EXPERIMENTAL DEVICES IN MATHEMATICS AND PHYSICS STANDARDS IN LOWER AND UPPER SECONDARY SCHOOL, AND THEIR CONSEQUENCES ON TEACHER'S PRACTICES

Fabrice Vandebrouck, Cecile de Hosson, Aline Robert

University Paris-Diderot, Laboratoire André Revuz

The new French Standards for the teaching of science subjects in secondary school advantage the experimental dimension by a revival of words such as "experiment", "experimental" and by the introduction of quite new teaching concepts such as "inquiry-based teaching" and "practical experiment test". Our study deals with the introduction of a new teaching paradigm which includes a strong experimental dimension in both mathematics and physics instructions. The "double approach" frame, including both didactic and ergonomic approaches, constitutes the global frame for the analysis of the teachers' practices we wish to focus on. This allows us to go back over some variables that could be essential to take into account in order to choose appropriate educational devices.

The new French Standards for the teaching of science subjects in lower and upper secondary school advantage the experimental dimension by a revival of words such as "experiment", "experimental" and by the introduction of quite new teaching concepts such as "inquiry-based teaching" and "practical experiment test". This novel approach is common to mathematics, physics, chemistry and biology instruction in lower secondary school. Conversely, in upper secondary school specificities appear depending on each scientific subject. In mathematics, this specific approach leans on more or less implicit references to the use of ICT.

Our study deals with the introduction of a new teaching paradigm which includes a strong experimental dimension in both mathematics and physics instructions. First, we will survey the meaning and the possible place of experiments in the physics and mathematics learning by examining the textbooks and standards. Then, we will focus on the practices of the teachers who intent to implement such experimental elements in their classroom. In that perspective, we use a common frame of analysis ("double approach didactic and ergonomic") in order to raise the predictable complexity of the recommended approach. Some examples are given which analysis leads to the conclusion that either the approach suggested by the teacher is too open and nothing happens or it is too restrictive or reductive, and students have no real access to what is required.

In the "double approach" frame, a didactic point of view and an ergonomic one are interwoven. It constitutes the global frame for the analysis of the teachers' practices we wish to focus on (Robert & Rogalski, 2005, Robert, 2008, Pariès, Robert, Rogalski, 2007). This frame allows us to describe both planed sequence and expected tasks proposed by teachers (in terms of available knowledge and adaptations), and to confront them to an analysis of the possible children's activity.

To conclude, we will go back over some variables that could be essential to take into account in order to choose appropriate educational devices, that is, concepts or situations that fit with a relevant experimental approach. At the same time, the efficiency of our methodological frame will be thus attested.

THE PLACE OF THE EXPERIMENT IN THE MATHEMATICS AND PHYSICS CURRICULA

In an international context, a lot of researchers looked into experimental activities and enlightened their different objectives. Their results led the authors of curricula to take new directions for science education. It consists in showing a richer image of scientific processes, giving more autonomy to pupils and proposing more open tasks allowing them to develop higher level cognitive activities: the statement of scientific questions, the statement of hypotheses, the design of experimental protocols, the choice and treatment of data and the communication of the results. These different elements have been made explicit in several projects, such as Science for All Americans or in the recent report ordered by the European Commission. More particularly in France, this kind of process in the classroom at low secondary school, is a continuation of a pedagogical practice implemented at primary school since 2000. In France, it appeared in the curriculum in 2005, and was reasserted in 2007 under the name of "démarche d'investigation" in French, that has been translated here into "inquiry-based teaching" (IBT). This process concerns both mathematics and science teaching.

Despite this common educational text for both mathematics and physics instruction (grade 6 and 7), it seems difficult to implement and to analyze this type of approach in the classroom in the same way in mathematics and physics, insofar as the actual objectives are on both sides different. Indeed, this requires at least to question the very nature of the subject itself (in an epistemological point of view) and the different type of problems involved in a scientific process learning such as modeling the real world, complex operating of tools previously elaborated, etc.

In mathematics, the experimental test in upper secondary school (end of grade 12) includes a consistent and open problem. Students can be asked to model a part of this problem, but this is not systematic (BOEN HS n°7, 2000). From the perspective of potential acquisitions, the experimental test doesn't seek to introduce new knowledge but to make students' knowledge (assumed available) operate. This type of process includes rich, various and possibly new adaptations of this knowledge. Students often face a number of choices: choice of cases to deal with specific software, choice of the software itself, etc. It seems appropriate to *a priori* consider what we want to "win" in terms of students' knowledge (start-up knowledge, knowledge supposedly already there, and also the distance between the two). It is to estimate how students can stage and work with the "experimental" part itself, given the management developed by the teacher that determines the whole work in the classroom and also number of other constraints such as time, material organization, etc.

In the IBT context, physics teachers are now invited to elaborate problems that are favorable to the development of processes and construction of new knowledge by the pupils themselves (BOEN HS n°6, 2007). At the same time, pupils are given more responsibility and autonomy (the statement of hypothesis or conjectures, the elaboration of an experimental device in order to test these hypotheses). At last, teachers are expected to know pupils conceptions in various subjects and be able to exploit them in the elaboration of sequences that would aim at making these conceptions evolve by using a hypothetico-deductive process. The implementation of the IBT in the classroom requires profound changes in science teachers' practices and experience. A focus on the spontaneous transition between IBT in the curriculum and teachers' practices leads us to draw a picture of the way teachers appropriate the new instructions and allows us to identify the underlying difficulties.

SOME COMMON ELEMENTS OF METHODOLOGY FOR ANALYSING TEACHERS' PRACTICES IN THE CLASSROOM

The « double approach frame » (Robert & Rogalski, 2005) postulates that the analysis of teachers' practices requires for the researcher to draw what tasks are chosen by the teacher for its pupils, and to derive the way its courses are organized. The corresponding analyzes lead to reorganize the activities the pupils could have performed. These analyzes are guided by the choices of the teachers, but they remain inadequate to understand teachers' practices as a whole. Other analyzes, inspired by the ergonomic framework complete the former ones: they include the constraints and the resources associated with the profession of "teacher": institutional constraints (connected with the curricula), social constraints and the constraints connected with the personal resources of the teacher, that is, his beliefs, knowledge and experience.

This theoretical framework is not a model; it is drawn from the Activity Theory (Leont'ev, 1984, Vygotsky, 1997, Vergnaud, 1990). The conversion of fundamental elements of this theory into specific theoretical elements adapted for mathematics or physics and for learning situation allows us to question teachers' practices and to legitimate our research questions whether there are local or global. Thanks to this approach, our questions can be in kipping with a unique framework associated with specific methodologies.

These methodologies involve on the one hand the presentation of a large planed-teaching course that includes the analyzed sequence(s) (either because many sequences are involved or at least to clarify the place of the sequences into the whole course), and on the other hand, the statement of the possible activities of the students. The latter is done trough the confrontation of an *a priori* analysis (including the study of expositions or instructions and the examination of the data given by tools) with an analysis of the teaching processes.

The *a priori* analysis provides the tasks the students should perform and the corresponding knowledge **(**Horoks and Robert, 2007**)**. The second analysis (**the analysis of the teaching processes**) refines the *a priori* analysis by taking into account teachers' interventions. This concerns the organization of students' work (including the timing of the different phases) and this also covers their actual work (self-working, part of initiatives, students' involving, teachers' help to the making tasks, aid to overcome the action, reports). Starting from **the recovery of students' activities** we can question and understand the choices done by the teachers and think about alternatives strategies that take into account the standards, different constraints (e.g. time), the habits of the job, and individual characteristics.

CASE-STUDIES

In mathematics

We develop in this communication two examples of grade 12 teaching sequences (12th grade). The two sequences last one hour, with pupils working alone on a computer, and with the teacher helping them individually.

The objective of this session is to discover a property of the slope of the exponential curve, then to prove this property.

EXPERIMENTAL PHASE

To answer this question, you will use the software **Geogebra**

1) Realization of the diagram

(…)

2) Experimentation

Vary the point A on the curve. Observe simultaneously the X-coordinates of A and B

3) Hypothesis

What property seems to be true for all positions of the point A? Try to imagine a method to confirm this hypothesis with experimentation.

RESEARCH OF A PROOF

1) Let *a* be a real and A the point on the curve y=exp(x) which X-coordinate is *a*. Find the equation of the slope T of the curve on A.

2) Can you use this equation to prove your hypothesis?

3) Make the proof of the hypothesis.

Table 1: exposition given in the first example of mathematics teaching sequence

The a priori analysis shows that the experimental activity potentially made by the pupils is banished. Indeed, the ICT tool to be used is given and the objective “discover a property of the slope of the exponential curve” is too hazy to allow an autonomous pupils’ activity. Then, the experimental construction is given by the exposition “realization of the figure” (question 1) and the activity described as experimental (question 2) is reduced to vary a point on the curve and to observe the conjecture as an evidence (question 3): “The X-coordinate of A is always the one of B plus 1”. There is no more one demonstration exercise fairly traditional with no experimental dimension anymore. Even if the introduction of the parameter and the calculation of the equation of T is explicitly asked in the exposition, some intermediary tools have to be introduced by pupils. So this traditional exercise is complex in comparison with the task.

The analysis of **the teaching process** confirms this complexity: the teacher says that “even the best student asks for an indication” and that she finishes the session by showing in a collective way how to do the proof. So, in this first example, there is no experimental activity of students but only several immediate applications of some explicit pieces of knowledge.

The exposition for the second studied sequence is the following:

Let k be a real positive. **We are interested about the number of roots of the equation ln(x)=kx^2 for x positive..**

1. Open the software **Géogébra**.
2. In the entry windows, enter f(x)=ln(x) then validate. Enter x^2 then validate. Do the same with 0.5x^2, then 0.1*x^2 and then $-x$^2. Fill in the table :

Value of k				
Nomber of roots according the graphical curves				

3. We want now to determine in a more precise way the number of roots. Click on “Fenêtre”, then “Nouvelle Fenêtre” and then let appear the curve of the function ln in this new frame.
4. Enter $k=1$ in the entry window then validate. This number appears in the algebra window. In the entry window, define now $g(x)=kx^2$.
5. Vary the number k, then click with the right button of the mousse on this number, then click on “Afficher l’objet”. A cursor appears. Click on  to define the mode “déplacer”, and then displace the cursor with the mousse.
6. **Conjecture following the values of k the number of roots of the equation** $\ln(x)=kx^2$**.**

Call the teacher to validate your answer.

7. If $k>0$, graphically find a value of k with two right digits after the decimal point for which the equation admits only one solution (you can right click on k and then on “Propriétés”, “Curseur”, to reduce the increment inside the

interval) *Call the teacher to validate your answer.* Demonstrate on your sheet that for any negative value of k, the equation admits a unique solution.

Table 2: exposition given in the second example of mathematics teaching sequence

This second example assumes a level of software's competencies which is lower than the first one but we don't want to enter in this problematic for this communication. However, **the a priori analysis** shows that the experimental construction is again given by the exposition (questions 3, 4, 5, 6). Moreover, the exposition initiates the activity of testing some particular cases of the whole open problem (question 2). The so called experimental part is again isolated from the one more strictly mathematical. This last one is cute in two sub tasks (questions 7 and 8) while a real experimental activity should lead to treat the whole task.

The teaching process shows that lot of pupils don't see the link between the curve they draw during question 2 and some particular cases of the problem. The teacher says that they didn't see how to fill in the table. This reinforces the idea that there is not at all experimental activity during this sequence. Moreover, the question 8, even if it is simplified by the exposition, remains very difficult for pupils.

With these two examples, we understand that the expositions, as in educational texts, are effectively open problems: "to discover a property of the slope of the exponential curve" and "we are interested in the number of roots of the equation $\ln(x) = kx^2$ for x positive". But the field of activity is too large to allow an autonomous activity of students and the tasks are simplified by the expositions: "Realization of the figure", "Fill out the table". In other words, the experimental management is not in charge of the students but it is explained by the detailed expositions. So the hypotheses are evidenced at the end of the explained manipulations. There is no reason to question these hypotheses even if some questions can be awkward in this direction, as in the first example: "Try to imagine a method to confirm this hypothesis with experimentation".

Then, a classical proof ("research of a proof", question 8), isolated from the manipulation phase, is asked. Moreover this proof can be difficult for students because of complex uses of available knowledge and because manipulations don't help for this purpose at all. However, in general, we think that there could be an interaction between the two parts of the session. For instance, in the first example, the manipulation of software Géogébra requires the internalisation of some commands. More precisely, the command "curseur" of the software is deeply associated to the introduction of parameter to prove the hypothesis. So there could exist a though to help students to introduce parameters in their proofs by training them to associate parameters and "curseur" in ICT environment.

In physics

An analysis of 26 teachers' worksheets available on pedagogical websites and supervised by the educational authorities was conducted a few months ago (Mathé & al. 2008). This analysis revealed important gaps between IBT in the curriculum and teachers' perceptions or appropriation. In particular, it has been shown that few of them make pupils' conceptions explicit in their worksheets and build their sequence in order to destabilize these conceptions. Moreover, while the curriculum comprises a phase of statement of hypotheses, only 11 worksheets ask pupils for stating hypotheses. Furthermore, only 9 protocols are entirely designed by the pupils. In the other worksheets, the teacher plays a more or less important part: whether he designs the protocol himself or he imposes the experimental equipment, or corrects the pupils' propositions (Mathé 2008, Mathé & al. 2008).

The sequence we take as an example concerns combustion processes. The new knowledge aimed by the sequence is exposed as following:

- the combustion of carbon requires oxygen and produces carbon dioxide;
- a fire naturally occurs when air, heat and fuel are combined.

These three elements form the "fire triangle". When one of these elements is missing, the fire stops. The problem to be solved –"How to extinguish a fire"– is connected to an everyday-life starting situation which is supposed to motivate the pupils. They are asked to go outside the classroom, to find all the anti-fire and fire protection devices of the school and to explain the way they operate. Doing so, the teacher expects the children to make hypotheses on combustion process such as "oxygen is necessary for the combustion process" or "combustion produces carbon dioxide". This hypothesis should be tested by appropriate experiments elaborated and performed by the children. The sequence is implemented with grade 7 children and last two hours. It is video-recorded and transcribed. We focus here on specific heading: children's conceptions, the statement of hypotheses, and the hypothetico-deductive process.

The a priori analysis shows that the tasks proposed to the pupils can't destabilize children's conception about fire such as "fire is an object endowed with material properties" widely studied by philosophers and science education researchers (Bachelard 1938, Méheut 1982), and we wonder to what extent it doesn't strengthen it. Indeed, attention to the anti-fire devices operation does not automatically leads to the idea that the air supply is necessary in the combustion process. Consequently, the problem to be solved can't lead to the statement of the expected hypotheses either. Thus, no spontaneous hypothetico-deductive process can be expected.

The analysis of the teaching processes confirms this difficulty. Children are easily involved in the preliminary activity which consists in describing the anti-fire and fire protection devices of the school. A difficulty appears when the teacher asks them to describe the way the devices operate. We observe a misunderstanding between the teacher's expectation which concerns the underlying chemical process and the pupils' answers that exclusively focus on the description of the way the device is used. This unexpected difficulty leads the teacher to formulate a more precise and guided question: “can you explain why these devices extinguish the fire?”. At that time, a second difficulty occurs which is directly connected to the way that “the fire” is considered in pupils’ mind. As an example, pupils think that fire-resisting doors close in order to prevent the fire to move forward. According to them when the doors are closed the fire “bounces” on them. None of the pupils spontaneously establish a link between the air (specifically the oxygen) and the existence of the fire. This difficulty is widely underestimated by the teacher during the effective sequence. Finally, after one hour of discussion, the expected hypotheses are given by the teacher himself: “oxygen is necessary for a fire to exist” and “a fire produces carbon dioxide”. Pupils are then invited to elaborate experiments in order to test the hypotheses. In this phase, they must isolate the different air contents to prove that only the oxygen plays a part in the combustion process. They also have to elaborate an experiment in order to evidence the carbon dioxide. In the next course, contrary to what was planned, the experiments are imposed and performed by the teacher. This is directly connected to management constraints.

According to the a priori analysis, we observe significant gaps between the teacher’s intentions and what really occurred during the effective sequence. Children’s ideas about the burning process and the fire are not destabilized by the inquiry-based activity itself. The teacher plays a determining part in the knowledge transmission and the starting situation doesn’t allow the implementation of a cognitive-conflict as expected in the IBT. Moreover, the teacher asks the pupils to design an experimental protocol but he finally imposes his own experiment.

CONCLUSION

We assume that no generalities can be asserted as the analyses previously presented remain clinical. Nevertheless, some regularity seems to emerge that form tracks to explore.

What is specific to us is the need for teachers to make a quadruple prior analysis, lighter than the researcher’s one of course, in order to effectively implement this type of process in their classroom:

- an analysis of the aimed knowledge or the knowledge to be used (different from a subject to another);
- an analysis of the available knowledge to permit an autonomous activity of pupils;
- an analysis of the role played by the experimental process in the connection between the aimed knowledge (or knowledge to be used) and the available knowledge considering both content and teaching processes;
- an analysis of the way the teacher can manage this experimental activity.

Moreover, in physics, depending on the nature of the referred content, an inquiry-based teaching can be adapted or not. IBT in the classroom requires choosing relevant scientific content and problem that aim at destabilizing pupils' conceptions and that allow the implementation of a hypothetico-deductive process by the pupils implying more autonomy for the statement of hypotheses and the design of a protocol. However, it may be that students cannot develop hypotheses highlighting their misconceptions. In that perspective, the choice of the scientific subject remains fundamental.

In mathematics, we have seen that there is a problematic amalgam between an experimental approach of mathematical activity and an activity with ICT tools, these tools being able to lead pupils easily to emit correct conjectures for complex problems. The experimental constructions being given by the expositions, the experimental activity can only exist in a one to one correspondence between manipulations (not experimentations) and proofs. This activity, even if it is far from scientific one, can be interesting for using mathematical knowledge (activity with available knowledge or activity with adaptations of knowledge). But it is difficult for students who are not accustomed with these activities. It is also difficult for teachers who have to find adequate situations permitting these go and return between manipulations and proofs and who have to manage at the same time the learning of the new knowledge as well as the learning of software's competencies. This kind of studies has to be completed by some results on individual different students' attitudes when working on computers (Vandebrouck, 2008).

REFERENCES

Bachelard, G. (1938). *The formation of the scientific mind*. Clinamen Press Ltd.

Horoks, J., Robert, A. (2007). Tasks Designed to Highlight Task-Activity relationships, *Journal of Mathematics Teacher Education*, vol 10, 279-787

Leontiev, A., (1984) Activité Conscience Personnalité. Moscou, Editions du Progrès

Mathé, S., Méheut, M., de Hosson, C. (2008). La démarche d'investigation au collège : quels enjeux. *Didaskalia*, vol. 32, 41-76.

Mathé, S. (2008). Inquiry-based teaching in low secondary school in France: which stakes? *Proceedings of the ESERA summer school.* York (England): 25-29 august 2008.

Méheut, M. (1982). *Combustions et réaction chimique dans un enseignement destiné à des élèves de sixième*. Thèse de troisième cycle. Université Paris 7.

Robert, A., Rogalski, J. (2005). A cross-analysis of the mathematics teacher's activity. An example in a French 10th-grade class. *Educational Studies in Mathematics.* Vol 59, 269-298.

Pariès, M., Robert, A., Rogalski, J. (2008). Analyses de séances en classe et stabilité des pratiques d'enseignants de mathématiques expérimentés du second degré, *Educational Studies in Mathematics*. Vol 68, 55-80.

Robert, A. (2008). La double approche didactique et ergonomique pour l'analyse des pratiques d'enseignants de mathématiques. In Vandebrouck (Ed.) *La classe de mathématiques : activités des élèves et pratiques des enseignants* (pp 59-68). Toulouse: Octarès

Vandebrouck, F. (Ed) (2008). La classe de mathématiques : activités des élèves et pratiques des enseignants, Toulouse: Octarès

Vergnaud, G., (1990) La théorie des champs conceptuels, *Recherches en Didactiques des Mathématiques,* Vol 10 (2/3), 133-170.

Vygotski, L. (1997) Pensée et Langage. Paris, Plon