

CASE STUDY IN MATHEMATICS AND PHYSICS (TIME-DISTANCE ACTIVITY)

[Context](#)

[The school](#)

[The class](#)

[The teachers](#)

[1- Tasks and resources used](#)

[2- Work with teachers](#)

[3- Classroom teaching \(based on teacher interviews\)](#)

[4- Lessons](#)

[A priori analysis of the lesson](#)

[Organisation of the lessons](#)

[Session 1 \(maths, day 1\)](#)

[Session 2 \(maths, day 2\)](#)

[Session 3 \(maths, day 3\)](#)

[Session 4 \(physics, day 4\)](#)

[Session 5 \(maths, day 5\)](#)

[Session 6 \(physics, day 6\)](#)

[Session 7 \(physics, day 7\)](#)

[Session 8 \(physics, day 8\)](#)

[Session 9 \(physics, day 9\)](#)

[Session 10 \(physics, day 10\)](#)

[Analysis of observed sessions](#)

[Session 1 \(maths\)](#)

[Session 2 \(maths\)](#)

[Session 3 \(maths\)](#)

[Session 4 \(physics\)](#)

[Session 5 \(maths\)](#)

[Session 6 \(physics\)](#)

[Session 7 \(physics\)](#)

[Session 8 \(physics\)](#)

[Session 9 \(physics\)](#)

[Session 10 \(physics\)](#)

[Dynamics within the three-dimensional model](#)

[5- Pupil perceptions](#)

[Methodology](#)

[Results](#)

[Initial Q-sorting and movements after the FaSMEd lessons](#)

[Technology](#)

[Mathematics & Science](#)

[Assessment](#)

[Conclusive remarks](#)

[FA strategies](#)

[FA and technology](#)

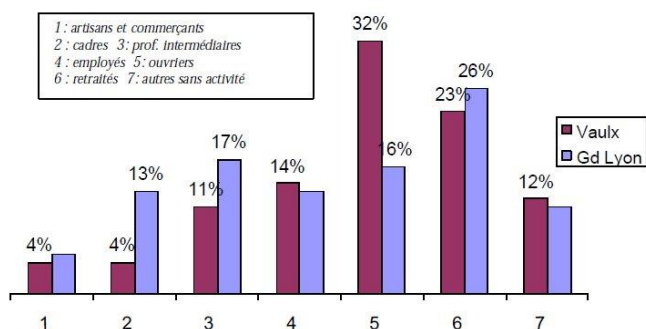
[FA and interdisciplinary work](#)
[Appendix A](#)
[Appendix B](#)
[Appendix C](#)
[Appendix D](#)
[Appendix E](#)

Context

The school

The “collège Henri Barbusse” is located in a disadvantaged area of the suburbs of Lyon in a town called Vaulx en Velin.

The socio-professional repartition of the town is summarized in the following graph in comparison with the average of Lyon urban area:



Répartition de la population selon la catégorie socio-professionnelle

Source : Insee, RGP 1999 Traitement : ORS

1: craftsmen and storekeepers 2. Senior managers and teachers 3. Middle managers 4. Employees 5. Workers 6. Retired 7. Others and inactive workers

The low secondary school Henri Barbusse obtained a success rate of 76.19% (in comparison of 86.92% in the whole regional education area) and a rate of distinction of 23.81% (in comparison of 54.47% in the whole regional education area).

The class

Grade 7 class of students (11-12 years old) with an average school level in the context of this school and a great heterogeneity. The class is rather turbulent and students concentration is unstable and not guaranteed even if students participate willingly.

The teachers

The originality of this case study comes from the common work done by a science

teacher (L in the following) and a mathematics teachers (T in the following). Both teachers chose to work together in order to help their students to make the link between the mathematics and the physics learning. The choice of the graph notion appears to be a good choice because it is a boundary object between Maths and Physics: it is a learning object in mathematics and it is a tool in Physics. Both teachers are involved in teacher training and have worked since four years with researchers in different research projects mainly dedicated to interdisciplinary. Both teachers were used to teach with technology for long years and tried to integrate them within the classroom in the usual development of lessons.

1- Tasks and resources used

Session 1 (maths, day 1)

Two multiple choice tests (MCT): ten questions about the coordinate plane and six questions about the representation of data in both tables and graphs.

Session 2 (maths, day 2)

Activity 1: *journey to the bus stop - writing a story for a given graph.*

Activity 2: *matching a graph to a story.*

Time of sharing about the Activities 1 and 2.

Sessions 3 (maths, day 3)

Activity 3, 4: interpretation of graphs modeling other situations: weight and size of a baby as a function of her age (Fig. 1), and temperature as a function of time (Fig. 2).

A further activity *matching 10 stories with 10 graphs* was planned but did not take place.

16 SANTÉ

THÈME DE CONVERGENCE

Voici un graphique représentant des courbes de croissance d'un bébé :

Le graphique illustre la croissance d'un bébé de 0 à 5 mois. L'axe horizontal (X) représente l'âge en mois, gradué de 0 à 6. L'axe vertical gauche (Y) mesure la taille en centimètres (cm), avec des graduations de 47 à 63. L'axe vertical droit (Y) mesure le poids en grammes (g), avec des graduations de 2000 à 6400. Deux courbes sont tracées : une courbe bleue pour la taille et une courbe rouge pour le poids. La courbe de la taille commence à 47 cm à 0 mois et atteint 63 cm à 5 mois. La courbe du poids commence à 3400 g à 0 mois et atteint 5800 g à 5 mois.

Mois	Taille (cm)	Poids (g)
0	47	3400
1	50	3800
2	54	4200
3	58	4600
4	60	5000
5	63	5800

Source : balmana.web.chetz.tiscali.fr

- Que représente chaque courbe ? Où sont placées les graduations des tailles ? Où sont placées les graduations des poids ?
- Entre quels âges ont été construites ces courbes ?
- Combien mesurait et pesait le bébé à sa naissance ?
- À 3 mois, combien mesurait le bébé et combien pesait-il ?

101 Quel froid !

MÉTÉOROLOGIE

Voici un tableau qui donne les températures maximales et minimales relevées durant le mois de janvier 2009 à Paris :

Jour	Température max.	Température min.
1	2,1 °C	-0,9 °C
2	2,3 °C	-0,9 °C
3	1,8 °C	-1,7 °C
4	-0,4 °C	-4,1 °C
5	0,3 °C	-1,2 °C
6	-0,7 °C	-3,8 °C
7	0,2 °C	-8,9 °C
8	1,8 °C	-1,7 °C
9	-0,3 °C	-6,4 °C
10	1,9 °C	-6,3 °C
11	3,6 °C	-6,3 °C
12	5,8 °C	-2,1 °C
13	6,0 °C	3,1 °C
14	5,0 °C	3,2 °C
15	3,6 °C	0 °C

- Dans un repère orthogonal, placer des points représentant les températures maximales en mettant les jours en abscisse et les températures maximales en ordonnée.
 - De même, placer des points représentant les températures minimales.
- Quels ont été les jours les plus chauds ? Quels ont été les jours les plus froids ?
- Combien de fois les températures ont-elles augmenté d'un jour à l'autre ?
- Combien de jours la température a-t-elle été en dessous de 0 °C ?

Fig. 1: Exercice 16 p.109 (Triangle, 5eme, Hatier)

Fig. 2: Exercice 101 p.87 (Myriad, 5eme, Bordas)

Session 4 (physics, day 4)

Activity 5, practical work: physical experience of water solidification with collection of data in a table (time, temperature).

Session 5 (maths, day 5)

Activity 6: construction of the graph of the temperature as a function of time, starting from the data collected by the students during the session 4.

Session 6 (physics, day 6)

Activity 7, homework: write a story that corresponds to the graph in Fig. 3.

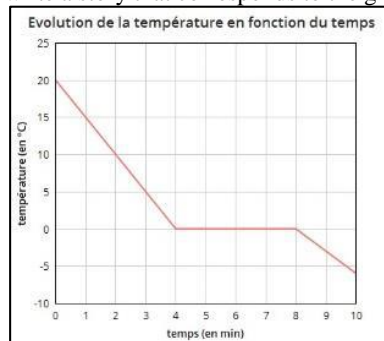


Fig. 3: Graph constructed by the physics teacher.

Activity 8: matching the graph in Fig. 4 to one of the three proposed stories.

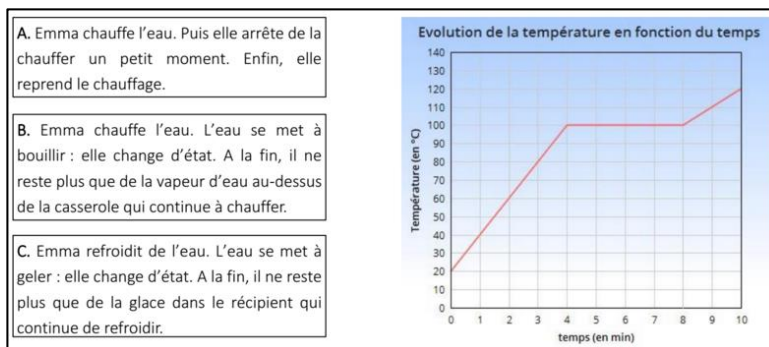


Fig. 4: Activity 8.

Session 7 (physics, day 7)

Activity 10: matching 10 stories to 10 graphs (adapted from the *card-matching activity: matching ten graphs to ten stories*).

Session 8 (physics, day 8)

Lesson about magnitudes and units of measure.

Activity 11, homework: mathematical and physical interpretation of a given graph (Fig. 5).

EXERCICES : Exploiter un graphique

1. Des réponses à Connaître :

- Quels sont les états de matière ?
- Comment s'appelle le passage de l'état solide à l'état liquide ?
- Qu'est-ce que la vaporisation ?
- Quels sont les températures de changement d'état de l'eau ?
- Les températures de changement d'état sont toujours les mêmes pour des liquides incolores ?
- Les températures de changement d'état sont toujours les mêmes pour des liquides incolores ?

2. Exploiter un graphique :

Un élève relève toutes les minutes la température d'un liquide incolore contenu dans un tube à essai que l'on refroidit. Il obtient le graphique ci-contre

- Quelles sont les grandeurs sur chaque axe ?
- Quelle est la durée de l'expérience ?
- Comment varie la température entre 16°C et 6°C ?
- Colorer la partie de la courbe qui représente le palier de température : qui représente le changement d'état.
- A quelle minute débute le changement d'état ?
- Combien de temps à durée le changement d'état ?
- A quelle température s'est effectué ce changement d'état ?
- Dans quel état est le liquide incolore en début d'expérience ?
- Dans quel état est cette substance en fin d'expérience ?
- Cette substance est-elle de l'eau ?

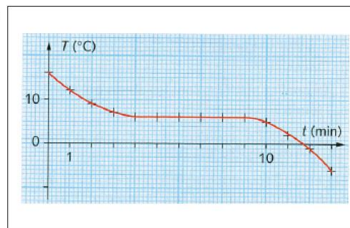


Fig. 5: Exercise of interpretation of a graph given as homework.

Session 9 (physics, day 9)

Correction of the exercise through a multiple choice test, where the answers for each question are proposed by the teacher.

Session 10 (physics, day 10)

Activity 12: remediation and complementary work on magnitudes, values and units of measure.

Technology used:

- By the students: student response system.
- By the teachers: computer linked to a projector and to the student response system, software [Je lève la main \(Speechi\)](#), micro-document camera, [online simulator](#).

Type of formative assessment used:

Multiple choice tests where each question aims at evaluating the degree of achievement of one particular competence. This allows teachers to detect the students' difficulties in order to build new learning tasks, but also to give feedback to the class about students' improvement.

Class tests

Maths class test (session 5): The marked activity for constructing the graphs time-temperature starting from the data of the physical experiment and of the online simulator. See Fig. 12 for the text.

Physics class test (session 9): The multiple choice test, based on the exercise in Fig. 5, was considered as a class test. Data about students' achievement was elicited through the student response system and analysed as a class' overview after the FaSMEd sequence of lessons. The English translation of the questions and the students' results are in appendix (see Appendix C).

2- Work with teachers

The French research team has worked since the beginning of the school year 2014-2015 with science and mathematics teacher of the school. The work between the maths and physics teachers and researchers was essentially organized around the lessons contents, the FA philosophy and the potentialities of technology in terms of FA. But also, a previous work has been done regarding the inter-disciplinary teaching where each teacher keeping his/her own subject epistemology discuss with other teachers to understand the possible links between their subjects.

During the school year 2014-2015 we met

The whole team :

- 2 February 2015 : Organisation of European partners visits. planning of FA lessons.
- 30 March 15 : Reflexion about FA and technology for FA
- 4 April : Description of resources

The physics teacher :

- 4 February : FA and graphs
- 16 June : work on the website

The science teachers

- 10 April : conception of FA lessons about scales in Physics and sciences. Use of student response system
- 4 May : observation FA lesson

The Maths and Science teachers

- 20 and 30 Avril : conception FA lessons about scales in maths and physics with student response systems
- 5 May : observation

During the first trimester of the school year 2015-2016, we met teachers 6 times in presence:

- October 5, 2015: school meeting with all the teachers involved in the FaSMEd project.
- October 12, 2015: meeting with L and T for preparing the observations (see the schedule below).

Date	Mathematics	Physics	Students	By
November 2 8-10 am			Interviews (q-Sorting)	Researchers
November 5 9-10 am	Formative assessment MCT about the coordinate plane.			Video taken by the teachers
November 5- 19	Work on Time-distance activity as an introduction of the work on graphs. Weight and size of a baby as a function of her age, and temperature as a function of time	Properties of water: introduction		Nov 16 (8-10 am): Observation of the "time-distance" activity in maths classroom by the researchers
November 19		Practical work: each		Video taken by the

3:30-4:30 pm		student builds a table (time, temperature) with the data collected during the experiment.		teachers: - students' work - collection of data during the experiment - experimental device
November 23 8-10 am	Building a graph with data that students collected in Physics.			Exchange by email about the activity "time-temperature" of Nov 26
November 26 3:30-4:30 pm		Activity time-temperature on the same model as time-distance activity : Tell a story from the graph.		Observation by the researchers
December 2 10-11 am		Graph interpretation built in mathematics from a physics point of view.		Teachers' remarks.
December 3 3:30-4:30 pm		MCT regarding the homework revising. Analyse of the answers on the spot.		Video taken by the teachers
December 10 3:30-4:30 pm		Remediation after reflection.	Students' interviews	Observation by the researchers.

Table 1 : school visits and observations in the classroom

3- Classroom teaching (based on teacher interviews)

This section corresponds to the report written by the teacher starting from the questions here written in bold characters.

Your experience on the use of technology in the classroom before FASMED.

T : "Before my participation to the FaSMEd project, I was curious about technology in classroom. When I discovered the first dynamical geometry software I saw the potentialities of GDS. I also understood that with a beamer I could share this software with students without having to move to the computer lab, that is sometimes difficult. I was convinced that it was time saving, despite it's often difficult to get familiar with."

L.: "Before my participation to the FaSMEd project, I worked with an IWB in my classroom but also with the camera allowing to view and to share students' work. For my own I was also a frequent visitor of simulation websites in order to illustrate my courses."

Your experience on the use of formative assessment in the classroom before FASMED.

T : "Before, FA was only for me some questions relatively to lessons, and oral questions in order to try knowing which student switch off from the course."

L.: “Before my participation to the FaSMEd project, FA was for me assessment of some lessons, or exercises either with an optional marking (the mark was taken into account only if it increased the student’s average) or with questions that I gave beforehand and that students could prepare at home. The goal was to show them important things, that is to say, stuff that I really wanted they learned or delicate notion that I wanted to highlight. My goal was to prepare them to better learn important knowledge and to prepare summative assessment.”

What it is now for you formative assessment?

T : “Now, FA, it’s an opportunity to know where the students are. It’s a question of taking information about the class, to send it back and the objective, after that is to propose adjustments”

L.: “I completely agree!”

What are the advantages and disadvantages of using technology for the formative evaluation? (difficulties, inputs, constraints ...)

T : “The technology gives opportunity to collect easily a lot of information. It is also very fun for students who are living in a digital world. It allows to motivate some students. All this information allows to validate, or not the teacher’s feeling regarding students understanding. It also gives an opportunity for students to situate themselves. So, it allows to clarify learning goals. However, the analysis is often complicated and tedious. Adjustments and remediation are difficult to imagine and often it’s only a rephrasing of the same explanations”

L.: “But, it allows also to analyse results on the spot and to take into account students’ difficulties immediately.”

T : “Getting familiar with a new technology is always time-consuming. First trials are often at risk and it is necessary to be able to take that upon yourself in front of a class. Even with experience, using technology is always uncertain (computer out of order, uninstall driver, missing battery,...).”

More specifically in this class sequence: what are the difficulties you had planned that students would encounter?

T : “Regarding graph interpretation (time-distance), I expected difficulties about the fact that the distance was the distance to the house. I thought that they would not be careful. I minimized this difficulty because even pointing overtly this fact, students didn’t actually understand. In the graph drawing, I thought at difficulties regarding the scale choice on the axis.

L.: “I expected difficulties on graph reading, but it didn’t occur because of T.’s lessons. I also expected difficulties on graph interpretation and particularly when the graph becomes constant because of the temperature stabilization. Students made the mistake during the first session, but very quickly they understood this fact.”

4- Lessons

During the cluster meeting of July, the time-distance activity has been presented and commented. The maths and physics teachers of “college Barbusse” decided to implement this activity in their grade 7 class in the first trimester of the school year 2015-2016. They planned to implement an interdisciplinary learning sequence where

the time-distance activity is adapted and declined in different mathematical and physical contexts, keeping the fundamental idea of interpreting a graph through a story or a story with a graph. They considered the graph as a boundary object between maths and physics, allowing to make connections between the two subjects.

In October 2015, we (two researchers) and the two teachers discussed in presence this implementation of the FaSMEd material concerning the time-distance activity. Some of the activities chosen came from the toolkit (see Fig. 1, 2 and 5) and some others from local material (see Fig. 3, 4). In particular, the adaptation of the time-distance activity in a “time-temperature” activity has been designed by the teachers for better fitting in the physical course. The mode of implementation, as well as the organisation of the work in the classroom, were planned by the teachers. When possible, T attended L’s lessons and vice versa (we will specify it in the section “Organisation of the lessons”), and then they met for discussing of what happened in the classroom. Some of the lessons in November-December 2015 have been observed and videotaped by the researchers (see Table 1). The other lessons have been videotaped by the teacher who was not in charge of the lesson. The Q-sorting activity has been proposed to the whole class.

The camera was focused on the teacher during the collective moments and followed a group of students when they were working in groups. We met the teachers before and after each observation.

***A priori* analysis of the lesson**

Time-distance activity was implemented in mathematics and seen as a preparation for the physical study of the variation of the temperature of water over time during a change of state. In this physical context, the time-distance activity was adapted as a “time-temperature” activity. More precisely, the interdisciplinary work between mathematics and physics was carried out within the science chapter called “Characteristic magnitudes of water”. The general goal of the interdisciplinary learning sequence was working on the notions of magnitude, unit and measuring device. In particular, the study focused on magnitudes characterising water: temperature (of change of state), mass and volume (volumetric mass). The main difficulties detected by the teachers within this sequence were:

- defining magnitudes and distinguishing them from units;
- definition the mass
- distinguishing mass and volume.

Specifically, the learning objectives of the mathematics lessons, within this sequence, were:

- Classifying integers;
- Constructing a graph and reading information on it: magnitudes on axis, scale, evolution curve;
- Associating units with the corresponding magnitudes (and measuring device);
- Magnitude and unit : calculating/measuring a volume.

The learning objectives of the science lessons, within this sequence, were:

- Associating units with the corresponding magnitudes (and measuring device);
- Reading mass and volume measures;
- Practising an experimental process for highlighting how mass and volume behaves during a change of state.

- Detecting a temperature using a thermometer or a sensor.
- Realising, observing, schematising experiences of change of state.
- Constructing the graph that corresponds to a change of state, verifying and exploiting the results.

Teachers' didactic choice, in the perspective of the interdisciplinary work, consisted in sharing vocabulary, notation and tools.

For instance, after session 6, when L talked about the slope of a graph, L and T discussed about the term "slope":

T: *The term "slope" is interesting, but... later.*

L: *Yes, but actually without explaining it, you see, I think they understood.*

T: *However, time-distance, they could have said "it goes down, it goes up". What is going down, what is going up? It is what you read on the y-axis. The distance increases or decreases.*

L: *Yes.*

Concerning the efforts for carrying out an interdisciplinary work, T wrote in his diary: "For carrying out accurately an interdisciplinary work on the use of new technologies as a support for formative assessment, we have discussed a lot informally. Actually, it was necessary, for optimising the link between the two disciplines, to constantly adjust the plannings and the progressions".

During the observations of the school year 2014-2015, we could identify a common scheme of action that has become stable in both L's and T's formative assessment practices:

- proposing a multiple choice test the classroom;
- showing or/and commenting results with students;
- analysing results on the spot or/and later, outside of the lesson time, for designing remediation.

Technology plays an important role in each of these phases. Questions are projected in the classroom and students have to type their answer on their personal clicker and send it through the student response system. The system allows teachers to collect data from all the students in a short time and to have them organised in tables, that serve as a support for teachers' analysis of the students' difficulties. This analysis influences a possible remediation phase that can be designed and implemented with or without technology.

Organisation of the lessons

Session 1 (maths, day 1)

Objective: detecting students' state of knowledge about the coordinate plane and representations of data (tables, graphs, charts, ...).

T was alone in his mathematics classroom during this session.

Multiple choice tests (20 minutes): students answered individually to each question with the student response system; the teacher did not comment the results on the spot but stores them in the memory of the computer for further analysis. The whole test is present in appendix (see Appendix A and B), but below we present two significant questions and their results.

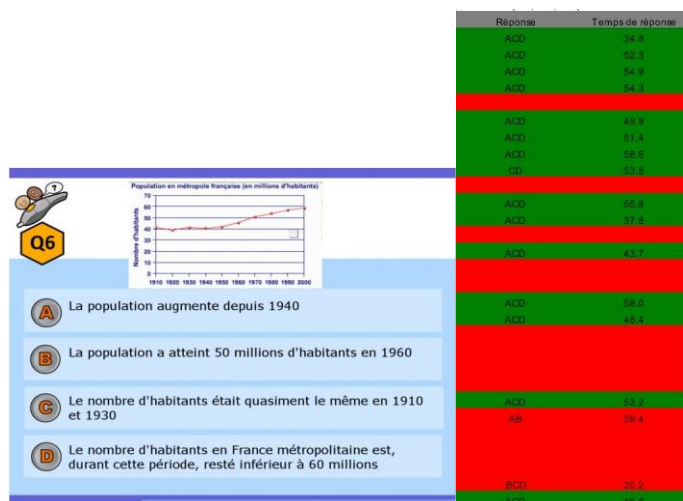


Fig. 6: A question of the MCT regarding a graph reading and the students answers

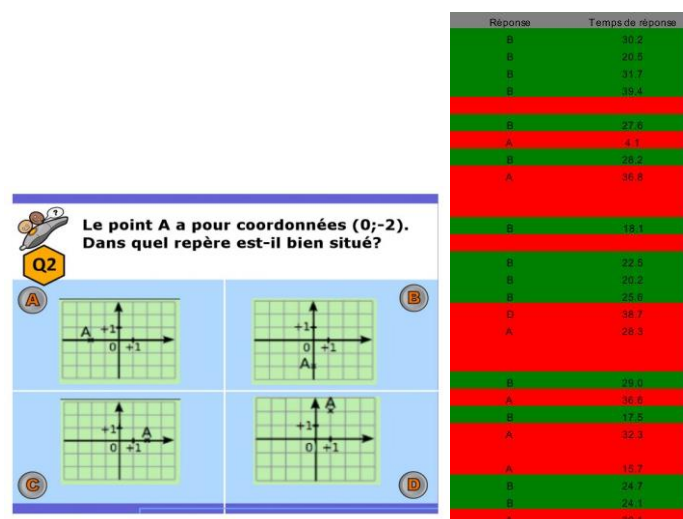


Fig. 7: Another question and students' answers

The student response system gave information for each student about his/her answer but gave also information for the whole class. As said by T, the interpretation of these answers was not always easy in the perspective of modifying his teaching: is the wrong answers due to a bad use of the clicker, or a lack of time or a misconception? Watching accurately to the video of the lesson shows that, despite T's remarks, some students did not answer in time. And even, often they answered to the previous question but a bit too late and the answer was taken into account on the next question. The teacher was able to observe this kind of behaviour during the lesson because when a student answered it appeared in yellow on the screen shared within the classroom, but interpreting what the students exactly did was difficult.

[Go to the analysis of this section.](#)

Session 2 (maths, day 2)

Objective: understanding students' interpretations of a time-distance graph.

As he declared before the teaching experiment, T considered the interpretation of a time-distance graph as a challenge because he expected difficulties, and particularly regarding the fact that the y-axis has to represent the distance to Tom's house and not the walked distance.

T was alone in his mathematics classroom during this session.

Concerning the two first activities (activity 1 *journey to the bus stop - writing a story for a given graph.* and activity 2: *matching a graph to a story.*), the teacher organised the lesson with a first individual work where students had to think alone to a story that could fit for the graph. Thereafter students work by groups; within each group, T designated a spokesperson who had to take notes on the group's answer. The goal was to make students compare their proposals and to highlight the good interpretation of the y-axis. The group session ended with a pooling of ideas and interpretations. None of the groups gave a good interpretation of the graph:

"The path is climbing" or "Tom turns on his right" show that the graph was more interpreted as a map and the line was seen as Tom's trajectory instead of the representation of the distance to the house as a function of time. Paradoxically, the final plateau of 10s was interpreted as a waiting time for the bus. It is interesting to notice here that the two interpretations that is to say the graph seen as a map and the graph seen as a distance as a function of time, coexisted in the students' mind and the reference to their own experience (each morning they had to wait for the bus) mixed with the scientific interpretation of the graph.

Although it was not observed, session 2 is briefly analysed in terms of formative assessment: [go to the analysis of this section.](#)

Session 3 (maths, day 3)

Objective: understanding students' interpretations of a graph in different contexts.

Both teachers were present in this mathematics session. T led the students' work and L helped with technical problems and monitoring students' work in the groups.

T revised the activities 1 and 2 with the students, by projecting the text and commenting on the results found in session 2. Then, he proposed to students the activities 3, 4 and 5.

Activity 3: On the coordinate plane, two curves represent the growth of a baby: the size (cm) and the weight (g) over time (months) (Fig. 8).

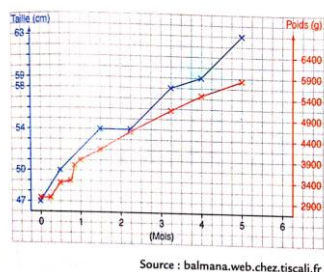


Fig. 8: Graph of the Activity 3.

Students had to answer the following questions:

- What does each curve represent? Where are placed the graduations of the size? Where are placed the graduations of the weight?
- Between which ages have the curves been constructed?
- Which were the size and the weight of the baby at his birth?
- At the age of 3 months, what was the size and the weight of the baby?

Students worked individually for a while, then shared their answers in groups of 3 or 4 and finally the teacher led the time of sharing.

Activity 4: The table in Fig. 9 collects the max. and min. temperatures measured every day for 15 days.

Jour	Température max.	Température min.
1	2,1 °C	-0,9 °C
2	2,3 °C	-0,9 °C
3	1,8 °C	-1,7 °C
4	-0,4 °C	-4,1 °C
5	0,3 °C	-1,2 °C
6	-0,7 °C	-3,8 °C
7	0,2 °C	-8,9 °C
8	1,8 °C	-1,7 °C
9	-0,3 °C	-6,4 °C
10	1,9 °C	-6,3 °C
11	3,6 °C	-6,3 °C
12	5,8 °C	-2,1 °C
13	6,0 °C	3,1 °C
14	5,0 °C	3,2 °C
15	3,6 °C	0 °C

Fig. 9: Table of the Activity 3.

Students had to solve the following tasks:

- In a coordinate plane, place the points that represent the max temperatures, marking the days on the x-axis and the max temperatures on the y-axis.
 - In the same way, place the points representing the min temperatures.
- And they had to answer the following questions:
- Which were the hottest days? Which were the coldest days?
 - How many times did the temperatures increase for a day to the next one?
 - How many days have the temperature been under 0 °C?

For each activity, students were organised in groups of 4 students: they worked individually in paper and pencil for about 10 minutes and then they could discuss their answers in the group. The teacher walked through the classroom and checked what the students wrote, sharing students' doubts and questions with the whole class. Finally the teacher led the pooling of all of the students' responses.

Working on activity 3, some students wondered if the two curves represented on the coordinate plane (Fig. 8) corresponded to two different babies. Thanks to the collective discussion, started by the teacher in the classroom, students agreed on the fact that they were studying the weight and the size of the same baby.

Working on activity 4, several difficulties emerged. The main obstacles encountered by students were the following ones:

- the meaning of the given table of values (Fig. 9);

- the meaning of a graphical representation;
- the number of curves to be drawn;
- the axis definition;
- the identification of the extreme values in the table for deducing the range and eventually the scale of the graduation.

Students did not complete the work during the lesson and have been asked to reflect upon the choice of the scale for the lesson after (not observed). In his diary, T commented on the end of this work: they discussed and validated the scale in classroom and he provided students with graph paper with graduated axis.

A further activity *matching 10 stories with 10 graphs* was planned but did not take place. T decided not to give it to students because of their great difficulties in solving Activities 3 and 4.

[Go to the analysis of this section.](#)

Session 4 (physics, day 4)

Objectives: Carrying out an experiment; following an experimental protocol.

The two teachers worked together in the classroom. L led the students' work and T helped with technical problems and monitoring students' work during the experiment.

The fifth activity was a practical work where students had to realise an experiment of water solidification and to collect data. The title of the lesson was a question: "How is it possible to know if the achromatic liquid in the test tube is water?". The first work that L asked to her students was to write an hypothesis; after a questions-answers phase, L wrote on the whiteboard: "If the achromatic liquid in the test tube is water, then the freezing point is 0°C."

The class was divided into groups of three students by lab bench. They had to collect the temperature of the water at regular intervals while placing the test tube with the achromatic liquid in the cooling mixture. The protocol of the experiment (Fig. 10) was given by the teacher.

Expérience : Comment réaliser la solidification du liquide ?	
MATERIEL	PROTOCOLE
<ul style="list-style-type: none"> - mélange réfrigérant ; - thermomètre ; - chronomètre ; - tube à essai ; - liquide à tester ; 	<ul style="list-style-type: none"> <input type="checkbox"/> mettre le liquide à tester dans le tube à essai ; <input type="checkbox"/> mettre le thermomètre dans le tube à essai ; <input type="checkbox"/> allumer le thermomètre <input type="checkbox"/> noter la température à $t = 0$ min, dans le tableau sur la feuille ; <input type="checkbox"/> mettre le tube à essai dans le mélange réfrigérant ; <input type="checkbox"/> ajouter 5 cuillères de sel dans le mélange réfrigérant (et pas dans le tube à essai) <input type="checkbox"/> lancer le chronomètre ; <input type="checkbox"/> - noter la valeur de la température, toutes les 30 secondes.
Schématisation de l'Expérience :	

Fig. 10: The protocol of the experiment

In order to illustrate the experiment, L showed a simulation on the computer, explaining the different components needed and the first steps of the experiment.

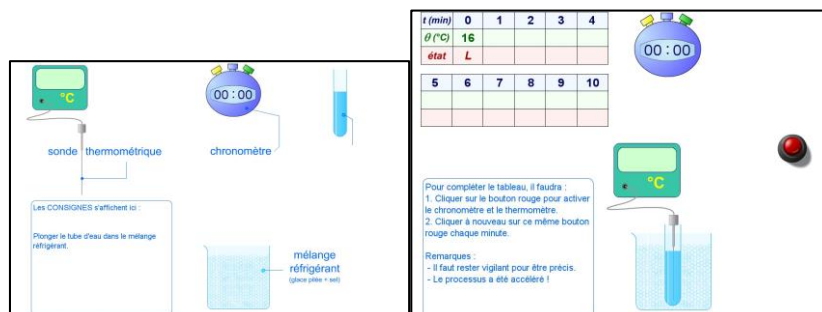


Fig. 11: Explanations given to students about the experiment from the online simulator.

Students had to draw a detailed schema of the experiment. After some questions, L gave the cooling mixture (ice and salt) and the students began the experiment.

One difficulty came from the length of the experiment that was longer than the expected time. Therefore, at the end of the session, T intervened explaining that in the next maths lesson they would have continued the work, namely by drawing the graph time-temperature. Moreover, T said that, as some of the experiments failed, students would have had to draw both the graph with their own data and the graph with the data coming from the simulator.

Session 4 is analysed in terms of formative assessment with technology in the [next section](#).

Session 5 (maths, day 5)

Objective: construction of the graph of the temperature as a function of time, starting from the data collected by the students during the previous session.

T worked alone in this mathematics session.

Drawing the graphs was laborious. According to T, it was essentially due to the difficulty, with these students, to actually make them do their homework. T explained that he had no choice but to ask students to write their response as a marked summative assessment requiring them to:

- draw the curve of the evolution of the temperatures that come from the simulation software
- draw the curve of the evolution of temperatures coming from his/her own data
- write his/her own data.

Here is the given sheet:

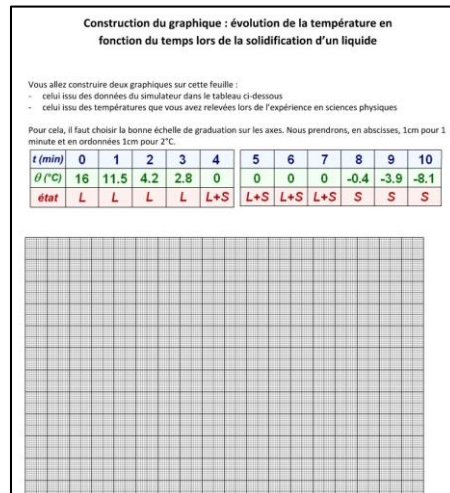


Fig. 12: The report file

Although it was not observed, session 5 is briefly analysed in terms of formative assessment with technology: [go to the analysis](#).

Session 6 (physics, day 6)

Objectives: Analysing a graph, in terms of increasing and decreasing temperature and temperature plateau during a change of state.

Both teachers were present in this physics session. L led the students' work and T was seated with the students, participating in the moments of classroom discussion.

Activity 7, that students had to solve for homework, was revised in classroom during this session. Here is the task:

Emma does an experiment: she puts some (liquid) water in a container with a thermometer in the freezer. She measure the temperature every minute.

Describe what could have happened. You can include details of Emma's experience, the state of the water, the change of state, the temperature: change or not, the duration of the experience, the time of the change of state.

Students had to write a story that corresponded to the graph in Fig. 3. The teacher had prepared one multiple choice question where she proposed three stories for explaining the graph (see Fig. 13). Students had to choose, through the student response system, which story was more similar to their story.

Une histoire pour un graphique

Activité 1 : Choisir la bonne histoire

- Histoire A :** La température de l'eau baisse régulièrement jusqu'à atteindre la température dans le congélateur (-6°C).
- Histoire B :** La température de l'eau baisse jusqu'à 0°C . A cette température là toute l'eau passe de l'état liquide à l'état solide instantanément. Quand toute l'eau est devenue solide, la température recommence à baisser.
- Histoire C :** La température de l'eau baisse jusqu'à 0°C . Puis elle reste un moment à 0°C : le temps de passer de l'état liquide à l'état solide. Quand toute l'eau est devenue solide, la température recommence à baisser.

Fig. 13: Multiple choice question for answering to Activity 7 (translation below).

One story for one graph:

Activity 1: choose the good story

1. Story A: The temperature of the water decreases regularly till getting the temperature of the freezer (-6°C)

2. Story B: The temperature of the water decreases till 0°C . At this temperature, all of the water change from the liquid state to the solid state instantaneously. When all of the water is becoming solid, the temperature begins to decrease again.

3. Story C: The temperature of the water decreases till 0°C . Then, it remains at 0°C for a while: the time for changing from the liquid state to the solid state. When all of the water is becoming solid, the temperature begins to decrease again.

The teacher displayed immediately the graph of the results: only 21% of the students had given the good answer C. The teacher discussed with the students some keywords of the stories: “regularly”, “instantaneously”, making reference to the practical experiment that they had done during the previous session (session 4).

As a complement to this activity, students had to fill in the table in Fig. 14. Three parts had to be detected on the curve, according to the different slope: the task consisted of specifying, for each part, if the temperature changes (first row) and what is the state of the water (second row).

1. Sur le graphique, la courbe est composée de trois segments de **pent**es différentes : on appellera

- 1 : le segment compris entre 0 min et 4 min
- 2 : le segment compris entre 4 min et 8 min
- 3 : le segment compris entre 8 min et 10 min

Placer les nombres 1, 2, 3 sur la courbe du graphique.

2. Compléter le tableau suivant :

Partie de la courbe	1	2	3
La température change (oui/non)			
Quel est l'état de l'eau ?			

Fig. 14: Complement to activity 7.

Activity 8 was then introduced by the teacher for verifying students' understanding of the previous activity. Students had to work in group of 3 to find the story that matched the graph (see Fig. 4). The task had been transposed by the teacher as a multiple choice question in the student response system of the classroom (Fig. 15). Thus, for collecting all of the students' answers, the teacher asked students to type their answer individually on their clicker. She showed immediately the results to comment them

with the class.

Une histoire pour un graphique :

Activité 2 :

- Histoire A :** Emma chauffe l'eau. Puis, elle arrête de la chauffer un petit moment. Enfin, elle reprend le chauffage.
- Histoire B :** Emma chauffe l'eau. L'eau se met à bouillir : elle change d'état. A la fin, il ne reste plus que de la vapeur d'eau au-dessus de la casserole qui continue à chauffer.
- Histoire C :** Emma refroidit de l'eau. L'eau se met à geler : elle change d'état. A la fin, il ne reste plus que de la glace dans le récipient qui continue de refroidir.

Fig. 15: Multiple choice test for answering Activity 8 (see translation below).

One story for one graph:

Activity 2:

- Story A:** Emma warms water up. Then, she stops to warm it up for a while. Finally, she starts the heating again.
- Story B:** Emma warms water up. Water boils: its state changes. At the end, only vapour remains upon the pot that keeps on warming up.
- Story C:** Emma cools water down. Water freezes: its state changes. At the end, nothing else but ice remains in the container that keeps on cooling down.

L displayed the graph of the results on the spot: 63% of the students had given the good answer B. L discussed wrong stories with the students, asking why they were wrong. She made reference to some students' mistakes during the practical experience that they had done during the previous session (session 4), as for example remove the container with the water from the cooling mixture to read the temperature on the thermometer. She made also reference to students' possible experiences in their daily life.

[Go to the analysis of this section.](#)

Session 7 (physics, day 7)

Objectives: Reading, analysing and interpreting a change of state graph.

L worked alone during this physics session.

Activity 9 is an adaptation of the task *matching 10 graphs to 10 stories* from the time-distance activity. Indeed, the teacher aimed at interpreting the graphs from a physical point of view.

Ten graphs and ten stories were given to students that had to find the good matches.

Graphiques :

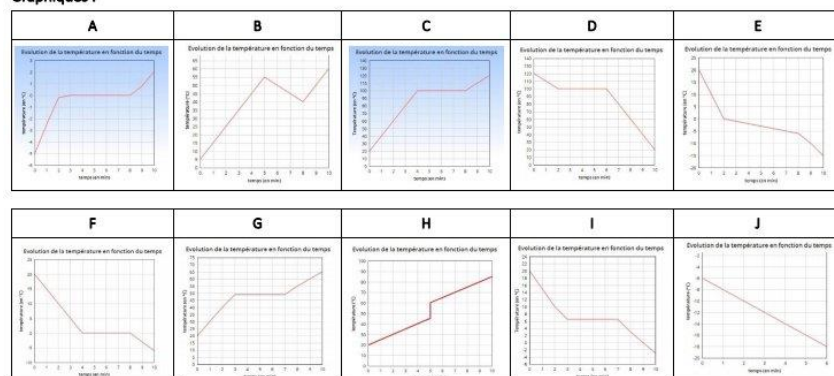


Fig. 16: Ten graphs

1. Emma measures the temperature of the salted water state change. The water comes from a puddle on the road that has been salted for winter. She realizes that the state change temperature is not constant: it decreases a bit.	2. Emma places a thermometer in the pressure cooker which has just heated up: it contains steam. She let water cooling down and takes the temperature of the water each minute with a sealed system so that steam does not escape.
3. Emma put in the freezer a container with liquid water. She takes the temperature each minute.	4. Emma decreases the temperature of her fridge from -6°C to -18°C .
5. Emma doesn't remember the liquid in a glass: it is an uncoloured liquid. In order to discover which liquid it is, she cool down the liquid. She sees that the change of state from liquid to solid is not 0°C : it's not water!	6. Emma doesn't remember the liquid in a glass: it is an uncoloured liquid. In order to discover which liquid it is, she heats up the liquid. She sees that the change of state from liquid to gas is not 100°C : it is not water!
7. Emma heats up liquid water which comes from the fridge. She stops heating. Later on she starts again heating up the water.	8. This graph is just plain wrong. How could water be at two different temperatures at once?
9. Emma heats up liquid water in a pan. The water is boiling. When all liquid water is changed into steam, the temperature of steam increases.	10. Write your own story!

Fig. 17: Ten stories

The final report, made by the teacher, leaned on the states of the matter and characteristic temperatures of the water's changes of state.

Although it was not observed, session 7 is briefly analysed in terms of formative assessment: [ego to the analysis of this section](#).

Session 8 (physics, day 8)

Objectives: making the word *magnitude* emerge and distinguishing it from *units*; discovering the device for measuring volumes; distinguishing volume and mass.

L worked alone during this physics session.

A set of words was given to students who worked in groups (3-4 students) for classifying them in three groups by placing them in a table with three columns. Here are the given words:

Temperature, Thermometer, Celsius degree, Mass, Weighing scale, Kilogram, Volume, Litre, Graduated test tube, Time, Second, Chronometer.

After this first phase of the work, the teacher asked students to add the following symbols to their table: T, t, V, °C, L, m, kg, s. Moreover, students had to specify the name of each column, and finally to give a definition of volume and mass answering the questions “What is volume?” and “What is mass?”. This sequence of tasks of increasing difficulty were given orally by the teacher according to the different progressions of the groups.

The teacher chose some of the students’ responses, took pictures with a micro-document camera and projected them one by one in the classroom.

In particular, they discuss the students’ responses displayed in the classroom in terms of:

- the name of the measuring device;
- the names given to the columns;
- the definition of volume and of mass.

Finally, a new table prepared by the teacher was provided to students (Fig. 18). The teacher led the institutionalisation phase by filling in the table projected at the whiteboard. Students took notes and stuck the paper table in their notebook.

Définition						
	Nom	Symbole	Nom	Symbole	Nom	Symbole
La dépend	
Le volume est	
	

Fig. 18: Table to fill in during the institutionalisation phase.

The teacher specified that the units of volume would have been recalled during the mathematics lessons, in a future learning sequence called “Area and Volume”.

In conclusion of the lesson, the teacher gave some homework to students, namely the Activity 11 about the mathematical and physical interpretation of a given graph (see Fig. 5).

Although it was not observed, session 8 is briefly analysed in terms of formative assessment: [go to the analysis of this section](#).

Session 9 (physics, day 9)

Objectives: Reading and interpreting a graph that represents a change of state.

Both teachers were present in this physics session. L led the students' work and T was seated with the students, participating in the moments of classroom discussion and of analysis of the students' answers.

Exercise 2 in Fig. 5, that the students did for homework in paper and pencil, was revised through a multiple choice test, where the answers for each question had been proposed by the teacher (see Appendix C for the whole MCT). For example, the first question "What are the magnitudes represented on each axis?" was displayed as follows:

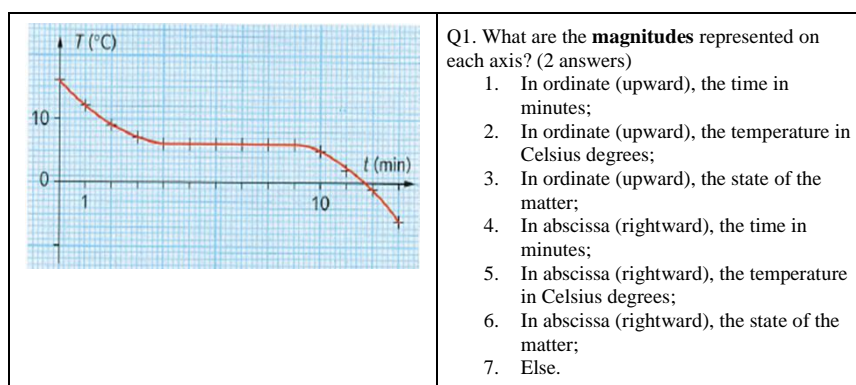


Fig. 19: An example of question of the MCT (the others are in Appendix C).

The teacher collected the students' answers for further analysis. In classroom, during the MCT, she paused the quiz for coming back on a group of questions. First she asked to some students to give and explain their answer, then she displayed and commented the graph of the results, provided by the software: "Je lève la main".

All the results were stored by the software for the teacher's further analyse, in preparation of Session 10 that aims at working again on the target competences for remedying students' misunderstandings and difficulties.

[Go to the analysis of this section.](#)

Session 10 (physics, day 10)

Objective: Remedying students' misunderstandings and difficulties linked to the mathematical and physical representation of a graph.

L led this physics session alone.

The teacher started the lesson with a MCT on the main physical concepts of this sequence: magnitudes, units and measuring device. The whole MCT is in Appendix D, here below we report one question as an example:

Q1.	The	terms	kilogram,	litre,	Celsius	degree	correspond	to
(1)								units
(2)								magnitudes
(3)	values							

Commented [1]: Commentaire de Lisbeth, à mettre à la fin de l'étude
Résultats : il y a une nette évolution dans les résultats de cet exercice par rapport à l'an passé ou je n'avais pas fait les activités "histoire de graphique".

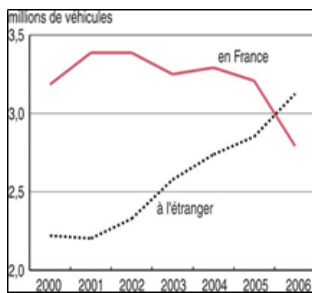
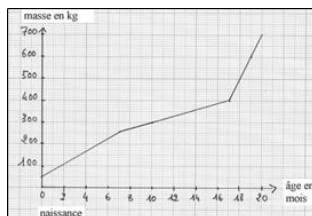
Commented [2]: Mis dans la conclusion

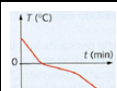
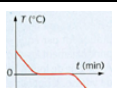
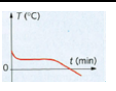
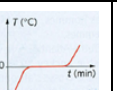
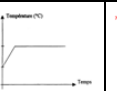
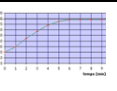
The teacher displayed the students' results to the question 1-4 as an intermediary correction of the quiz. Then she simply collected all the answer through the student response system for a further analysis.

In the second part of the lesson, students had to work on Activity 12 as remediation and complementary exercises on magnitudes, values and units of measure. The activity is composed of three parts:

- I. Magnitude, unit, measuring device (vocabulary)
 - II. Characteristic magnitudes of water: characteristic temperatures of water
 - III. Characteristic magnitudes of water: characteristic mass of water
- In each part, some exercises are proposed with increasing difficulty.

We focus on the second part that has been observed. The full text of Activity 10 is in Appendix E.

II. Characteristic magnitudes of water: characteristic temperatures of water						to be revised
<p>Part A : <i>Creating: Construction, reading of a graph:</i></p> <p>1. What magnitude is represented on the y-axis?</p> <p>2. What magnitude is represented on x-axis?</p> <p>3. How does the curve <i>en France</i> evolve between 2000 and 2006 ?</p> <p>4. Is there a plateau on one of these curve? YES / NO If yes, color the part of the curve that forms a plateau</p>						
<p>Part B : <i>Creating, analysing: Analysis of a graph:</i></p> <p>5. How long is the experience?</p> <p>6. Which is the increasing of the mass of the baby during the experience?</p> <p>7. Color the part of the curve where the mass increases less quickly:</p> <p>8. What is the duration of this “weak” increasing?</p> <p>9. Color the part of the curve where the mass increases more quickly:</p> <p>10. What is the duration of this “strong” increasing?</p>						
<p>Part C : <i>Analysing, validating: Interpretation of the results</i></p> <p>1. Match the titles of the experiences of change of state at the graphs:</p> <p>2. Justify by giving temperatures of change of state in each case where it is possible.</p>						
Solidification de l'eau pure	Fusion de l'eau pure	Vaporisation de l'eau pure	Solidification du cyclohexane	Vaporisation de l'éthanol	Solidification d'un mélange	

					
$T = \dots^{\circ}\text{C}$					

[Go to the analysis of this session.](#)

Analysis of observed sessions

Session 1 (maths)

In this session, the used technology was a student response system. The observation of the lesson shows some initial difficulties for students to answer with the clickers, although it is difficult to understand if students did not answer because they did not know the answer or because they forgot to confirm their answer:

T : *You have 10 seconds left, hurry up!... D, for me you didn't answer, hurry up.*

D.: *Yes, I click on 2*

T : *Click on return, return!*

T can see on the screen all the students' answers as well as the remaining time as shown in the figure below:

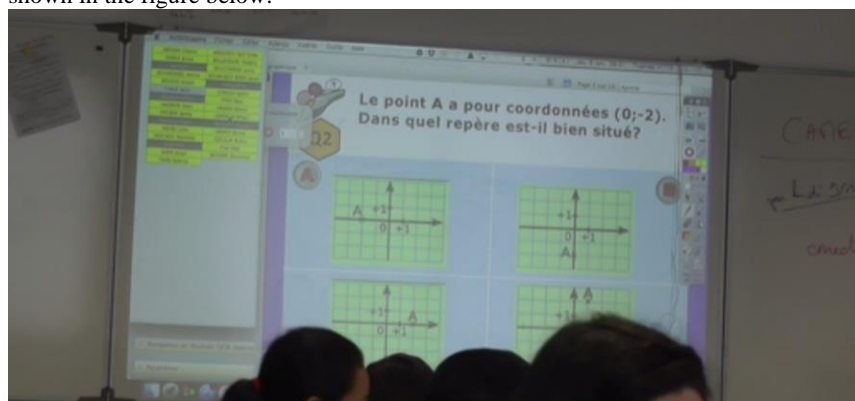


Fig. 20: When a student answered, his/her name was highlighted in yellow.

Later, T said: "We will not get to have all the answers!"

Another problem came from the difficulty for the students to correct an answer:

Sal: *Sir, when we have made a mistake, what can we do?*

T: *You should be able to correct... ah, crumbs, too late!*

But two minutes later, T spoke to the whole class:

T: *We have found with Sal that when you type another time on a letter, it deletes the answer.*

During the lesson, confronted to the students' difficulties, the teacher adapted the use of digital tools to the needs and abilities of the students and he changed his strategy: for each question, he paused to read the question with students and to explain which kind of answer he was waiting for:

T: *I pause... Look, here in the table, you can see the categories, car or bike. I ask you: are there 500 cars from abroad in the parking?* (He read all the affirmations on the screen)

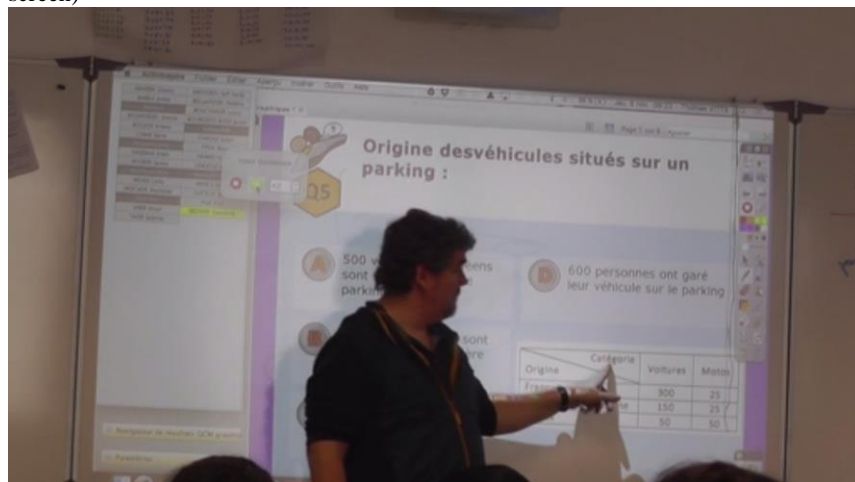


Fig. 21: T took time to explain the questions

Referring to the three-dimensional model of FA with technology, we can detect the teacher's position in the cube participants-strategies-technology: (teacher, clarifying learning objectives and criteria for success, sending and sharing). Teacher's actions in this position were oriented to (students, being active as the owners of their own learning & understanding criteria for success, sending and sharing).

T did not interpret the answers of students on the spot, but he recorded the answers and made an analysis at home. However, during the lesson, he modified his strategy in order to make the students results more reliable.

The student response system is used to collect information on students' knowledge. At the end of the lesson, T knew better where the students were and was able to organise the next lesson from the students' knowledge but also from the difficulties they encountered.

Regarding the analysis of the second quiz (see Appendix B), T wrote:

"Half of the class succeeded in the first question. It was about information, in general, that we can read in a table. The second question got very bad results (only 12% of correct answers). One of the affirmations about the total number of computers caused a problem. 25% of the students succeeded in the third question. A large majority of students interpreted badly the chart. Half of the students succeeded in the question 4. But the common sense was sufficient to answer correctly and I'm not sure that students actually did the calculation. The question 5, that was about the comprehension of a double entry table, was badly succeeded (8%). Several reasons can explain it: 3 affirmations over 4 were true and 3 answers were expected. It's not sure that students proceeded by elimination. However, easy answers like for example the affirmation C has been given unanimously, which prove that students answered

seriously. The sixth question which focused on graph reading has been well succeeded as 65% of students gave the three good answers, even if the only false answer was obviously false.”

Session 2 (maths)

In this part of the lesson, students had to tackle the interpretation of the global representation and lots of difficulties occurred. The teacher took time to explain that the y-axis corresponded to the distance to Tom’s house. Even if some students seemed to take into account this fact, most of them did not seem to actually understand. The formative assessment in that phase rested on the dialogue between the students and the teacher. The debate that has been organised by the teacher came under the FA strategy of getting information about where the learners are. The class’ feedback led T to modify his teaching, giving more information about the interpretation of the y-axis, and showing on the graph the specific moment when Tom is coming back to his house before getting away from his house to the bus stop.

Regarding the second activity, we observed the same difficulties, even if in a group a debate occurred starting from the observation made by a student when the distance to the house was equal to zero: “The house cannot be at two different places!”

In this case, the time-distance activity has been considered by the teacher as a first encounter with the types of tasks allowing to draw a graph, to read a graph and to interpret a graph. In the sequence of maths and physics lessons, these two initial sessions began the reflection on the notion of graphical representation starting from technical tasks:

- how to place a point in the plane?
- how to read the coordinates of points in the plane?
- how to link a table and a graph?

and going on with interpretation of the graph which correspond in term of praxeology to a justification of the techniques:

- what does it mean that the line is climbing?
- how to interpret in term of increasing quantity as a function of another one?
- how to read the axis scales?
- how to link the two axis meaning?

In term of FA these two sessions gave to the teacher the opportunity of understanding where the students are. But also, they allowed to clarify learning goals for students as well as criteria for success. In term of relationship with physics, the time-distance activity gave the opportunity to contextualise the meaning of the axis. From the mathematical interpretation of the position of points or variation of two quantities to the physical interpretation of the distance as a function of time, the students began to see the two faces of the boundary object. The next session is organised by T to strengthen these knowledge and competencies.

The teacher started the lesson recalling activities 1 and 2. He recalled students’ main difficulties:

- the idea that the graph was a drawing: for example, in Activity 2, Tom climbed a hill and then went down on the other side of the hill.
- the idea that the graph was a map: for example, in Activity 2, Tom turned on the right and then again on the right.

He recalled the main result they found the session before:

T: *I remind you that the graph expresses the distance between Tom and his house as a function of time.*

These initial remarks allowed T to share with the students where they were in their learning. Then, he gave to students the sheets of the activities 3, 4 and 5, highlighting the interdisciplinary features of this learning sequence:

T: *We are preparing an experience that will take place with Madam L and these three activities will be the most useful ones for this experience.*

Through these words, T engaged students in the activities: the interdisciplinary work was presented as a motivation for engagement, since the activities were all interconnected and useful the one for the other.

T walked through the classroom while students worked individually and then in groups. Checking what the students were writing, sometimes he decided to stop the work for focusing the students' attention at the whiteboard, where the text of the activity was displayed (Fig. 22). He gave a feedback on students' answers to the first question of activity 3: "What does each curve represent?"

T: *You answer "the growth of a baby", I agree, that's good, you have read well. But there are two curves: what does the red one represent? what does the blue one represent? Please.*



Fig. 22: T discussing the answer or the doubts of some students with the class.

He shared the doubts of a student (Sal) for discussing it with the class.

1- T: *Sal is asking to which baby... which baby is concerned by the question "Which were the size and the weight of the baby at his birth?"*

2- Div: *But there is only one baby.*

3- T: *Eh?*

4- Ous: *They are two!*

5- Div: *Ah no, there are two babies.*

6- Ss: *How is it possible that there are two babies?*

7- Ali: *No! There is only one baby!*

(T invited students to lift their hand and gave the word to Sam)

8- Sam: *There is one baby... No, they are more than one, because we say "of a baby". It's, it's, ...*

9- Ss: *No! There is only one baby.*

- 10- T: *Div?*
 11- Div: *There is one baby who has a size and a weight.*
 12- T: *So?*
 13- Div: *On the graph there are several things.*
 14- T: *So?*
 15- Div: *Well, of one baby.*
 16- T: *What do you think, Sal?*
 17- Sal: *I think that they are two, because there are the red one and the blue one.*
 18- T: *They are a boy and a girl! (Students laughing) The blue one is what?*
 19- Ss: *The size.*
 20- T: *And so, how do we measure it? Sal?*
 21- Sal: *In centimeter.*
 22- T: *In centimeter. [...] And the red one?*
 23- Sal: *The weight.*
 24- T: *Do you agree, Sal?*
 25- Sal: *Yes.*
 26- T: *How many babies are there?*
 27- Sal: *One.*
 28- T: *Is it ok for everybody?*
 29- Ss: *Yes!*

T detected Sal's difficulties and some confusion also for the other students, reading their answers. Thus, he decided to share Sal's doubt with the class: he wondered whether the babies are two [1]. Students reacted in different ways to this doubt: some of them were sure that there was only one baby [7, 9]; some others were sure that they are two [4, 17]; other students did not have clear ideas [2 and 5, 8]. Finally one student came out with a justification that there was only one baby, whose both size and weight are represented on the same graph [11, 13, 15]. T asked to Sal what he thought [16], and the student defended his idea that there were two babies: one red and the other one blue [17]. T exaggerated Sal's idea [18] and students, included Sal, understood that it was wrong [25, 27].

In this episode, the teacher guided an effective classroom discussion, by sharing the doubts of one student with the class and waiting that peers got to evaluate their classmate's idea. The technology was used only to display the task that they were discussing. Therefore, we recognise a dynamic between (teacher, engineering classroom discussion, sending and sharing) and (peers, activating students as instructional resources for one other, sending and sharing).

In the time of sharing, the teacher used more directly the technology, by exploiting the projected figure at the whiteboard for working directly on it (Fig. 23). Concerning the question "At the age of 3 months, what were the size and the weight of the baby?", he invited a student to come at the whiteboard for reconstructing with him the procedure to detect the points on the graphs (Fig. 24).

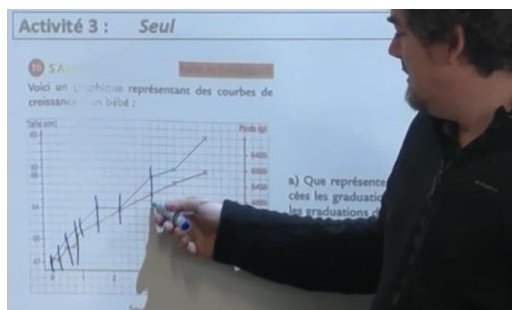


Fig. 23: T detecting correspondences on the graph projected at the whiteboard.

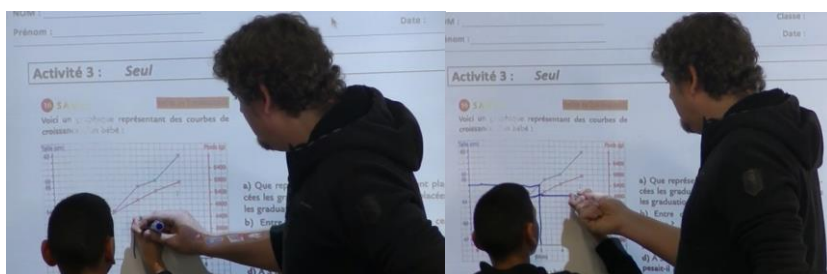


Fig. 24: T reconstructing with a student the procedure to read the graph projected at the whiteboard.

The teacher institutionalised the emerging knowledge about the interpretation of a graph. A student simply said “the blue curve represents the size, the red curve represents the weight” and the teacher agreed but asked to the class if they had any other formulation to propose. Another student said:

30- Nai: *I write “the blue curve represents the size in centimeters”.*

31- T: *Yes. So what did you specify?*

32- Nai: *In centimeter.*

33- T: *Yes, what is it? What did you specify?*

34- Nai: *Centimeter.*

35- T: *What is it? The measure?*

36- Nai: *The size.*

37- Eth: *The unit.*

38- L: *Yes.*

39- T: *Eth?*

40- Eth: *The unit.*

41- T: *He specified the unit. All right?*

This first part of the sharing is interesting for one of the objectives of the sequence: defining and distinguishing magnitudes, values and units of measure. In the idea of a interdisciplinary work, L assisted to T’s lessons [38] and vice versa. Both teachers insisted on the correct use of the terms expressing magnitudes and units [31-41]. In another moment, T insisted also on the measuring devices that allowed to construct the given graphs.

Discussion went on for finding the good formulation of what the curves represented.

42- T: *I heard here... Something that seems “they didn’t talk about months!”.*
 43- Ss: *Yes!*
 44- T: *No, in your response, Sam, you didn’t talk of months. Do you agree, right? Who has got to talk about them in his formulation? [...] Jen?*
 45- Jen: *The blue curve represents the size per month. No...*
 46- T: *Yes! The size per month. Anyway, she tried to take it into account. The size... how can it be expressed?*
 47- Had: *In centimeters!*
 48- T: *Yes, but... Did you talk about months, Had?*
 49- Had: *Per month, in centimeters per month.*
 50- T: *In centimeters per month...*
 51- Nai: *Per month in centimeters.*
 52- Ted: *Every month.*
 53- T: *Every month. OK. I’m going to tell you how it is formulated. [...] The blue curve expresses the size, if you want in centimeters, AS A FUNCTION OF the age, that is in months. All right? We’re going to be more precise: the blue curve expresses the EVOLUTION of the size in centimeters as a function of the age in months.*

T got to formulate the interpretation of what the graph represented [53] starting from students’ proposals and suggestions: the size “per month” [45, 49], “in centimeters per months” [49, 51] or “every month” [52]. By saying “I heard here something like...” [42], T involved another group in the discussion, sharing with the class their proposal. Through questions like “Who has got to talk about them in his formulation?” [44], he invited the students to participate in the debate. With questions like “Did you talk about...?” [48] he encouraged students to analyse their proposal.

For concluding the time of sharing on the activity 3, T asked one more question about the plateau in the blue curve representing the size.

54- T: *What happened there? (He circled the plateau of the blue curve)*
 55- Jen: *He stopped growing. Well, he hasn’t grown there.*
 56- T: *You have not lifted your hand. Naw, what happened there?*
 57- Naw: *He stops growing.*
 58- T: *He stops growing. Like this, suddenly.*
 59- Sam: *He didn’t go to the doctor.*
 60- T: *Well, yes. He went before, do you see the first point, on the left? [...] And he went after [...] My question is on the fact that before it goes up, after it goes up and there it is horizontal. Why?*
 61- Div: *Because he has grown more slowly.*
 62- T: *He has grown more slowly... You think that it is a question of speed. Before someone said that he stopped growing.*
 63- Div: *Well, yes. [...]*
 64- Jen: *He stopped putting on weight.*
 65- T: *He stopped putting on weight too?*
 66- Div: *His size and his weight were not the same, and then yes.*
 67- T: *Oh, I didn’t expect this at all! It means that his weight was 54 cm and his size was 4650 kg?!*
 68- Div: *No.*
 69- T: *No, it’s a chance [...] determined by the graduation of the size and that of the weight. I wanted to speak of the horizontal line here (he retraced it). You were right: he stopped growing, while he continued to put on weight.*

70- T: *We can explain it... The baby cries and moves a lot when he goes to the doctor.*
 [...] *What could have happened is that one of the two measures is not that accurate.*
 [...] *This remark about the inaccuracy of a measure is important!*

This episode is interesting in terms of both formative assessment and interdisciplinary work. Indeed, T used the technology as a visual support for asking his question [57]. He wanted to focus the students' attention on the constant part of the blue graph [60, 69]. This remark is important in preparation of the following work in physics on the graph of a change of state, that has a temperature plateau. Moreover, T's remark about the inaccuracy of a measure [70] is important for its physical consequences. Students' answers were feedback for the teachers, indicating where they are at the beginning of their learning path. Some misinterpretations emerged: someone stressed that no data has been collected in the chosen interval thinking that this fact had some influence [59]; someone thought that it is a question of speed of growing [61]; someone made links between the two independent curves [64, 66].

The work moved on to the activity 4. T recalled what is a coordinate plane giving a help to students on the whiteboard (Fig. 25).

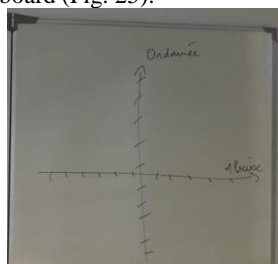


Fig. 25: Coordinate plane, with graduated axis and indication of where the ordinates and abscissas are

After a first time of individual work, the teacher focused the attention to the whiteboard. He projected the task with the given table on the left of the whiteboard and discussed the suitable choices on the coordinate plane on the right. He was leading the conversion between the register of the tables to the graphical register, with the support of the video-projector (Fig. 26).

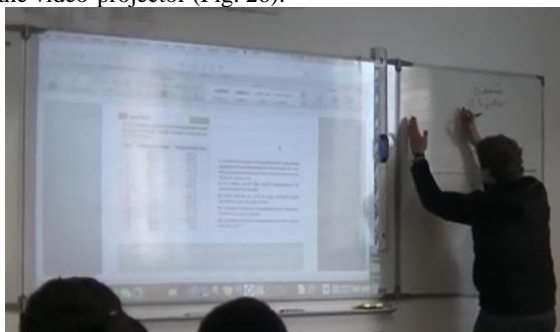


Fig. 26: From the register of representation of the tables to the graphical register

For instance, T made the students reflect upon the fact that for “negative days” no data have been collected. In Fig. 26, he was asking “Something happened in this part? For negative days? No, we start at day 1 and we go till day 15 in the table”. Thus, he

provided a feedback to those students who placed the origin in the middle of the graph paper. He gave a new graph paper and suggested to place the origin on the left of it.

71- T: *Concerning the axis of the days, we have to write them. Div, do you have any proposal? Do you have any idea? Come and show us.*

The technology again served as a support for sharing proposals and ideas on the graph projected at the whiteboard. Div went to the whiteboard and detected the days from 1 to 15 as in Fig. 27.



Fig. 27: Graduation on the axis.

Some students intervened saying that they could do it better taking one whole square for one day. Div's proposal was analysed and amended by the other students, thanks to the functionality of the technology of sending and sharing. T specified that they were talking about the scale of the graduation, providing to students the correct vocabulary.

This session is typical of a knowledge under construction lesson where students did not go beyond certain difficulties but also began to make links. At the end of the session, basing on these students' difficulties, T decided to exclude the activity consisting of matching ten stories to ten graphs. He wrote in his diary:

T: *I didn't use this activity because I considered that my students have experienced enough difficulties in the first activities and that they didn't actually succeeded in giving complete sense to the graphs.*

Session 4 (physics)

This session was dedicated to the physics experiment and technology appeared with the role of providing a dynamic environment: L used the simulation software with two different goals.

- First, it was a link between the theoretical protocol, the diagram and the reality of the experiment. L showed the different materials needed for the experiment and asked students to compare their experimental organisation with the simulated one before starting their experimental work. L: *Look, here the temperature stays for a long time at the temperature 0°C and after, it decreases, and I want to see that!*

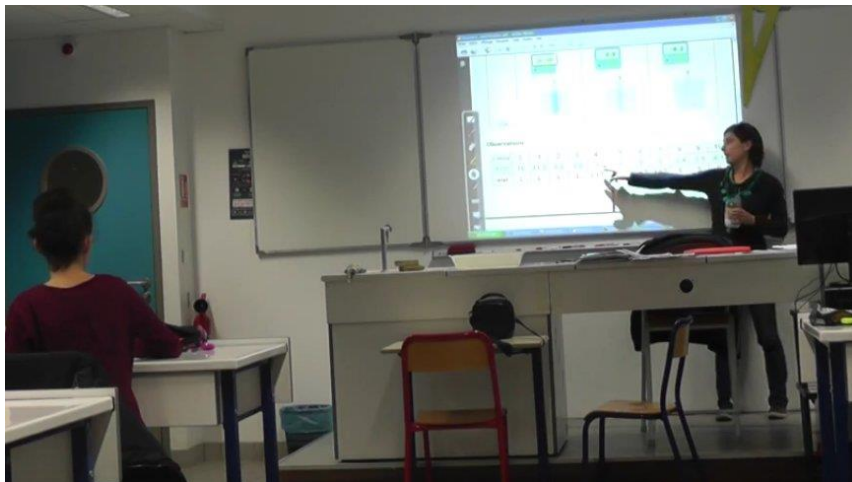


Fig. 28: The simulation software as a link between the protocol and the reality

- Second, it was a model of the actual experiment that allowed the teachers to overcome difficulties coming from the bad achievement of the experiment by some students.

Both a scaffolding and a substitute, the simulation software played an important role in the experimental session as well as in the next sessions, because the results coming from the simulation possibly replaced the real data. For the students, it appeared also as a feedback of the good achievement of their own experiment.

In reference to the three-dimensional model, we can place this session in the cuboid (teacher, clarifying the learning objectives and criteria for success, providing an interactive environment) and (students, understanding criteria for success, providing an interactive environment).

In this session, the fact that both teachers were present in the classroom allowed to be more attentive to the work of each group. While L were attentive to the material needed on each lab bench, T was able to help groups in their organisation. For instance, a group had begun the experiment without starting the chronometer; T explained another time that each one in the group had a particular role: one student had to watch the time, the second one took the temperature and the third one wrote the result in a table. T and L went from group to group to supervise the experiments. Later on, he interrogated a group:

T: *Where do you write your results?*

S: ...

T: *You didn't write your results? OK you need to start again. I'll help...*

In term of FA, the organisation of this session gave a sufficient autonomy to the students to engage them to be the owners of their own learning and the maths teacher attendance in the physics lesson allowed him to be aware of the actual work of the students before the next step, that is to say the effective drawing of the graph.

Session 5 (maths)

Even if the specific context of this class and particularly students' difficulty to work at home, T succeeded in making students draw the graphs from their data as well as from the simulation software data as shown in the following pictures.

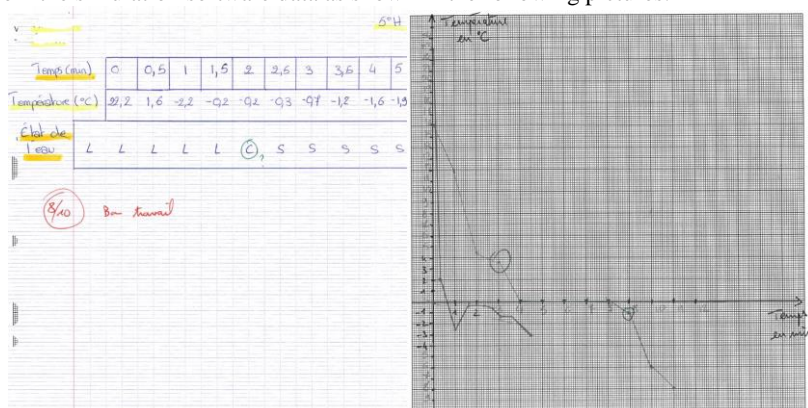


Fig. 29: Good job!

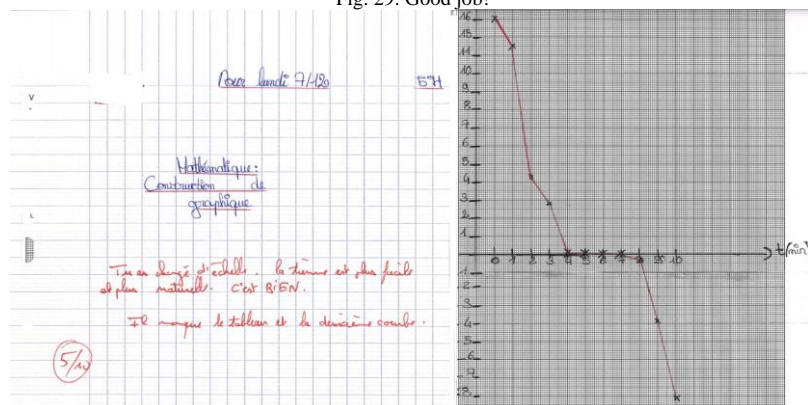


Fig. 30: You change the scale. Yours is easier and more natural. It's good! The table and the second curve are missing

In this context, T marked the work of students and this summative assessment was a progress report about the understanding of the drawing of a graph from a table of data. But we can notice the way the teacher supported students with positive appraisals: “good job, it's good,..” (Fig. 29 and 30). With this assessment, the teacher clarified the criteria for success as well as he provided to students feedback about their skills at doing the work.

Session 6 (physics)

During this session, we could observe a standard procedure in the way L proposed questions through the student response system in her classroom.

First, she projected the question. Students answered on their clickers and the corresponding number became yellow in the bottom of the screen. If numbers were purple, it meant that the corresponding student pressed a button that was not allowed

(different from 1, 2 or 3). See Fig. 31 for the question of Activity 7 and Fig. 32 for the question of Activity 8.

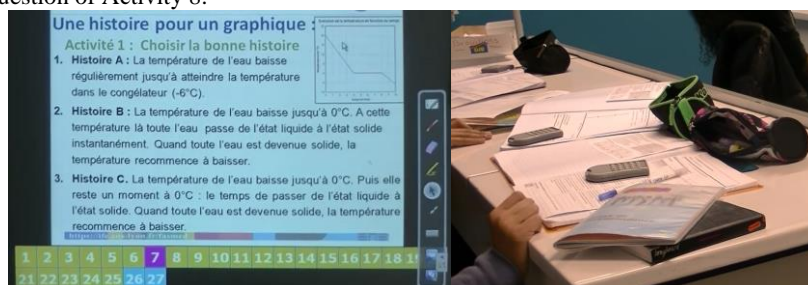


Fig. 31: Question of Activity 7 and students' corresponding numbers were displayed. Students' clickers on the desks.

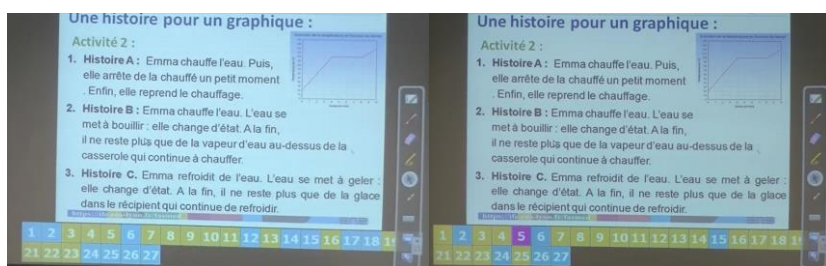


Fig. 32: Two successive moments of Activity 8 with the student response system.

Students could check the state of their answer (sent/not sent, allowed/not allowed) and the teacher could follow the collection of answers in real time. L encouraged slower students to answer, giving help:

L: *Cel, are you OK? Did you answer? Had, you see, it is 1 for Story A, 2 for Story B,...*

Second, when all the answers were collected, the teacher displayed the graph of students' results. See Fig. 33 for the results of Activity 7.

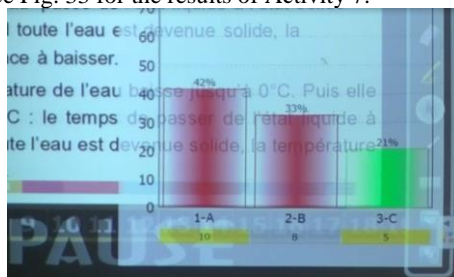


Fig. 33: Graph of students' results of Activity 7.

The teacher could have a quick overview of the students' answers. In this case, only 21% of students found the good story that matches the graph; the majority of the students (42%) answered Story A. L commented such results with the students, focusing in particular on the wrong stories (A and B), that were however the most appealing for the students.

- 1- L: *The majority of you have chosen the answer... which answer, Jen?*
- 2- Jen: *Answer A.*
- 3- L: *Answer A. So, remember that... First of all, remember what happened the last week when we made the experiment. Did the temperature go down regularly?*
- 4- Jen: *No.*
- 5- L: *No. What happened at a certain moment?*
- 6- Jen: *It stabilised.*
- 7- Ali: *It stopped.*
- 8- L: *It stopped doing what?*
- 9- Yas: *Of going down.*
- 10- L: *Of going down. [...] So, this word "regularly"... Did you understand what it means in Story A? What does it mean?*
- 11- Naw: *Not that often.*
- 12- Sal: *More or less the same.*
- 13- L: *Not that?*
- 14- Naw: *Not that often.*
- 15- L: *Not that often?*
- 16- Jen: *Always at the same time.*
- 17- L: *Regularly means not that often?*
- 18- Ted: *No, several times.*
- 19- Jen: *All at the same minute.*
- 20- L: *It decreases always in the same way. Temperature goes down always in the same way. Is what happened when you made the experiment?*
- 21- Ss: *No.*
- 22- L: *No. Actually, what does the temperature do on this graph (indicating the graph of Activity 7)?*
- 23- Jen: *It goes down, it remains normal, and then it goes down again.*
- 24- L: *It remains normal. What does it mean?*
- 25- Ss: *It remains stable. It stabilises.*
- 26- L: *Stable, it stabilises, it remains at a constant temperature.*

The great majority of answers A led the teacher to question the students about the text of the Story A. For giving them a reference, she reminded them of what happened in the physical experiment of water solidification (session 4) [3]. We notice that a student (Jen) gave the correct answers to the teacher's input [4, 6, 16, 19]: she understood why Story A was not the correct choice. Nonetheless, L seemed not considering her answers, for giving space in the discussion to those students who answered wrong. Engineering an effective discussion in the classroom, she could collect some of the students' misconceptions, and in particular, she realised that their greatest difficulty was on the interpretation of the term "regularly". Some students associated it with "not that often" [11] or with "several times" [18], in relation to the daily life when we currently say for example "I *regularly* go to the doctor".

In the same way, L discussed the word "instantaneously" of Story B with the class, making repeatedly reference to the physical experiment.

The functionality of the student response system of sending and sharing information and of processing and analysing data has been fully exploited in this episode.

L's questions encouraged the students to engage in the debate, to express their ideas, and allowed her to gain more insights into the students' misunderstanding.

L's references to the experiment allowed her to activate students as the owners of their own learning. As L asked to link students' memories of the experiment to what

they could read on the given graph [22], they discussed about the temperature plateau: the teacher corrected the students' "normal temperature" [23] in "constant temperature" [26]. In this occasion, the functionality of displaying the graph and the stories as a support for the classroom discussion has been exploited. For example, the teacher used the displayed graph to define what is a temperature plateau on a graph as "the part where it is flat" (Fig. 34).



Fig. 34: L showing the temperature plateau on the displayed graph.

Another interesting moment of analysis of the students' results provided by the technology occurred when the teacher asked to students if there was any clue allowing them to recognise that the right answer was Story C. Students' answers referred to the experimental process:

Jen: *Because it did not happen instantaneously, it took a while to become all solid.*

Mat: *Then it [the temperature] remains at 0 °C.*

Eth: *There is a moment when the state of the water is both solid and liquid.*

And only at the end, someone looking at the graph of the results (Fig. 33) said "It is the only answer that is green".

Concerning the temperature plateau, T, who was attending the lesson, intervened for asking the students if they were not surprised by the fact that during the experiment there was a moment when they continued cooling water down but its temperature did not decrease. Students' answers showed a real difficulty to separate the different aspects of the experiment interpretation: T's question was on the change of state and students' answers were about the state of the water and what happens after the change of state:

Mat: *No, because after it is iced, it cannot freeze more than this.*

T: *Yes, after a while it begins to cooling down again, we arrive at -6 °C.*

Eth, Mat, Had: *It gets colder.*

T: *It doesn't remain at 0 °C.*

Mat: *Yes, but it remains...*

Eth: *It remains solid.*

This brief dialogue allowed L to clarify the objective of the lesson:

L: *In general, this is the difficulty of this lesson: understanding that we put it in the freezer, we tried to decrease, decrease temperature, but the temperature of water stopped decreasing, because it is changing state.*

L followed the same scheme of action for proposing and revising Activity 8. The only difference was that, this time, students worked in groups on Activity 8 and then they submitted individually their answers through the student response system (see Fig. 32).

We observed a group, where a student (Fai) doubted that the right story was C, where Emma cooled water down, even if the given graph was increasing.

27- L: *So, do you agree?*

28- Nai: *Yes, we agree, but she doesn't!*

29- L: *And you have presented your argument, Fai, haven't you?*

30- Fai: (reading Story C) *Emma cools water down...*

31- Nai: *Cools water down?!?* (pointing at the graph)

32- L: *And now do you agree?*

33- Nai: *Yes.*

34- L: *What is the answer?*

35- Nai: A. (Reading a part of Story A) *Then she stopped warming water up for a while* (retracing the temperature plateau of the given graph with his finger, Fig. 35).

36- Fai: *OK, it's A* (circling it).

37- Nai: *Thank you!*

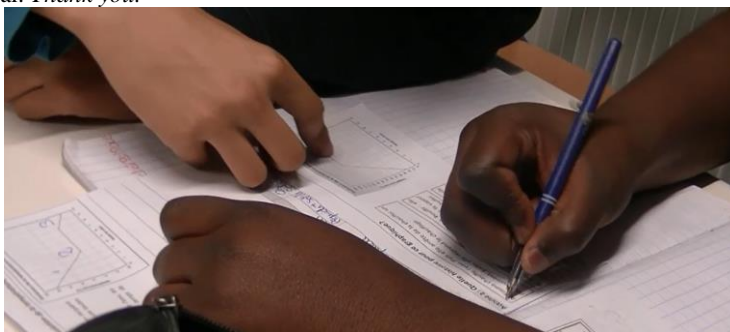


Fig. 35: Nai retraced the temperature plateau while reading Story A.

In this short excerpt, we can notice that Nai showed to have well understood that the increasing graph could not correspond to Story C, where “Emma cools water down” [31], while Fai read this part of the Story for justifying her doubt [30]. The teacher intervened for asking if they agreed and encouraged them to propose their arguments [27, 29, 32]. While adapting the time-distance activity to the context of time-temperature, L had justified her choice of Story C as a distracting answer, because of the expected difficulty in the global reading of the graph, in terms of increasing and decreasing temperature. This was effectively Fai’s difficulty. Although Nai seemed sure about the fact of excluding Story C, he made another kind of mistake: he misinterpreted the temperature plateau as the moment where “Emma stops warming water up” [35, Fig. 35]. We can observe that, for L, it is important to encourage students to become instructional resources for one other, even without the use of technology.

As it happened for the previous activity, L discussed students’ results to the activity 8 (see Fig. 36).

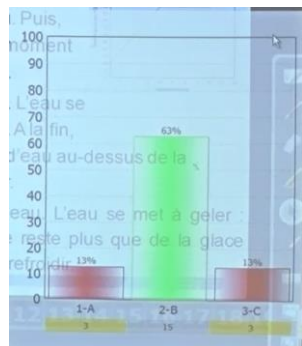


Fig. 36: Graph of the results of Activity 8.

In conclusion, if we place this session within the three-dimensional model, we can detect two dynamics. The first one, at the teacher's level, between the two positions: (teacher, engineering effective discussion and learning task, sending and sharing) and (teacher, providing feedback to students, processing and analysing). The second one between these two positions of the teacher using technology and (students, being active as the owners of their own learning, sending and sharing & processing and analysing).

Session 7 (physics)

This session was not observed, but we rely on the interview with the teacher to interpret students work. L wrote down that "the lesson was longer than anticipated, but students showed that they have understood the concepts"; the physical concept of latent heat of fusion (or freezing) that leads to plateaus in the temperature vs time graph had been understood. It appears that the previous work done in mathematics facilitated the understanding of the physical concepts. It is interesting to notice that even if a lot of difficulties occurred in the mathematics lessons, the joint approach of maths and physics gave to the students opportunities to make links and, finally, to better understand the concepts at stake both in mathematics and in physics.

Session 8 (physics)

This session was not observed but it was important in the learning sequence, because it was during this lesson that the students worked directly on the notion of magnitudes, units, values and measuring devices.

After a phase of individual work for classifying magnitudes, measuring devices, units and symbols, the teacher chose some of the students' responses, took pictures with a micro-document camera and projected them one by one in the classroom. This way, they could discuss some proposals in order to share ideas in the classroom. Finally they got to a phase of institutionalisation that produced a tool for supporting the students in their learning: the table in Fig. 37.

1. Des grandeurs caractéristiques :

Définition	GRANDEURS		UNITÉ		Appareil de mesure	
	Nom	Symbole	Nom	Symbole	Nom	Symbole
La masse représente une quantité de matière.	Masse	m	kilogramme	kg	Balance	
Le volume représente l'espace (la place) occupé.	Volume	V	litre	L	Éprouvette graduée	
	Température	T	Degré Celsius	°C	Thermomètre	

Exemple : quelle est la température d'ébullition de l'eau ?

grandeur → $T = 100\text{ }^{\circ}\text{C}$ ← unité
Valeur

Exercice p 103 n°2

Fig. 37: Table constructed with students.

From her description of the session, L's position in the three-dimensional model was (teacher, providing feedback to students, sending and sharing) fostering the activation at the students' level of the cuboid: (peers, being active as instructional resources for one other, sending and sharing).

Session 9 (physics)

L employed the same scheme of action of the previous sessions (see session 6) for revising an exercise that the students had to prepare in paper and pencil for homework (see the sheet in Fig. 5). L immediately clarified the didactic intention for this lesson and in particular for using technology:

L: We are going to revise it using the student response system, so that I can store your answers. And I will propose you some exercises for correcting your mistakes.

Students answered individually to each question, choosing the affirmations proposed by the teacher (see Appendix C) that correspond to the answers they prepared at home.

After three consecutive questions, L paused the quiz for discussing with students and for displaying the graph of the results to each question. L led the classroom discussion making reference to the physical experiment that they carried out in session 4. This strategy accompanied students in their learning path, activating them as the owners of their own learning.

Revising students' responses, by following this scheme of action, allowed L to clarify the criteria for success in the form "the answer that I expect is" (see line 4 below), as it happened concerning the third question: "How does the temperature vary between $16\text{ }^{\circ}\text{C}$ and $-6\text{ }^{\circ}\text{C}$?" (Fig. 38).

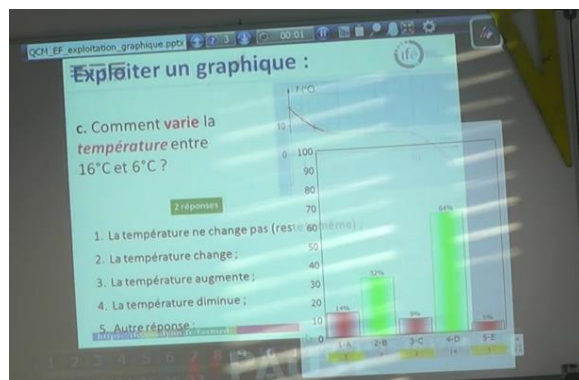


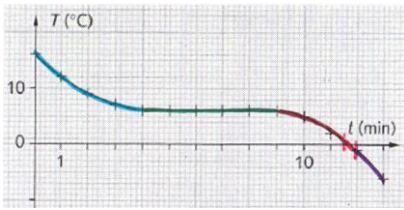
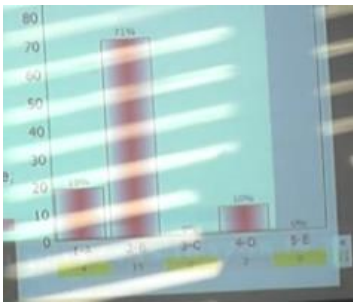
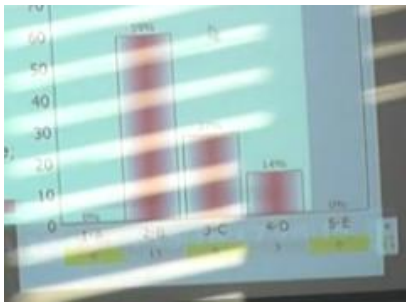
Fig. 38: Commenting the question on the variation of the temperature over time.

- 1- L: *This word “vary”... I know that this word is linked to some difficulties for you.*
- 2- Ais: *It’s like changing.*
- 3- L: *It’s like changing, indeed. When I ask you - also in maths, it’s a term that we really like - how does something vary?*
- 4- L: *The answer that I expect is: it increases (she wrote at the whiteboard) ...*
- 5- Ss: *Or it decreases.*
- 6- Ted: *Or it remains stable.*
- 7- L: *... it decreases, or it remains stable, does not change, remains the same. There is a lot of vocabulary. [...]*
- 8- T: *We can include “how does it evolve?”.*
- 9- L: *Yes.*
- 10- T: *Because “how does it vary?” is “how does it vary as a function of time?” and in the term “evolve” there is this notion of “as the time passes”. All right?*
- 11- L: *Evolve, too (she wrote “/evolve” next “vary”). It can be a synonym.*

Thanks to the fact that T attended L’s lessons, the links between physics and mathematics were strengthened: the vocabulary was shared between maths and physics not only from a lesson to the other, but also during the same lesson [8]. This moment was really interesting in terms of interdisciplinary work and we see all the possible advantages for students in terms of formative assessment. T and L were sharing within the same lesson the criteria for success for answering a specific question about the variation of a quantity/magnitude as a function of time. The technology here was used as a support for the classroom discussion, since the answer with the term “vary” underlined in red was displayed. Thus, the dynamics is between (maths and physics teachers, clarifying the shared learning objectives and criteria for success, sending and sharing) and (students, understanding learning objectives and criteria for success, sending and sharing).

The presence of both teachers was a resource in the classroom during another moment when data collected, processed and analysed by the student response system was interpreted jointly by T and L. They were analysing the answers to question Q5: “Which part of the curve represents the change of state?”. In particular, T compared in

his mind the results in question Q5 (Fig. 40) to those in question Q4 (Fig. 39). Such results would have been the same, since the two questions required to detect the same part of the graph, namely the temperature plateau.

<p>Q4. Which <i>part of the curve</i> represents the temperature plateau?</p> <ol style="list-style-type: none"> 1. The blue part; 2. The green part; 3. The red part; 4. The brown, red and purple parts; 5. Else. 	<p>Q5. Which <i>part of the curve</i> represents the change of state.</p> <ol style="list-style-type: none"> 1. The blue part; 2. The green part; 3. The red part; 4. The brown, red and purple parts; 5. Else.
	
	
<p>Fig. 39: Answer1 (19%); answer2 (the good one, 71%); answer4 (10%).</p>	<p>Fig. 40: Answer2 (the good one, 59%); answer3 (27%); answer4 (14%).</p>

12- L: *The good answer [...] is actually 2. And 59% it good.*

13- T: *Yes, and only a short comment: the good answers2 are less than answers2 to the previous question [Q4] because some of the students think that the change of state occurs at 0 degrees.*

14- L: *Ah yes!*

15- T: *Some students think that the change of state is the red part [which correspond on the graph to the 0°C temperature].*

16- L: *Ah yes! (She looked at the coloured parts on the graph) It's true (passing the mouse on the column corresponding to answer 3, Fig. 40).*

17- T: *And I heard it. And we could notice that there are more answers 4 than the previous question.*

18- L: *In the previous question actually... (she came back on the graph of the results of Q4, Fig. 39).*

19- L: *So, the change of state occurs when it is flat. It occurs at 0 °C when?*

- 20- Jen: *When it is water!*
 21- L: *When it is water.*
 22- Jen: *It is not water then!*
 23- L: *We will see with the last questions.*

Students received a feedback from L thanks to her interpretation of the graph of results provided by the software and displayed [12]. T contributed to the analysis of the results on the spot. He supported L in the interpretation of students' difficulties, because he noticed a significant difference between the graphs of the results to the fourth question and the fifth one [13]. The support of technology in processing and analysing students' data was evident here: the visual diagram of the results shown after the question 4 (Fig. 39) and then immediately after the question 5 (Fig. 40) allowed T to notice this difference that otherwise would have been difficult to grasp on the spot [14-18]. Thanks to T's remark, L stressed the correspondence between the change of state and a temperature plateau in the graph [19], and specified the particular case when it occurs at 0°C [20-23].

We can detect another interesting dynamics between (students, being active as the owners of their own learning, sending and sharing) and (maths and physics teachers, providing feedback to students, processing and analysing).

Moreover, L intervened on the displayed graph, adding information that could help the students understand the difficult notion of temperature plateau. For instance, while they were revising the sixth question about the duration of the change of state, L specified the value of each segment of the graduation on the x-axis, from 2 to 9, and counted how many parts are taken by the plateau (Fig. 41).



Fig. 41: L adding information on the displayed graph.

Session 10 (physics)

L started the lesson specifying its objectives:

L: We will revise some exercises. There are some groups or some students who made a very good job. For them the remedying exercises will be rather simple, rather quick too. There are other students that have something more to revise. So, today I'm going to see where are you with respect to magnitudes, measuring devices and units, and in

the same way, I will give you exercises of remediation.

Then, she displayed the table they constructed in session 8 (Fig. 37) and suggested to students to use it as a tool helping them answer the questions on magnitudes, measuring devices and units. In terms of formative assessment, the fact of providing a tool and some suggestion for preparing to answer to questions activates students as the owners of their own learning.

Students took the MCT and the modalities through which the teacher displayed questions, collected answers through the student response system, displayed results for discussing them with the students were always the same, with the same goals of formative assessment.

Then, they worked in groups on the sheets of Activity 10, in particular on Part II. Here is the response of a group:

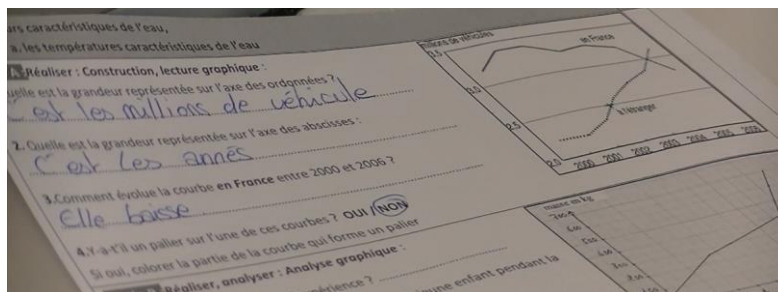


Fig. 42: Students' response.

This couple of students wrote that

- the magnitude represented on the y-axis is “the millions of cars”;
- the magnitude represented on the x-axis are “the years”;
- the curve *en France* “goes down” between 2000 and 2006.
- there are no plateau.

The main difficulty of this group and of many other groups was still to distinguish between the magnitudes, in this case “number of cars” and “time”, and the units to measure such magnitudes, in this case “millions of cars” and “years”. This was effectively one of the main objectives that L wanted to work on, during this remediation lesson. Thus, she intervened in the group, guiding students in the process of reading a graph. Moreover, they discussed of the definition of plateau.

In terms of formative assessment, such exercises made emerging students' difficulties for remedying to them. Technology was not used in the classroom, during this phase. L preferred that students focused on the reflection upon magnitudes and units in paper and pencil and that they had a written mark of such reflections.

Dynamics within the three-dimensional model

Legend

Red=Teacher / Blue=Peers or Group / Green=Individual student

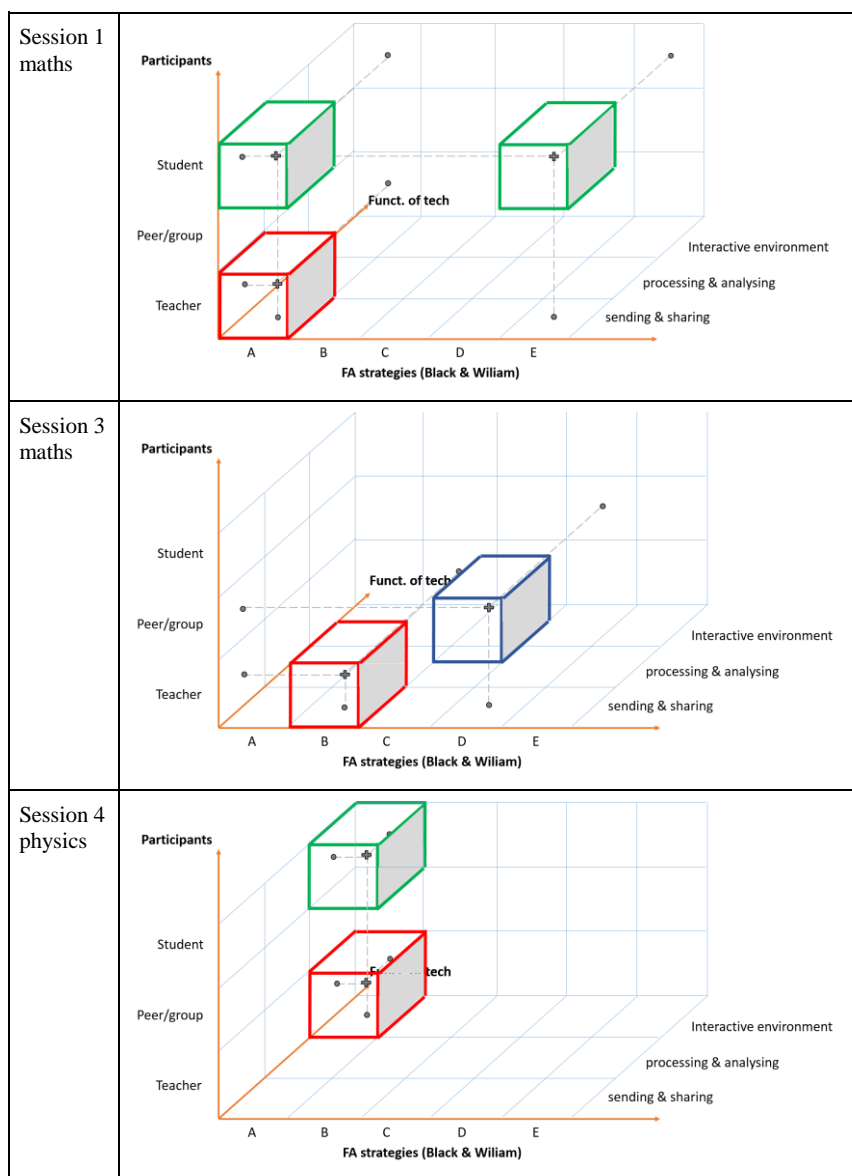
A: Clarifying/sharing/understanding the learning intentions and criteria for success

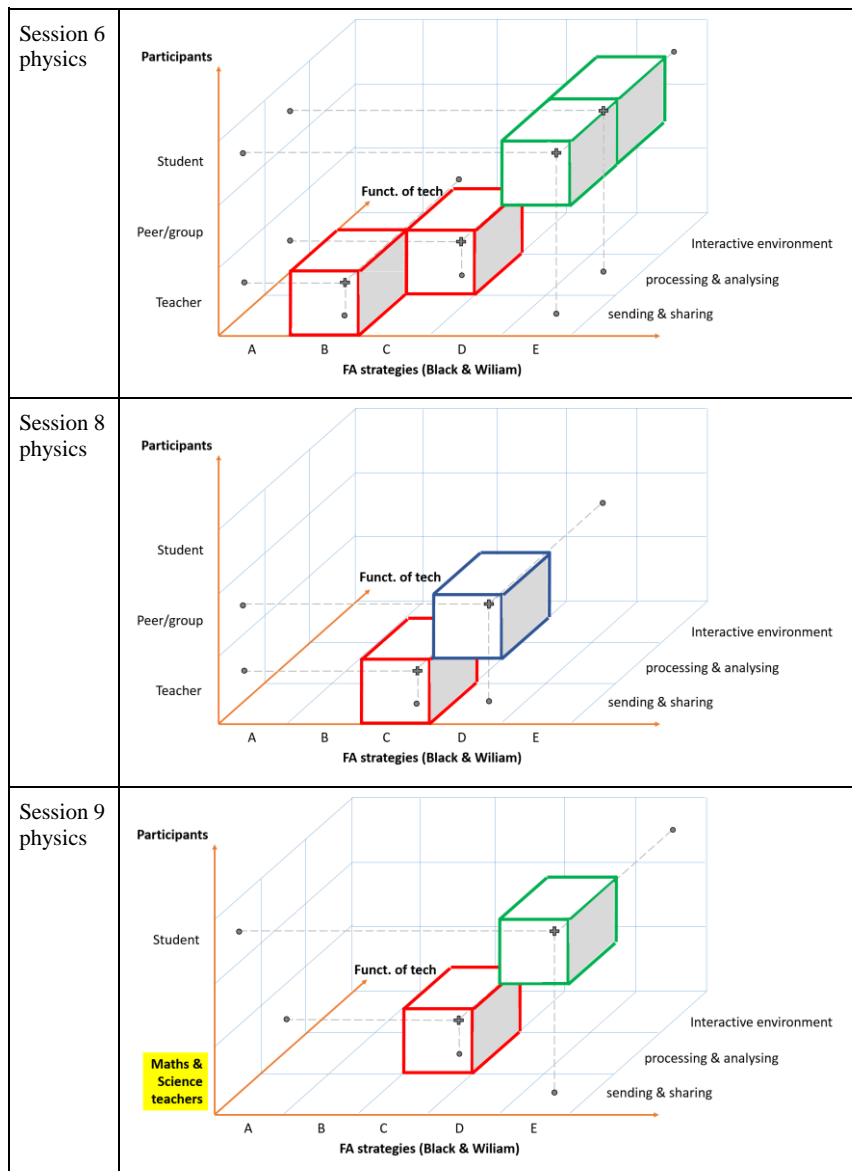
B: Engineering effective discussions and new learning tasks

C: Providing feedback that moves the learner forward

D: Activating students as instructional resources for one other

E: Activating students as the owners of their own learning





5- Pupil perceptions

Methodology

The Q-sorting activity was organised in two times.

- 1) At the beginning of the maths and physics sequence of lessons, we organised the Q-sorting with the whole class (24 students) divided into four groups of 6 students. We separated the affirmations in “positive” and “negative” (see list in Appendix E) adapting their formulation to the age of the students (11-12 years old) and to the technological tools they were going to use. Two of the groups had to sort the positive affirmations while the other groups had to work with the negatives. In particular, concerning technology, they had clickers for the first time in their hands, so we asked them to classify the sentences related to such tools according to their first impression about the future use of clickers in the classroom. After this work, we asked the groups to exchange their place to comment the choice of their peers; they had the opportunity to swap statements if they did not agree.
- 2) At the end of the maths and physics sequence of lessons, we proposed to each of the four groups to come back on their initial opinions. For this purpose, we recompose their initial Q-sorting diagram (that corresponds to the product of the first more debated phase of the previous Q-sorting). We asked them to analyse the diagram at the light of all of the work done during the last month in maths and science. They were invited to change the position of the cards, if they had changed their opinion about it, after having written the motivation on the back of the card.

In both sessions, we recorded the discussions and transcribed the dialogues. We will use students’ oral or written declaration for explaining some changes in the students’ opinions about technology, maths&science and assessment and proposing some elements of analysis “within the case”.

Results

Initial Q-sorting and movements after the FaSMEd lessons

The following pictures illustrate the results of the Q-sorting activity proposed at the beginning of the FaSMEd sequence for each groups. The added arrows indicate the movements recorded at the end of the FaSMEd sequence.

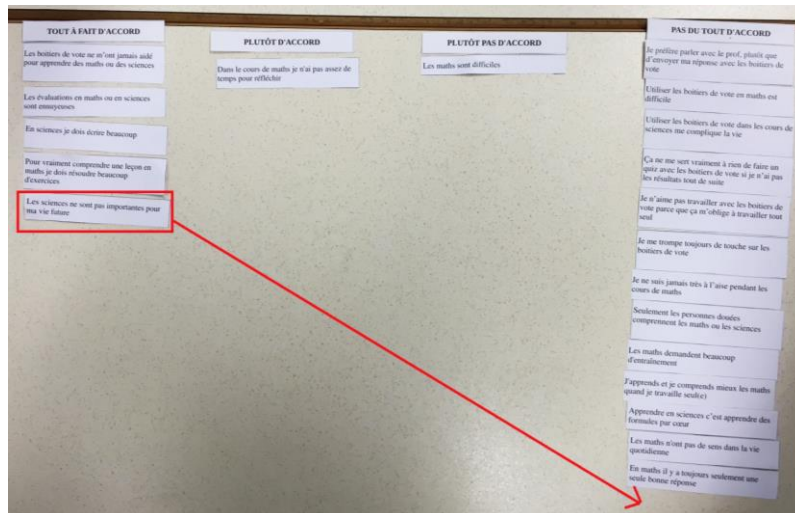


Fig. 43: Group 1's sorting of negative cards.

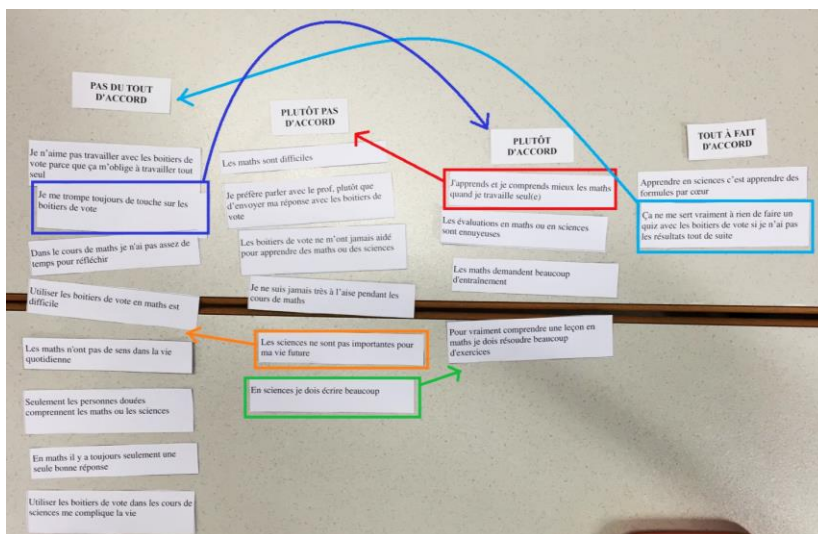
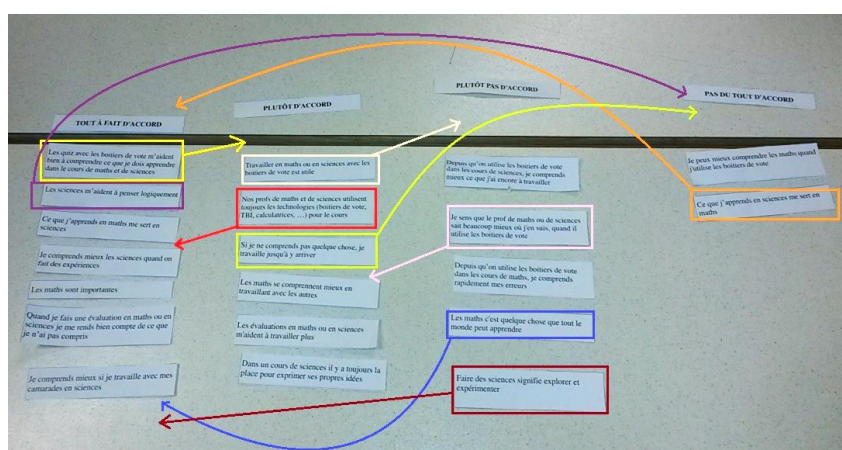
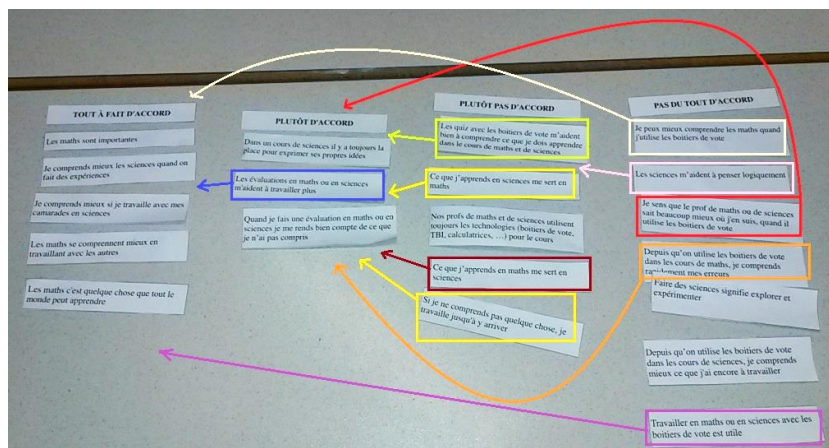


Fig. 44: Group 2's sorting of negative cards.



Technology

If we compare the students' opinions before and after the FaSMEd experience, we can notice that conceptions about technology became generally more positive (for two groups over four: Groups 2 and 3). The movements in the pictures above clearly illustrate this change: towards strongly agree for positive sentences and towards strongly disagree for negative ones.

At the beginning of the FaSMEd experience, students had never used this kind of tool in the classroom. This can explain the fact that, at the end of the FaSMEd lessons, they changed their mind on the utility of using clickers in maths and science lessons (**14p.** Group3, Fig. 45 in violet), in particular for having a discussion on the results (**16n.** Group2, Fig. 44 in light blue). Moreover, they felt that working with this tools

in the classroom helped them improve their learning (**16p.** Group3, Fig. 45 in white), facilitating their understanding of the mistakes (**17p.** Group3, Fig. 45 in orange).

For instance, after the FaSMEd lessons, for sorting the card **16n.** “It is really useless to take a quiz with clickers if I haven’t the results immediately”, Group 2 said:

Ted: *Totally disagree! It’s better that the answers come at the end and not directly displayed. Otherwise...*

Sal: *It’s too easy!*

Ted: *It’s not that it’s easy but... I don’t know how to say...*

Sal: *It’s not logic.*

Ted: *There is more suspense for checking if you have understand something.*

Researcher: *When Madam L showed you the answers during the quiz, for example.*

Ted: *This is better!*

Nevertheless, students discussed some difficulties that they encountered using clickers. For example, the sentence **19n.** “I usually made some mistake in typing my answer on the clickers” made arise a discussion in the group about mistakes in learning.

Ted: *I partially agree.*

Sal: *Yes, very often.*

Ted: *In physics, we generally make mistakes in physics.*

Researcher: *And does it bother you to have a correct answer but the fact that you badly type it on the clickers makes you appear in red?*

Sal: *Yes, it bothers me! You have found the answer and you got the button wrong.*

Ted: *But it doesn’t matter! It doesn’t mean that you are stupid.*

Sal: *OK, no, but anyway...*

Ted: *You made a mistake, that’s all, but you know that you have understood.*

Ted’s affirmation about the status of the mistake is very interesting in terms of awareness of his own learning. We recognise that not all the students were in the same position as Ted and needed further confirmation (from the technology, from the teacher) that he is working well.

For other students, as we observed in Group 1, the initial scepticism about the use of clickers in maths and sciences lessons was difficult to overcome. These students interpreted “the use of clickers” just as the moment when they had to press the button and did not consider the whole didactic exploitation that the teachers made of these tools (displaying results, commenting answers, revising exercises, preparing activities on the base of the results, ...) as linked to the use of clickers. It is like they saw only the functionality of “sending” in the technology they used in the classroom and not also “sharing, processing and analysing”. That’s why they declared that using clickers had been simple (strongly disagree with **17n.**, Fig. 43), but not more useful for their learning than the notebook or written tests (strongly agree with **18n.**, Fig. 43). We can deduce it from the following affirmations by Group 1 supporting the sentence **18n.** “Clickers never helped me learn maths and science”.

Jen, before FaSMEd lessons: *Yes! You press a small button and that's all. What have you learnt?*

Jen, after FaSMEd lessons: *It's just to answer questions. So, it doesn't teach us anything.* - Div: *It's like a written answer, indeed.*

Mathematics & Science

We can observe other important changes in the students' conceptions about science and mathematics, before and after the FaSMEd experience.

First of all, the practical work for realising the experiment of water solidification marked the students positively. In Group 4, for instance, students strongly agreed that "doing science means exploring and experimenting" (**4p.**, Fig. 46 in dark red), while in the initial Q-sorting they had put this card under the column "partially disagree". While moving it Fai said *It remind me of the experiment with ice and salt.*

Secondly, we can notice an interesting result for the interdisciplinary work carried out by the teacher in this classroom. Both Groups 3 and 4 recognised, at the end of the FaSMEd lessons, the connection between maths and science, by being in agreement with the sentences "what I learn in ... is useful in ...". In particular, Group 3 partially disagreed on this affirmation in both senses, at the beginning, but they shifted to a positive feeling (**3p.** and **5p.**, Fig. 45 in yellow and dark red). Group 4, instead, already agreed on the fact that what they learnt in science was useful in maths but, at the end of the experience, they were in strong agreement also with "what I learn in maths is useful in science" (**5p.**, Fig. 46 in orange). As a motivation, on the back of the card, they wrote "it is useful for the graphs", showing that they understood the link between the activities in maths and science and the objectives of the interdisciplinary work.

Assessment

In terms of formative assessment, we can identify students' increasing awareness of the teacher's monitoring of the work done in the class, thanks to the clickers (**20p.** Group 3, Fig. 45 in red; Groupe 4, Fig. 46 in rose). The only opinion that changed in the groups was about the sentence **12p.** "Assessment in maths or in science helps me work more" (Group3, Fig. 45 in blue).

Conclusive remarks

FA strategies

In this sequence of lessons, technology is not central at the difference of the other French case study where students worked daily with their tablets but appear as a tool playing a very important role to report progress from time to time. As in the other case study, technology even if not central, appears as an accelerator of FA strategies in its different properties: sending and sharing, displaying and analysing, providing a

dynamic environment as shown in the cuboids representations. All along the sequence the two teachers match the digital tools and their communication to the needs and abilities of the class and lean students progressively to a shared understanding of the graph concept from both the mathematical and the physical point of views. The different phases where teachers appear as a resource for students (interpretation of the graph, experiment, drawing the graph from data, etc.) alternate with phases where students appear as a resource for their peers (debate in the classroom, work in group,...).

In the particular context of the school and of this class in the school, we can notice amongst the different lessons a real evolution of knowledge regarding both the physical concepts at stake and the graph understanding. Teachers, working together, often conjointly in the classroom, offer students an environment that allows a development of autonomy in front of the knowledge at stake. The difficulties which occur at the beginning have been analysed by teachers with the help of technology. This analysis allows them to organize lessons in order to match students actual knowledge to their learning without leaving a demand relatively to the concepts at stake. The good results to the final assessment that the teacher noticed constitutes a clear evidence of the effect of FA in this lesson: "Looking at the past year results where I didn't spoke of "story of a graph", there is a clear evolution".

FA and technology

The role of technology is important to stress because of the different properties that came as a support of FA strategies. The dynamics that the three dimensional model highlighted, show that each property of the technology helped in supporting FA strategies both from the point of view of teachers and the point of view of students. Step by step, the students' knowledge construction leant on teachers' support evolved in term of mathematical and physical skills. The graph, as a boundary object, became an object of knowledge in the two scientific disciplines. In mathematics, technology is used for displaying the task while the teacher and the students are discussing (Fig. 22, 26, session 3), or sometimes as a support for stressing something on the graph (Fig. 23, 24 session 3). In physics, technology is used for sending and sharing in order to develop the engineering of effective discussions and new learning tasks (session 6) or providing feedback that moves the learner forward (session 8) but also processing and analysing on the spot (session 6) in order to provide feedback that moves the learner forward. Finally, the interactive environment that the teacher provided in session 4 facilitates for the teacher to clarify the learning objectives and for students to understand criteria for success. As a link between the theoretical protocol and the reality of the experiment, the interactive environment facilitated the understanding of the relationships between the experiment and the data coming from this experiment.

In terms of interdisciplinary work, each teacher assisted to almost all of the other's lessons. They intervened on the vocabulary and preparing or recalling the learning objectives of one other. L wrote in her diary: "Thanks to the cross observations, students make the link between the work done in physics and in mathematics".

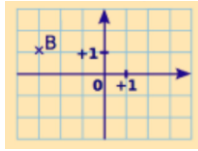
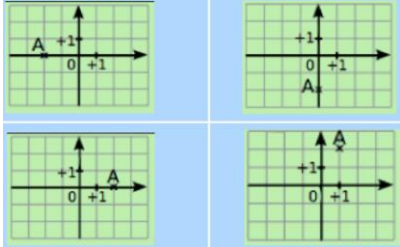
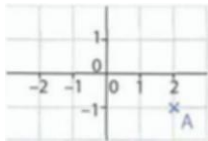
FA and interdisciplinary work

The dynamics between the cuboids (maths and physics teachers, clarifying the shared learning objectives and criteria for success, sending and sharing) and (students, understanding and sharing learning objectives and criteria for success, sending and sharing) that the representation in the three dimensional model shows in session 9 are linked to the dynamics between (students, being active as the owners

of their own learning, sending and sharing) and (maths and physics teachers, providing feedback to students, processing and analysing). In that sense the case study shows an evidence of the relationships between the FA assisted with technology implemented in the class and the construction of knowledge and students' understanding.

Appendix A

Multiple choice test on the coordinate plane (see session 1).

<p>Q1: In this coordinate plane, what are the coordinates of the point B?</p> <p>A. (-3;1) B. (1;3) C. (3;-1) D. (-3;-1)</p>	
<p>Q2: The point A has coordinates (0;-2). In which coordinate plane is it well-placed?</p>	<p>A</p> <p>B</p>  <p>C</p> <p>D</p>
<p>Q3: In this coordinate plane, which are the coordinates of A?</p> <p>A. A(2;1) B. A(2;-1) C. A(-1;2)</p>	
<p>Q4: The x-axis is:</p> <p>A. The horizontal axis B. The vertical axis C. Else</p>	
<p>Q5: The y-axis is:</p> <p>A. The vertical axis B. The horizontal axis C. Else</p>	
<p>Q6: Let A be the point (1;2). Select the good answer(s):</p> <p>A. 1 is the abscissa of the point A B. 2 is the ordinate of the point A C. 1 is the ordinate of the point A D. 2 is the abscissa of the point A E. A is on the y-axis</p>	
<p>Q7: Let C be the point (-3;0). Select the good answer(s):</p> <p>A. C is on the x-axis B. -3 is the abscissa of C C. 0 is the ordinate of C D. C is on the y-axis</p>	

E. -3 is the ordinate of C
Q8: Let H be the point (0,-15). Select the good answer(s): A. 0 is the abscissa of H B. -15 is the ordinate of H C. The point H is on the y-axis D. -15 is the abscissa of H E. 0 is the ordinate of H
Q9: We want to place in the coordinate plane the following points: A(2;4) B(-7;2) C(4;2) D(5;0) E(0;-3) F(-3;-5) G(5;-2) Among these points, which has the smallest abscissa?
Q10: We want to place in the coordinate plane the following points: A(2;4) B(-7;2) C(4;2) D(5;0) E(0;-3) F(-3;-5) G(5;-2) Among these points, what is the value of the biggest ordinate?

Appendix B

Multiple choice test on representation of data in both tables and graphs (see session 1).

Q1: This table gives the number of computers owned by the families of the students of the collège Fontbruant.

To which question(s) is it possible to answer thanks to the table?

A. How many students have one (and only one) computer?

B. How many students have more than 4 computers?

C. How many families are equipped of computers?

D. How many students are in the school?

Nombre d'ordinateurs	0	1	2	3	4
Nombre d'élèves	5	19	25	13	8

Q2: This table gives the number of computers owned by the families of the students of the collège Fontbruant.

Thanks to this table, we can say that:

A. 24 students have at least two computers

B. Together they have 145 computers

C. 21 students have more than two computers

D. There are 70 students in grade 6

Nombre d'ordinateurs	0	1	2	3	4
Nombre d'élèves	5	19	25	13	8

Q3: Looking at the table, which diagram(s) doesn't (don't) match the situation?

Q4: If computers would have been fairly distributed, each student would have roughly

A. 1 computer by person

B. 2 computers by person

C. 3 computers by person

D. 4 computers by person

Nombre d'ordinateurs	0	1	2	3	4
Nombre d'élèves	5	19	25	13	8

Q5: The vehicles of this parking come from

A. 500 vehicles coming from the European union are present in the parking

B. 50% of the vehicle come from abroad

C. There are five times more motorbikes than cars

D. 600 people park here

Origine \ Catégorie	Voitures	Motos
Française	300	25
Etrangère européenne	150	25
Autres	50	50

Q6:

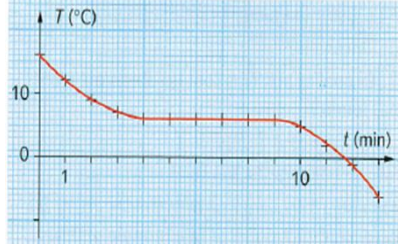
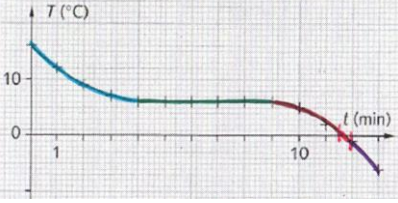

- A. Population is growing since 1940
- B. Population reaches 50 millions of inhabitants in 1960
- C. The number of inhabitants was almost the same in 1910 and 1930
- D. The number of inhabitants in France has, during this period, remained less than 60 millions



Appendix C

Multiple choice class test, based on the Exercise 2 in Fig. 5 (see sessions 8 and 9).

Exploiting a graph

	<p>Q1. What are the magnitudes represented on each axis? (2 answers)</p> <ol style="list-style-type: none"> 1. In ordinate (upward), the time in minutes; 2. In ordinate (upward), the temperature in Celsius degrees; 3. In ordinate (upward), the state of the matter; 4. In abscissa (rightward), the time in minutes; 5. In abscissa (rightward), the temperature in Celsius degrees; 6. In abscissa (rightward), the state of the matter; 7. Else. <p>Q2. How long is the experience?</p> <ol style="list-style-type: none"> 1. The experience lasts 11,5 min; 2. The experience lasts 10 min; 3. The experience lasts 16 °C; 4. The experience lasts 13 min. <p>Q3. How does the temperature vary between 16 °C and -6 °C? (2 answers)</p> <ol style="list-style-type: none"> 1. The temperature does not change (it remains the same); 2. The temperature changes; 3. The temperature increases; 4. The temperature decreases; 5. Else.
	<p>Q4. Which part of the curve represents the temperature plateau?</p> <ol style="list-style-type: none"> 6. The blue part; 7. The green part; 8. The red part; 9. The brown, red and purple parts; 10. Else. <p>Q5. Which part of the curve represents the change of state.</p> <ol style="list-style-type: none"> 6. The blue part; 7. The green part; 8. The red part; 9. The brown, red and purple parts; 10. Else.
	<p>Q6. Which minute does the change of state begin?</p> <ol style="list-style-type: none"> 1. The change of state begins at 1 min;

	<ol style="list-style-type: none"> The change of state begins at 4 min; The change of state begins at 6 min; The change of state begins at 9 min; Else.
	<p>Q7. How long is the <i>change of state</i>?</p> <ol style="list-style-type: none"> The change of state is instantaneous (it lasts 1 second); The change of state lasts 5 min; The change of state lasts 4 min; The change of state lasts 11,5 min; Else.
	<p>Q8. At what temperature does the state <i>change</i>?</p> <ol style="list-style-type: none"> The temperature of the change of state is 0 °C; The temperature of the change of state is 4 °C; The temperature of the change of state is 6 °C; The temperature of the change of state is 11,5 °C; Else.
	<p>Q9. What is the physical state of the substance at the beginning of the experience?</p> <ol style="list-style-type: none"> The achromatic liquid is hot; The achromatic liquid is transparent; The achromatic liquid is liquid; The achromatic liquid is gaseous; Else.
	<p>Q10. What is the state of this substance at the end of the experience?</p> <ol style="list-style-type: none"> The substance is cold; The substance is transparent; The substance is liquid; The substance is solid; Else.
	<p>Q11. Is this substance water?</p> <ol style="list-style-type: none"> Yes, this substance is water because the change of state of the water occurs with a temperature plateau; Yes, this substance is water because the shift from the liquid state to the solid state occurs at 6 °C; Yes, this substance is water because the shift from the liquid state to the solid state occurs at 0 °C; No, this substance is not water because the shift from the liquid state to the solid state occurs at 0 °C ; Else.

Students' results

Élève	mathématiques Partie A						Math / phys Partie B					Physique Partie C			
	Q1	Q2	Q3	Q4	Bilan/6		Q5	Q6	Q7	Q8	Bilan/4	Q9	Q10	Q11	Bilan/3
1	2	4	4	2	4	2	6	2	2	2	3	4	3	4	3
2	2	4	*2	2	4	2	5	*3	2	2	3	3	4	*3	2
3	*1	4	*2	*3		2	2	2	2	*5	*5	2	*2	*1	4
4	*5	4	4		4	2	4	2	2	2	3	4	3	4	3
5	2	4	*0	*1	4	*1	3	2	2	*5	*5	2	3	*3	*1
6	2	4	4	2	4	2	6	2	2	2	3	4	3	4	3
7	2	4	*1		4		3	*4	*4	2	*1	1		4	*1
8	2		4		4	2	3	*4	*4	2		1	*0	4	4
9	*5	4	4	*5	4	2	4	*3	*4	*5	3	1	*1	4	*3
10															
11	2	4	*3		4	2	4	2	2	*5	*0	2	3	4	*2
12															
13	2	4	*2		4	*1	3	2	2	2	*0	3	*0	*3	*3
14	2	4	4	2	4	2	6	2	2	2	3	4	3	4	4
15	2	4	*2	2		*4	3	2		2	*4	1	3	4	4
16	2	4	4	*1		2	4	*3	*5	*4	*1	0	3	4	4
17															
18	2	4	4		4	*1	4	2	2	*5	3	3	*2	4	*2
19	*1	4	*2	*1		2	2	*3		*4	*2	0	*2	*2	4
20	2	4	4	2		2	5	2	2	2	3	4	3	4	*2
21	2	4	4	5		2	5	*3	2	2	*1	2	3	4	4
22	2	4	4	2	4	2	6	*4	2	2	3	3	3	4	4
23	2	4	4		4	2	5	2	2	*4	*4	2	3	*5	*2
24	2	4	*1		4	*1	3	2	*4		*5	1	3	4	*2
Nombre de réponses correctes	16	19	12	6	14	14		12	13	11	9		13	15	11
nombre de réponses	20	20	20	20	20	20		20	20	20	20		20	20	20
pourcentage de réussite	80	95	60	30	70	70	81	60	65	55	45	56,25	65	75	65

Table A1: Students' results (the sign * marks a wrong answer)

Appendix D

Multiple choice test on the main physical concepts of the learning sequence, implemented in Session 10.

Q1. The terms kilogram, litre, Celsius degree correspond to

1. units
2. magnitudes
3. values

Q2. The terms mass, volume, temperature correspond to

1. units
2. magnitudes
3. values

Q3. The mass of the ice is 180 L. This sentence is true or false?

1. true
2. false

Q4. In the sentence “The mass of the ice is 180 L”, the student made a mistake

1. on the unit
2. on the magnitude
3. on the value

Q5. The volume has

1. the litre as magnitude
2. the kilogram as unit
3. the litre as unit
4. the mass as magnitude

Q6. “kg” is

1. the symbol of kilogram
2. the symbol of the unit of the mass
3. the symbol of the unit of the volume
4. the symbol of the magnitude “mass”

Q7. What is the symbol of the magnitude “mass”?

1. T
2. m
3. V

Q8. When a student writes as an answer “5 kg”, he forgot to specify

1. the magnitude that corresponds to this value
2. the unit that corresponds to this value

Q9. $T = 24\text{ }^{\circ}\text{C}$ is the answer to the question:

1. Which is the number of degree in the classroom?
2. What is the temperature of the classroom?

Appendix E

Questions proposed at the Q-sorting activity: “positive” (p) feelings | “negative” (n) feelings.

Students’ conceptions about maths/science

1p. Maths is important	1n. Maths is difficult
2p. Maths is something that everyone can learn	2n. In maths there is always one right answer
3p. What I learn in science is useful in maths	3n. Science is not important for my future life
4p. Doing science means exploring and experimenting	4n. To understand a maths lesson I have to solve a lot of exercises
5p. What I learn in maths is useful in science	5n. Maths doesn’t make sense in the daily life
6p. Science helps me think logically	6n. Learning science is learning formulas by heart

Students’ conceptions about learning maths/science

7p. I better understand science when we make experiments	7n. I better learn and understand maths when I work alone
8p. If I don’t understand something, I work hard to succeed	8n. Maths requires a lot of exercise
9p. Maths is more comprehensible when we work with classmates	9n. In science I have to write a lot
10p. I understand better if I work with my classmates in science	10n. In a maths lesson I haven’t enough time to think
11p. When I do maths and science assessments I realise what I haven’t understand	11n. Just gifted people understand maths or science
12p. Assessment in maths or in science help me work more	12n. I never feel comfortable during maths lessons
13p. In a science lesson there is always space for expressing ideas	13n. Assessment in maths or in science are boring

Students’ conceptions about technologies

14p. Working in maths or in science with clickers is useful	14n. Using clickers in maths is difficult
15p. Our maths and science teachers always use technology (clickers, interactive whiteboard, calculators, ...) for doing lessons	15n. Using clickers during science lessons makes things harder
16p. I can better understand maths when I use the clickers	16n. It is really useless to take a quiz with clickers if I haven’t the results immediately
17p. Since we use clickers during maths lessons, I quickly understand my mistakes	17n. I prefer talking with the teacher instead of sending my answer with the clicker
18p. Since we use clickers during science lessons I better understand what I have to revise	18n. Clickers never helped me learn maths and science
19p. Tests with clickers help me understand what I have to learn in maths and in sciences lessons	19n. I usually made some mistake in typing my answer on the clickers

20p. I feel that maths and science teachers know better where I am, when we use clickers	20n. I don't like working with clickers because it obliges me to work alone
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