;

Cristiano reveals a marked delay in global development both at the level of cognitive development and at the level of language and autonomy, presenting a mismatch between chronological and intellectual age. This student needed a more individualized monitoring and special conditions of evaluation and curricular adaptations and was also sent for monitoring in the scope of educational psychology and vocational guidance;

Filipa has some family problems. She reveals little autonomy, is very little participative and assumes she doesn’t like to study.

With regard to social support, with the exception of three students, all the others benefit from educational social support: 3 students with grade A, 5 students with grade B and 1 student with grade C.

PCS classes take place on Mondays, between 8:15 a.m. and 9:45 a.m. in the laboratory room (fig.1).

All the students live in the surroundings of the school, so they use school transportation as a way of transportation. On average, they take about 20 minutes to get from home to school.
Classroom layout:

This shift consists of twelve students distributed according to the layout below:

![Classroom Layout Diagram]

Figure 2: Layout of the classroom where the classes take place.

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<tr>
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<tbody>
<tr>
<td>1</td>
<td>Bruna</td>
<td>4</td>
<td>Diogo</td>
<td>7</td>
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<tr>
<td>2</td>
<td>Bernardo</td>
<td>5</td>
<td>Eliana</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Cristiano</td>
<td>6</td>
<td>Filipa</td>
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<tr>
<td>10</td>
<td>Jorge</td>
<td></td>
<td></td>
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<tr>
<td>11</td>
<td>Margarida</td>
<td></td>
<td></td>
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<tr>
<td>12</td>
<td>Marlene</td>
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Synthetic narrative of the entire lesson:

In the previous lesson the students did the pre-tests. At the end of this lesson, the teacher asked the students to form groups to work on two jobs that she would have done. For the formation of the groups she elected a student who was to choose with whom he wanted to work. This choice fell on the 3 best students in the class (Marlene, Bruna and Jorge), in an attempt to get each group with one of these students:

1st group: Marlene, Diogo, Margarida and Eliana;
2nd group: Bruna, Paula, Filipa and Bernardo;
3rd group: Jorge, Cristiano, João Marcos and João Pedro.
She then presented the following tasks:

1st do a research on the evolution of the atomic model to present orally in the next lesson in approximately 10 minutes;

2nd build an atomic model based on the Bohr model, to present to the class in the next lesson in approximately 10 minutes.

These tasks were written on the board. Not all students had time to copy them into the notebook. It was up to the group leader to pass this information to the other students.

The students started this lesson by trying to work on the atomic models while the first group was preparing for the presentation. They had requested an overhead projector that took time to arrive. Meanwhile, the teacher wrote the summary on the board.

At 04min 50s, the 2nd group started their presentation which took approximately 8 minutes. This was followed by the presentation of the first group. They took about the same time. Both groups distributed photocopies of their work to the other colleagues. The boys’ group (3rd group) did not present the work. The students finished this presentation at 21min 40s.

Then, at 21min 50s the students started working again on the atomic models. The teacher suggested that they work with the materials they brought in, but there was one group who, thinking they were going to do in the next lesson, did not bring any material. They used the material the teacher had provided: styrofoam, plasticine, aluminium foil, wire, pioneers, spikes and cardboard. They took their time in this work until the end of the lesson, when the teacher, seeing that there was no more time to make the presentation, asked about the constitution of the atom.

Episode(s) related to this lesson:

<table>
<thead>
<tr>
<th>1st Episode</th>
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<td><strong>Beginning:</strong> 00min 02s</td>
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The teacher begins the lesson by writing the summary in the board "Evolution of the atomic model; how atoms are; construction of atomic models". While this is going on, the students try to work on the models, since the employee had not yet brought the overhead projector requested by the 2nd group for the presentation of their work.

At 1min 55s, the 3rd group has difficulty cutting the wire. The teacher offers a pair of pliers.

At 2min and 50s, the teacher suggests they turn off the lights because the Bruna group is ready to start the presentation. After 2 minutes the student asks if she can start, after having
distributed copies of their work to the other students in the class. It is the student who makes the introduction and mediates the presentation, giving the same speaking time to all the participants (she, Paula, Filipa and Bernardo). The class is attentive to the presentation of their colleagues. At 8min and 18s, one student shuts up another who tried to talk. During this presentation, Bruna questions the class:

- So... this planetary model can be compared to the Solar System model. So, if we compare this model with the Solar System, the nucleus of the atom could be?

  **Bernardo** - the Sun.

  - Exactly, and if the electrons revolve around the nucleus, what could they be?

  **Jorge** - the planets.

  **Bruna** - the planets - agrees - so I can compare the two things. I can compare the planetary model to the Solar System.

  **Teacher** - and you have two types of particles in the nucleus. What are those particles?

  **Paula** - neutrons and protons.

  **Teacher** - neutrons and protons?

  **Bruna** - the protons he discovered in 1919 and which were the positive charge particles.

  **Teacher** - yes, well. And the other particle that you have there, what is it? - refers to the second particle in the nucleus.

  **Bruna** - this? - indicates, the student in the acetate.

  **Teacher** - you have two types of particles in the nucleus. Look. A few blue spheres and a few red ones. What will each one of them represent? ... I don't know. You investigated it. What do you say about that? Until then, you hadn't discovered the neutron, that's it," she says, based on what was presented by the student, "you have already represented the neutron and what else?

  **Bruna** - the proton.

  **Teacher** - the proton. So he had already proposed that there was another particle...

  **Bruna** - but then Chadwick discovered it - completely - in the '60s.

  The teacher agrees with the explanation.

  **Bruna** - so we will also see the elliptical orbits and the planets around the Sun. ... - continues with his presentation.

  **Teacher** - there are many more black spots next to the nucleus because...? - asks Bernardo, who had just explained in the image of the acetate, referring to the model of the electronic cloud, the greater or lesser proximity of electrons to the nucleus as well as the possibilities of being, more or less, close to the nucleus.

  **Bruna** - this is where the electrons are most likely to be.
Bernardo - this is like a hive. The bees are always close to the hive.

Bruna - the nucleus is made up of neutrons and protons and where they exist more, it is close to the nucleus.

Bruna - in 1932 Chadwich discovered the neutron, which Rutherford already predicted existed - refers to the image previously questioned by the teacher.

Teacher - so the nucleus has what?
Bruna - protons and neutrons.
Teacher - what about electrons?
Bernardo - around him. (13min 00s)

At 13 minutes the teacher asks the other group, who are ready to make their presentation and if they need the overhead projector. They don't. They will present orally, following the written work that they also photocopied for their colleagues (fig. 3).

Figure 3: Photocopy of Marlene’s group work.

Marlene suggests that her colleagues follow the images through the manual on pages 92 and 93. She explains that they didn't get images to distribute because everyone brings the book to class. The presentation of this group also includes the participation of all the members of the group who distributed the times evenly.

At 15min and 19s, Marlene begins the presentation "we will present the evolution of the atomic model with a detailed order and at the same time deepen our knowledge of other personalities. We start with the atomists in ancient Greece..."

The presentation is initiated by Marlene. However, the presentation times are, as with the 1st presentation, evenly distributed among the other members of the group.
Eliana - ... Rutherford came to the conclusion that most of the atom is empty, with practically the totality of its mass in the nucleus ...

Teacher - it means that although the mass is concentrated in the nucleus... the nucleus is very small in relation to the size of the atom, is that it? - she asks Eliana in an attempt to value her participation, since this student had never participated (orally) before in classes.

Eliana - yes - answers the student who, being very shy, avoids talking at all costs.

Marlene returns to the presentation (Bohr’s model), according to the previously agreed distribution.

At 21min and 25s they finish.

Teacher - very well. Yes, sir.

The teacher asks if no one else is going to present it. The group of boys did not do the work. They are to present at the next class. The teacher agrees.

### 2nd Episode

**Beginning:** 21min 50s  **End:** 1h 24min 50s

Teacher - so now take your materials and go build your models. Everyone in the group has this, don't they? - asks about the presentation of colleagues (photocopies). Everyone confirms that they do. The teacher then decides not to make a resume on the board.

The students work in groups on the model.

The second group did not bring any material. They thought it was to be done in the next class.

The teacher asks if they at least thought about it. They answer affirmatively.

João asks if he can use the plasticine that the teacher brought.

Teacher - you have to think about how you are going to make the nucleus - says in a group.

To the group that didn't bring material, the teacher says they have to do it in this class, using the available materials.

Bruna - Oh teacher, do we use several colors, or just one color?

Teacher - you know best.

Bruna - is it necessary to use several colors? - Bruna, despite being a very committed student, tends to "capture" the teacher's attention.

Teacher - what will you have at the nucleus? You said, a little while ago.

Bruna - we are going to have protons and neutrons.

Teacher - so it's convenient to have two colors, isn't it?
Bruna - yes. And the electrons have to be all the same color.

Teacher - yes, it is convenient.

The students question each other about the number of protons they will place.
Bruna asks if they can't do it at home because she thought it was in the next class and at home she has sheets of various colors. She is worried about not being able to make a beautiful model.

The teacher repeats that the model has to be done in this class "you can now adapt something there".
Bruna continues to say that it won't look so good. However, she immediately starts working with her colleagues.

The teacher checks, group by group, the progress of the work.
All the students use the plasticine.
Bruna continues to ask if they can’t do everything in the same colour.

Teacher - can. Explain there. How will they do it? - she asks, since the student continues to insist.

Bruna - we put a ball here in the nucleus. It doesn't look good?
Teacher - and then what? We have to distinguish between protons and neutrons.
The students agree on colour.
(31min 08s) in Marlene's group:
Teacher - is this going to be the electrons?
Students explain that they're going to have to put one more on because of the number of protons. Marlene asks for cardboard. The teacher goes to the storeroom to check if there are any, but she can't find them.

The teacher goes around the groups, while she encourages, without intervening in the work: is getting very handsome.

At 37 minutes, after having verified that there was no cardboard, the teacher gave her some card.

The students continue to work.
Teacher - you know about the number of particles - answers when questioned in this sense.

Bruna - but I can't do the protons.
Teacher - it's okay. Do as you can.
Jorge - Styrofoam - suggests.

at 41min and 30s, João asks for a knife. The teacher doesn't have a knife. The student goes to the bar to ask.
Marlene suggests nails instead of glue. The teacher gives up several nails.

The pliers are used by all groups. The teacher makes the materials available. The students improvise.

Jorge's group finishes at 51 minutes.

**Bruna** - how many laps must there be? - refers to the orbits.

Bernardo suggests 2.

In Bruna's group, the particles of the nucleus are all in the same colour. They no longer have plasticine of different colors. Bernardo suggests to paint them. Paula suggests buying more plasticine. The teacher intervenes.

**Teacher** - you also need little. So you put in 2 protons and 2 neutrons.

**Bernardo** - so let's paint it red here - says, referring to the base.

**Bruna** - do you think?

**Bernardo** - no, I'm joking.

**Teacher** - Did you have in your leaf, in your work, where is your work?

**Paula** - Filipa goes to get yours.

**Bruna** - we had what?

**Teacher** - you had how the atom was constituted... you had more information, I think - she says, while she confirms the work - by chance you don't, but in the atom, the number of protons is equal to the number of electrons - the students had already reached this conclusion before - if you have 2 protons you have to have only 2 electrons - she explains.

**Bruna** - we put only two.

At 58 minutes, some students still have problems gluing the particles. The teacher suggests that they use wire for the effect.

One group is using pioneers, which the teacher has given in to. The students ask for the white ones.

At 1h and 04min, the teacher asks them to hurry. Bruna's group finishes at 1h 04min 45s. The student asks the teacher if it is cute. The teacher confirms it.

After two minutes, the teacher "rushes" the groups, saying that they are not finished. She says that it will no longer be possible to work with the models.

After another ten minutes, the teacher says that there won't be time to do anything else but that they've already got an idea of how the atom is made up.

**Teacher** - how is the atom made? ... João helps your colleague.

João Pedro answers correctly.

**Teacher** - John, each one of these orbits here, corresponds to what?

John does not answer.
Teacher - in Bohr’s model, they correspond to what? He addresses the question to Filipa. Then to Marlene.

Marlene - they are orbits.

Teacher - they are orbits. What do they correspond to? According to Bohr’s model?

Marlene - when an electron emits or absorbs energy...

Teacher - so these are energy levels (1h 19 min)

The students are waiting for the ringtone. At the end of the lesson the students prepared the models shown in fig. 4.

Figure 4: Models developed by students of the 1\textsuperscript{st}, 2\textsuperscript{nd} and 3\textsuperscript{rd}, respectively.
Example 6 of Multimodal Narrative

**Context:** Formal Education

**Country:** Portugal

**Professional Code:** Ryan

**Professional activity:** Trainer

**Narrator:** Trainer who taught the training sessions

**Narrator’s code:** Ryan

**Teaching context:** Electrical Installations Course

**Discipline:**

**Education Level:** Equivalence with the 12th grade

**Age group:** 18 years old

**School year:** 2016/2017

**Topics:** C Language, Arduino Board

**Multimodal narratives related to this one:** n.a.

<table>
<thead>
<tr>
<th>Session (2017)</th>
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<tbody>
<tr>
<td><strong>Total lesson time:</strong> 1h 30min</td>
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</table>
Contextual Information:

The students, to whom the session was given, are between the ages of seventeen and nineteen. It is a group of six elements, from a class of professional teaching of the course of Electrical Installations. These students have immense difficulties in terms of programming. The session aimed to familiarize them with the C language, to support the PAP, applying this same knowledge to simple projects, using an Arduino board.

The session was taught in a room with a maximum capacity for sixteen students. I organized three groups of two elements each, with different levels of learning. At the beginning, a kit was distributed consisting of an Arduino Uno/Mega board (figure 1), a breadboard, four resistors of 220 Ω and one of 10kΩ, an LDR, four leds, an AB-type USB cable, the Arduino IDE software, a session guide (figure 2) and an electronic presentation in digital format provided the day before the session (figure 3).

Each group had an audio recorder, and the practical part was recorded on video. The session lasted eighty minutes, divided into four episodes.

![Figure 1: Kit provided to students.](image-url)
The main objective of this session was that students develop skills such as proactivity, research ability and deconstruction of programs in C language, through an expository/demonstrative approach of the Arduino platform, (Arduino IDE software and
Arduino hardware). It aimed to provide them with instructions to develop simple projects, giving them the ability to continue learning on their own.

During the theoretical exposition, I remained in a central position vis-à-vis the groups, however, in the practical component, I moved around the space, from group to group, to assess the execution of the proposed tasks.

**Synthetic narrative of the entire lesson:**

The lesson was divided into four stages, the first being a brief theoretical explanation using the projection of an electronic presentation (figure 3). In the following stages, the students developed three projects, in which in the last one they would have to autonomously reach the result without the help of the teacher.

![Figure 3: Example of an electronic presentation slide.](image)

**Episode 1 – Beginning at 0:0:0 and end at 0:13:40**

In this episode I made a brief theoretical explanation about the architecture of Arduino, focusing on its characteristics, namely the digital, analogue and power terminals doors. I also addressed the differences between two more common types of breadboard. Next, the components that would be used in the tasks to be performed were presented. Afterwards, I asked the students to access the Arduino IDE software, I made a brief explanation of its work surface. Based on a basic example of the program, I clarified the differences between the void
setup() and void loop() functions and took the opportunity to deepen a little more how to program in Arduino. After this explanation, we leave for the practical part.

**Episode 2 – Beginning at 0:13:40 end at 0:23:00**

After the deconstruction of the example, you set out for implementation on the breadboard, and tested the program (figure 4). In one of the groups it did not work immediately because the students did not put the positive pole of the led in the correct door.

![Figure 4: Practical work number 1.](image)

**Episode 3 – Beginning at 0:23:00 end at 0:58:50**

Explanation of practical exercise number two (figure 5). After the explanation, I questioned the students how the heat of resistance was calculated and found that the knowledge was not what I expected - only one student knew how to do it. During the elaboration of the code and its test there were difficulties in the implementation of the instruction "for", more precisely in the test condition.

![Figure 5: Practical work number 2.](image)
Episode 4 – Beginning at 0:58:50 end at 1:20:00

After the explanation of the exercise the students created a project to optimize the energy management (lighting) - this was turned on only when it got dark (figure 6).

Figure 6: Practical work number 3.

Episode(s) related to this lesson:

<table>
<thead>
<tr>
<th>4th Episode</th>
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<tr>
<td><strong>Beginning:</strong> 58min 50s <strong>End of 4th episode:</strong> 1h 20min 00s</td>
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Episode four aimed to create an intelligent energy-saving system based on luminosity. For its implementation the students had about twenty minutes. After explaining the exercise, I asked the students to use the multimeter to measure the resistance value (LDR), and I asked them how the LDR resistance varies, to which the student Daniel answered correctly.

Then, we passed the test of resistance variation with luminosity. I asked the student Filipe about the values he was reading in the measuring device, and he answered correctly to the questions asked.

Through the video recording (00:44:50), I verified, by their facial expressions of contentment and verbal that the group of Rui and Rafael, was proceeding correctly to measure the values of LDR resistance when the luminosity on this component was changing.

I’ve asked them to set up on the breadboard the scheme mentioned in the training file. At that moment I noticed that the group of Filipe and Rodrigo had difficulty in the
implementation of the scheme, because they were connecting the two LDR terminals to the same potential of the breadboard. I went with them and explained how they should proceed, suggesting that they check the connections according to the scheme provided. At that moment, I noticed that the students didn't have a resistance in sight with the value of 10kΩ, and Filipe indicated me a resistance that was in the breadboard. We then measured it and concluded that the resistance had an approximate value of 10kΩ.

I asked student Rui what polarity should link the resistance and his groupmate answered correctly. Through the recorded images (00:48:10), I verified that I moved with Rui and Rafael's group and they had implemented the circuit without any problems. At that same moment, I was questioning Filipe's group, who answered me correctly to the questions asked. Next, I went to check if all the groups had proceeded correctly to the assembly of the circuit and I could verify that all the groups had correctly implemented the assembly scheme.

Then I asked them to access the Arduino IDE program and load the "AnalogReadSerial" example. At that point, the projector stopped working. Student Daniel suggested removing the connection cables and reconnecting them. I apologized to the students for what happened and asked the student Filipe to read the procedures in the formative form. After the resolution of the video projection, I proceeded to the deconstruction of the example. During the explanation, some students were inattentive and I had to alert them to be concentrated, suggesting later to change the model program, and transfer it to the Arduino board.

I questioned student Rodrigo, which procedure we should carry out next, I questioned this student because he was inattentive, and I wanted at that moment to involve him in the learning process. Thus, I urged him to help his colleague with the procedures described by him, to which he was assertive. I asked the students to read the values obtained with and without luminosity and then informed them that they would have to create a program with the "IF" instruction. The student Filipe was worried about the exercise - I verified this by his expression, and then in the audio recording by the whistle he gave.

I challenged them to do the work without the teacher's help and suggested that they consult the information over the internet. However, the students were not being able to do the work on their own. So, through questions to the class, I helped them come up with a solution.

Filipe's group revealed little autonomy during the whole process, having difficulties in implementing the scheme in the breadboard and also in building the code in the Arduino IDE. However, Daniel and Denis's group had problems with the IF statement because it was incorrect syntax. After the fix, the project worked properly. Through the audio recording, I noticed that, after the conclusion of the work, the students started parallel conversations. With this episode, I found that one of the groups (Filipe and Rodrigo) could not achieve the goals they had outlined,
that is, develop simple projects, through learning on their own. However, Rui and Rafael’s group implemented this project practically without the help of the teacher, thus becoming autonomous. The Daniel and Denis group was able to carry out the tasks practically without the help of the teacher, namely Daniel, who only did not correctly interpret the IF instruction syntax. Your colleague, Denis, was always more apathetic and uncooperative.