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# Towards Research-Based Design of Teaching Situations In Physics at the Secondary School Level

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The relationship between research in science education and effective teaching in the framework of any educational system raises the question of the role of research in designing teaching situations. This design for each domain of physics can be an endless task. In this chapter I present an approach to designing situations based on teaching and learning where the knowledge to be taught, students' understandings of that knowledge and teaching resources are each viewed as important, and with the potential to influence each other. The theoretical bases of such designs are first presented and then three types of situations are analysed.

## THEORETICAL BASES

The theoretical elaboration presented here has been developed following a series of empirical studies carried out in the COAST research group (France), with data mainly collected in classrooms during practical work at the upper secondary school level (Bécu-Robinault, 1997a, b, Buty, 1998, Le Maréchal, 1998); it is also rooted in a collaboration with teachers (Gadioz et al. 1998). The results obtained, together with theoretical approaches on modelling (Tiberghien, 1994), on didactical situations (Brousseau, 1988), and on didactical transposition (Chevallard, 1991) constitute the main bases of this research-based design of physics teaching situations.

### Knowledge

First of all, it is necessary to note that in English, the single word ‘knowledge’ is the only one available, whereas in French there are two words: *savoir(s)* and *connaissance(s)*, with the associated verbs. This makes it difficult to present in English the theoretical framework constructed in the French language. Due to the international character of this book, this remark can help mutual understanding.
The theoretical position on knowledge is based on Chevallard's work (1991) — a French researcher in didactics of mathematics — who, to deal with knowledge, uses the metaphor of life and ecology. Knowledge "lives" within a group of people called an

institution and the *relation* between an individual and a piece of knowledge is termed 'understanding of knowledge'[1].

From this perspective, the official curriculum corresponds to the knowledge to be taught and the distinction between *scientific knowledge* and this *knowledge to be taught* is recognised. The process of developing this knowledge to be taught is termed *didactical transposition.* This transposition is made under several kinds of *constraints*, imposed by the educational system.
The design of teaching situations corresponds to another step of the didactical transposition - that is, from the knowledge to be taught to the knowledge that is effectively taught. This transposition is the main aspect of this chapter; it involves a *manipulation* of knowledge. The whole knowledge to be taught cannot be presented as such to the students, it has to be manipulated in order to decompose it into smaller pieces and integrate it into activities. Consequently in a research-based design of teaching situation, this manipulation should be theoretically based and *made explicit* (rather than being treated, implicitly, as being as close as possible to the "true" knowledge). In the work presented here, two complementary ways of analysing knowledge are presented: modelling and semiotic registers.

### *Modelling*

The modelling approach is a common basis to analyse the knowledge to be taught, the knowledge that is *actually* taught and students' understanding of the knowledge. This approach deals with the knowledge communicated by word, gesture or writing - in other words, knowledge which "lives".

Since we are only addressing physics teaching, the treatment of the modelling approach is restricted to understanding the inanimate material world. The following hypothesis is made: when a person or a group of people explain, interpret, or predict situation(s) in the material world, most of the time their productions entail observable objects or events, and/or physics parameters, and/or relations between them, and this involves a modelling activity. This activity involves both the world of objects and events and the world of explanatory or theoretical frameworks, as well as models derived from these explanatory or theoretical frameworks (Tiberghien, 1994). The world of objects and events refers to all observable aspects of the material world, whereas on the other hand, the world of theories and models refers to theoretical aspects and elements of the constructed model of the material situations, in terms of various principles, parameters or quantities (figure 1).

The nature of modelling activity in physics is not developed here, as this kind of analysis has been made by several epistemologists (e.g. Bunge 1973; Bachelard, 1979; Giere 1988). In the case of students' knowledge, it is stated that explanations or predictions can be based on people's explanatory systems (which will be called a theoretical framework) (Carey 1985; Vosniadou and Brewer, 1994). This theoretical framework is not unique -

[1] Un savoir donné S se retrouve en divers types d'institutions I, qui sont pour lui, en termes d'écologie des savoirs, auton d'*habitats* différents" (Chevallard, 1991, p. 210)

individuals draw upon frameworks according to the objects and events in question, and the social situation.

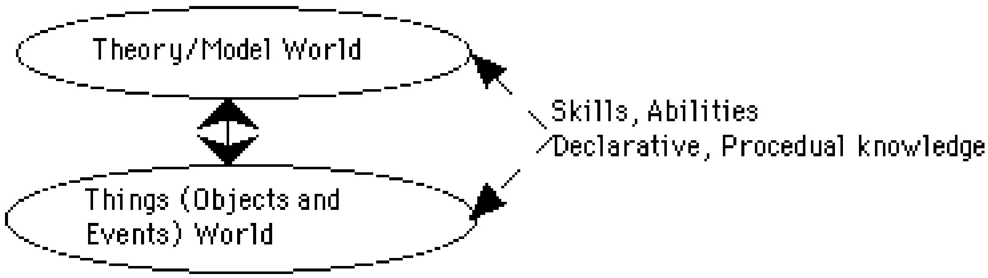



Figure 1: Categorisation of knowledge based on a modelling activity

Compared to other categorisations of knowledge, such as the classification into procedural and declarative knowledge that very often used in problem solving research, our categorisation is transversal. That is, both worlds can include declarative and procedural knowledge. Consider, for example, the statement "the red pen is on this table ". This statement, in itself, involves declarative knowledge in the world of objects and events. By contrast, the statement "the force of the system "pen" on the system "table" is equal to that of the system "table" on the system "pen"" is also declarative, but is sited in the world of theory/model.

This way of decomposing knowledge allows for the interpretation of a major characteristics of students' difficulties when they learn physics, as shown in all the studies on students' conceptions of which R. Driver was a pioneer (Driver, 1973; Driver *et al*. 1985). After receiving tuition, the students are able to solve physics problems with formulae, but they are not able to use formulae and the associated theory to predict and interpret experiments. The modelling perspective allows for the interpretation of these difficulties in terms of difficulties in establishing links between the worlds of objects/events and theory/model.

Different types of knowledge are involved in modelling (figure 2): the students can use their everyday knowledge, which may or may not overlap with the taught physics theory/model.

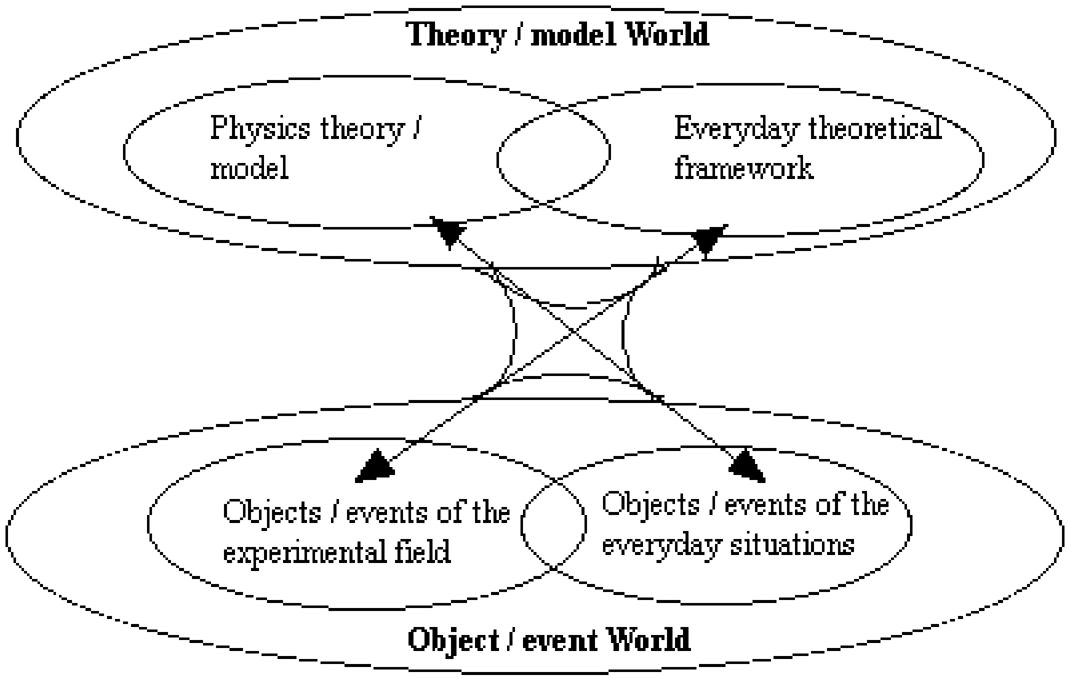



Figure 2: The two worlds of modelling

### *Semiotic registers*

Another way of decomposing knowledge is to take into account its representation. Duval (1993) uses the concept of semiotic registers. Graphs, algebra, geometrical mathematics, natural language and drawings are all different registers. These registers constitute the degrees of freedom at the disposal of a person to transform an idea, as yet unclear, into an object of thinking for him/herself (see p. 21). From this perspective, a hypothesis on learning is that an individual's understanding of a concept (or, more generally, an idea) develops when relations are established between different semiotic registers associated with the idea.

### Learning and Activities

The position on learning and activities that underpins the work described in this chapter is related to the position on modelling and semiotic registers described in the last section:

• The learners' existing theoretical framework is fundamental to his/her understanding of the whole situation. The situation includes all physical, mental, affective aspects.

• Acquisition of science understanding (conceptual, methodological and/or practices) requres the learner to construct links between the worlds of objects/events and theory/model.

• When students change registers to make explicit their ideas (for example, when they transfer ideas from a mathematical register to a graphical or linguistic (written or oral forms) register), this process in itself plays a role in helping students to construct meaning for the underlying idea (Duval, 1995).

A specific hypothesis, on which the design of situations is based, deals with the relationships between learning and students' activities. It is considered that the learners' activities, during which they construct meaning of the situation and establish links between the two worlds and/or between semiotic registers, allows them to acquire physics knowledge. It implies that the learner interacts with his/her environment which includes all the human and material resources in the situation.

The concept of *devolution* helps to specify the relationship between the teacher and the students (Brousseau, 1998): "Devolution is the act by which the teacher makes the student take responsibility for a learning situation or problem, and accepts the consequences of this transfer him/herself ". (p. 303).[2] This concept is associated to another concept, the *didactical contract* (Balacheff, and al., 1997) : The devolution is associated to the concept of *didactical contract* which consists of the "rules of the game" and of the management of the teaching situation. " The teacher must therefore arrange not the communication of knowledge, but the devolution of a good problem. If the devolution takes place, the students enter into the game and if they win learning occurs. But what if a student refuses or avoid the problem, or doesn't solve it ? The teacher then has the social obligation to help her [...]. Then a relationship is formed which determines -explicitly to some extent, but mainly implicitly- what each partner, the teacher and the student, will have the responsibility for managing and, in some way or other, be responsible to the other person for. This system of reciprocal obligation resembles a contract." (p. 31). We call it didactical contract. The consequence is rather often that, rather than addressing learning situations or problems in terms of the *underlying concepts*, students address them in terms of *what they think that the teacher will expect them to do*.

## THE DESIGN OF THREE TYPES OF TEACHING SITUATIONS

To design relevant teaching situations, the knowledge to be taught, and the sequence in which this knowledge is introduced, has to be made explicit. When working from the perspective of modelling, involving the two worlds, curriculum designers are faced with the task of selecting a set of material situations coherent with the theory/model, which itself has to be specified. Given this coherence, the theory/model should lead the students or the teachers to interpret and/or predict events that are relevant to the learning goals, and, furthermore, this relevance should be taught explicitly. This design is also guided by the students' prior knowledge; both the material situations and the theory/model should be "learnable" in the duration of the sequence[3]. Finally, the learning hypotheses on the role of activities leads to the choice of resources which bring the students to take responsibility for constructing an understanding of the knowledge.

[2] "La dévolution est l'acte par lequel l'enseignant fait accepter à l'élève la responsabilité d'une situation d'apprentissage (adidactique) ou d'un problème et accepte lui-même les conséquences de ce transfert (p. 303)."
[3] We do not discuss the aspect of teaching duration in this chapter even if we acknowledge its crucial role.

In France, such situations were rested at the upper secondary school level (age 15 - 17) in physics. They were designed within a group which included teachers and researchers. The organization of this type of work is rather similar to that done in the Children's Learing in Science Project (CLISP) (Scott and Driver 1998). Over a period of three years, a group of fifteen teachers and three researchers worked together designing teaching sequences, the teachers using these sequences, the researchers observing in the classroom and on videotape in the case of one or two groups of students.

The situations that were studied are research products, and as such they need to be validated (Artigues, 1990). This chapter only deals with a type of validation consisting of a comparison between students' actual activities during the session, and what was intended in the design. For this purpose, data needed to be collected throughout the teaching situations. Accordingly, at least two pairs of students were videotaped throughout the teaching situation.. A case study methodology was used. The students' verbalizations were transcribed in their entirety, and notes were made of the students' gestures as relevant to the experiment.

The three cases presented below correspond to teaching situations included in two different parts of the curriculum[4]. The first one is part of a sequence for students in the first year of higher secondary school (age 15-16)[5], addressing the topic "sound". The two other teaching situations are part of a sequence of the official curriculum of the second year addressing energy, thought this is only studied by students who chose the scientific orientation[6]. In this part, the sequences themselves are presented before an account of the design of the situations[7].

### Choosing the knowledge to be taught in the teaching sequences

The first teaching sequence deals with sound. In physics, sound is associated with waves, and their propagation. The students at this level do not have any knowledge about waves. Their prior knowledge of sound comes almost exclusively from everyday knowledge where sound is strongly related to sense perception (Vince, 1999). Consequently, it was decided to start from this type of knowledge and to design settings helping students to acquire several levels of modelling. The first one is a model which can be directly related to events perceived by hearing: the sound chain. This chain gives three categories to

[4] At this level of education, the current underlying goal of the official French curriculum is to improve students' understanding of the material world in terms of physics knowledge [next year the official curriculum will be different and it seems that the underlying goal will be the understanding of how physics functions.]

[5] This year is called "indifférenciée" which means that all students have the same programme.

[6] The French educational system is strongly different from most of the Anglo-Saxon ones in the sense that students have to choose *a set* of disciplines rather than individual disciplines. For example, physics programmes for students in the human sciences orientation are different from those in experimental sciences and mathematics orientation.

[7] The design is also strongly constrain by the organization and the resources of the schools; in the cases presented below the design is supposed to respect these constraints. This aspect will not be discussed here, even though it has a crucial influence.

interpret the material situations: source; medium of propagation; and receptor of sound. The second model includes the vibration, its frequency and its amplitude, its displacement and its velocity. Vibration is directly related to movements (back and forth motion of a vibration, and displacement of a vibration in a medium). This last model is then developed with the concepts associated to waves including a particular model of matter.

This analysis leads to a teaching sequence in three parts: (1) emission, propagation and reception of sound; (2) sound waves and their propagation; (3) musical acoustics. The first part aims at helping students to develop and relate the two phenomenologies, corresponding respectively to classes of sound events perceived by hearing and to classes of mechanics events which can be perceived by touching or seeing. The students should be able to differentiate high - and low - pitched sounds and sounds of different volumes (loud, soft), and relate these to the frequency and amplitude of vibrations.

This first part of the teaching sequence might appear pointless for students at this relatively high level of teaching, since they might already be expected to know and relate these two types of phenomena. However, research studies showed that it is not the case for sound (and may not be so for other aspects of physics). As a matter of fact, even if students are familiar with a domain, they may still remain unaware that the studied phenomena are a class of events explained by given theory/model. The familiarity of the situations can prevent the students from selecting the right events. The modelling approach guides the designer in making explicit some necessary aspects of knowledge to understand physics; these aspects may be obvious and implicit to the expert and unknown to the students. This is why the design of the first situation of this part is presented in this chapter. It illustrates what we term as "constructing a phenomenology".

The two other teaching situations are included in a sequence on energy. The part of the material world chosen as the object of study for students may draw upon either everyday social life (energy is what we pay for, what makes technical systems from toys to satellites work), or upon physics teaching traditions (i.e. mechanics and thermodynamics). Neither the selected part of the material world nor the corresponding theory/model are inevitable choices.

The first step of the teaching sequence took energy in everyday life as its referent, in accordance with the official curriculum. In several other curricula where this choice is made, the place of physics theory within the teaching is not very well specified; the word ‘energy’ has multiple meanings before the introduction of physical quantities and measurements. In the framework of the modelling approach, it was decided to propose a seed of theory/model as a part of the knowledge to be taught, this theory/model being understandable by the students and useful to interpret such a variety of material situations with the support of a symbolic representation (the energy chain). The design of the corresponding teaching situations illustrates the second case, which we term "constructing meaning for a qualitative theory". In the second step of the sequence, the aim is to differentiate energy from power in introducing a quantitative aspect of energy, its relation with power as a flow of energy per unit time. This corresponds to the third case, which we term "constructing a new concept by differentiation and by relationships within a theoretical network". The following steps develop quantitative relations between energy and mechanical, electrical and calorimetric physics quantities.

**Case 1: constructing a phenomenology**

In the situation illustrating this case, the students are already aware of the concept of a sound chain. In a prior session they had to interpret a variety of situations in terms of an emitter, medium of propagation, or receptor. Such a categorisation is a basic theoretical aspect since it implies a way of dividing up the world (Levy-Strauss, 1962). The first situation of the introductory practical session of the sequence on sound is presented here.

***Knowledge to be involved in the situation***

The aim is to help learners to go from "sense perception observation to theory-driven observation" (Duschl, this book) that is to transform their sense perception into "thinking" objects and made them explicit by way of debating, writing texts and possibly drawings.

The students' activities should lead them to constructing the idea that vibration is a common behaviour of all emitters. As it is shown in figure 3, the knowledge involved is physics knowledge, everyday knowledge, the overlap between them, and several links inside and between worlds.

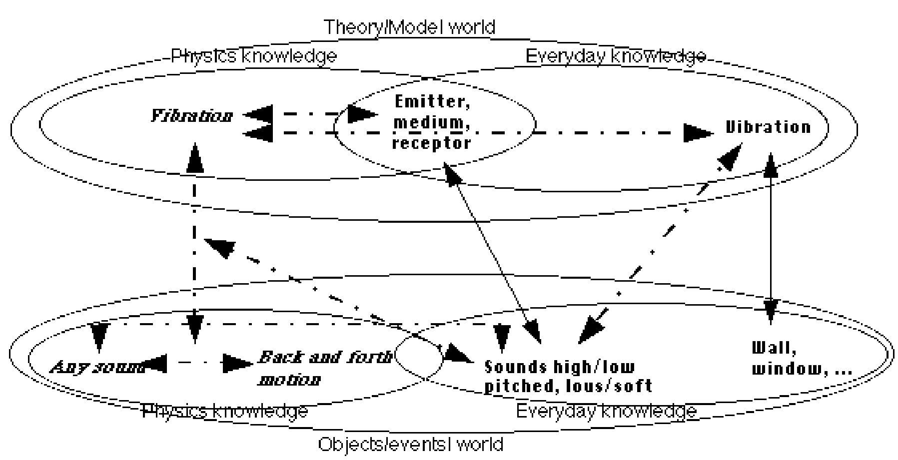



Figure 3: Knowledge to be constructed, and students' prior knowledge
In italics and broken lines: what students have to construct

In bold and continuous lines: prior knowledge

### *Characteristics of the design*

The knowledge to be constructed, together with the learning hypotheses, suggest that students should be given the opportunity to develop their sense perception corresponding both to sound and to back and forth motion. The students therefore have to hear, to see *and to touch* objects producing sound.

The specification of the teaching situation is not detailed here (see Barde, 1998 and SOC, 1999), only the main characteristics are presented. The main resource of the situation consists of a variety of objects (tuning fork, tambourine, low frequency generator with loudspeaker, cigarette paper to whistling sound and a pendulum which can move when the light pendulum bob touches the tambourine) with which the students can create events such as sound and observable movements of vibration. These objects are available for each group of students (they are handed from one group to another if necessary). The students are allowed and *advised* to touch the membrane of the loudspeaker and of course the other objects. The associated resources are:

- the same written question for each object: "Name the source of sound, and explain the behaviour of the source, possibly with a schema sketch for each experiment".
- a written question aiming to elicit the common characteristics of the perceived events: "Is there any common behaviour among all these sources of sound?"
-

The organization of the situation is very common. The students work in groups of two, they have to write a report (answers to the questions). The teacher manages the groups, gives help when a group asks for it and regularly invites the students to make explicit *what is for them* the behaviour of the source. This invitation can modify the type of didactical contract if necessary: the students give to themselves permission to write what they think and they know that there is not a single right answer.

### *Students' activities*

Two main features of these activities in relation to the design are presented (for an extensive analysis, see Barde, 1998).

• The videotapes and direct observations in classrooms show that verbalisation takes place, but it is not straightforward, as the dialogue (turns n° 194, 198) in table 1 shows. This is because students need to ask themselves about how the membrane moves, and the distinction between the air, the membrane movement, and the sound.

• The frequent touching of objects which emit sound, and in particular the membrane of the loud speaker at different frequencies of the LFG, in spite of the fact that the designers did not plan this high number of actions of touching and hearing. Let us note that even in the next two practical sessions, the students still touch sound sources when they are not specifically requested to do so. This result supports the hypothesis that the actions on objects involving sense perception, and the associated mental activities, are intrinsically linked. Table 1 illustrates this simultaneity.

| *Min* | *N°* | *Stud* | *Gestures* | *Dialogue* |
|---|---|---|---|---|
| 23 | 194 | Ni | touching the loud-speaker membrane | [...] it it it it moves it makes/ how can we say that/that that the air it does not it does not move (laugh) it does not move |
| | | | | |
| 24 | 198 | Ni | touches the loud speaker membrane | this this/ you know you have the air it passes/ therefore it is according to the sound which passes the/ there it is regular but you put the sound with low pitched sound and the high pitched sound and all the sound does not move the same it propagates differently the air / the sound it is a propagation of the air |
| 24 | 199 | Cr | | yes but what makes the noise it is when the membrane it moves |
| | | | | |
| 28 | 257 | | hitting the tambourine | it always is the membrane |
| | | | | |
| 32 | 319 | Ni | hits the tuning fork | the source of sound is the vibration of the tuning fork because when we hit it it vibrates but we do not see it but |
| | | | | |
| 32 | 328 | Ni | he holds the pendulum bob against the tuning fork | huh, yes because it vibrates it is logical |
| | | | | |
| 33 | 331 | Cr | | yes so in fact it always is the vibration roughly |

Table 1: Extract of transcription of a group of two students. Min: is the time (0 at the beginning of the teaching situation, including the teacher's introduction), N° is the number of dialogue turn, Stu means the student.

The analysis of the whole session shows that there are more relations between sound and movement made by students than any other type of relation (Barde, 1998). Thus for this group of students the design of the situation is validated, in that the students made the intended links between sound production and movement of the source. However, it appeared that some other students "do not play the game completely" - that is they do not take time to debate and write full sentences from their sense perceptions. One reason might be that the students are not interested, another is that they do not consider themselves to be allowed to make explicit their own thinking with their own words, and all the more so because of the problems that they experience in verbalising their ideas.

In conclusion, when students “play the game”, the designed resources result in students mobilising the relevant prior knowledge and elaborating different kinds of relevant links (figure 3). This result leads to the hypothesis that when the knowledge to be taught involves constructing phenomena, a major role of the teaching resources is to allow students to use sensory perception, frequently, and with the possibility of simultaneous verbalization.

### Case 2: Construction of a meaning for a qualitative theory

This case invovlves a type of situation in which a part of the knowledge to be taught is reconstructed for didactical reasons (termed "the seed of a theory/model"). Such an elaboration of the knowledge to be taught seems to be fruitful both as a tool which is "learnable" for the majority of students, and as a tool which can be used by them to understand the material world in a wide variety of situations. Furthermore, the tool offers common support for all the students in a classroom.
The situation presented here is the first practical session on energy following a teaching session aiming at creating a need for an energy theory/model (Tiberghien, 1996).

#### *Knowledge to be involved in the teaching situation*

The aim of this situation is to develop an understanding of a "seed" of a physics theory/model - that is, something from which further understanding can grow) - introduced through a text (see table 2). This text imposes a categorization of the world into three parts: reservoirs, transformers and transfers, and proposed a symbolic representation for this categorization.

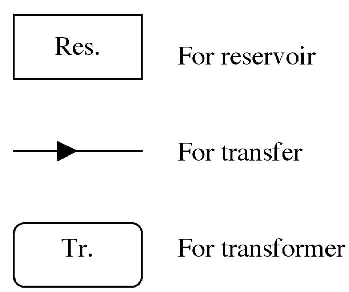
| **Theory (seed)** | **Model (seed)** |
|---|---|
| Energy can be characterized by<br>* its properties<br>- Storage<br>- Transformation<br>- Transfer<br>- by work: mechanical or electrical,<br>- by heat,<br>- by radiation<br><br>* a fundamental principel of conservation<br>The energy is conserved whatever the transformations, transfer and forms of storage | <br><br><br>* Under the constraints :<br>- a complete enrgy chain stars and ends with a reservoir;<br>- the initial reservoi is different from the final reservoir. |

Table 2. A simplified version of the seed of the theory/model. The left part presents the conceptual definitions for the target domain. The right part provides the symbols with which to draw the energy chain.

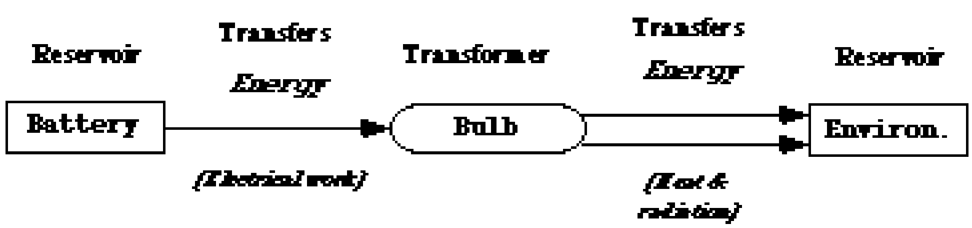


Figure 4 : The energy chain for battery-bulb experiment

Three experiments were designed. The choice of the first one, a battery and a bulb, is based on the results of studies of students' conceptions showing that the idea of battery as a reservoir of energy is close to the students' prior knowledge. The second one (an object hanging by a string attached to the axel of a generator connected to a bulb: when the object falls the bulb lights), and the third (a battery connected to a motor - the same object as the generator - an object hanging by a string attached to the axel of the motor rises up), involve events in mechanics, electricity and light.

The students' activities, when they elaborate the energy chain, should let them construct relations between elements of the theory/model and elements of the experiments (see figure 4, an example of a chain). The overlapping between everyday knowledge and physics knowledge should largely be involved in this session.

### *Characteristics of the design*

The main resources available in the situation are the text and the experiments. The students have to construct a symbolic representation which constrains the specification of elements of the experiments which are taken into account, and which corresponds to a different semiotic register from those of the resources (natural language for the text, and material objects for the experiments) (see Tiberghien, 1996 for detailed presentation).

The students carry out three successive tasks to construct the chains (each experiment is given after the drawing of the previous chain). After the first chain ("battery-bulb"), the teacher hands out a sheet showing the correct chain to the students without comment. During this session, the teacher only manages the different groups. This is because the students need time to think by themselves without having to understand further information from the teacher.  During the next teaching session the teacher takes the initiative to discuss and to state the relevant interpretations of these experiments.

### *Students' activities*

A series of research studies were conducted (reported in Tiberghien and Megalakaki, 1995). They show that students establish three types of relations between the worlds and that the number of complex relations and of intermediary interpretations (presented below) increases between the first and the second tasks whereas the number of simple ones decreases.

• In a simple relation, an element of one world is directly associated with an element of the other world. For example [F-L (batt-bulb, 22)] "the reservoir stores the energy / thus it is the battery / in the battery there is energy / OK?"   (see figure 5).

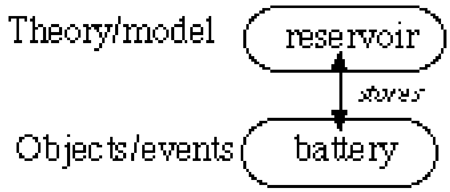



Figure 5 Example of a simple relationship between the two worlds

• There is a complex relation when{several elements or relations between elements} of one world are associated with one element or several elements or a relation between elements of the other world (see figure 6). For example*:*

P-F (object falling 124 - 126):

P : *I would have thought that the reservoir / that would be the motor plus object together and*

F : *why the motor plus object* (?)

P: *the motor plus object that makes the motor run, and after we would put the bulb/ and after we would put the environment*

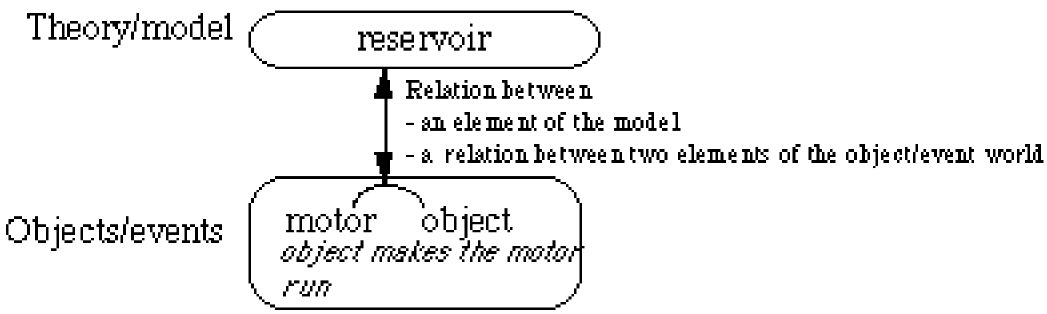



Figure 6 Example of a complex relationship between the two worlds

• The intermediary is more an interpretation than a relationship, because the elements of the two worlds are considered at a same level. For example :

F - L (object falling 168 - 169)

L : *which (energy) goes through the motor / which goes through the bulb?*

F :*The object produces the energy /OK (?) The object /it falls and that produces the energy which goes through the motor which arrives to the bulb / and the bulb shines / do you get it* (?).

The use of both everyday knowledge and physics knowledge can get in the way of devolution. If the didactical contract is such that the students consider that only the taught knowledge (that given in the text and that already taught on electricity) has to be used, they cannot construct meaningful relationships between the two worlds. The teacher's role to establish such a contract is crucial.

These results emphasise three significant characteristics of the design. First, students collect data in the form of experience of the material world. This is recorded in natural language (in the world of objects/events). Second, the same experience is recorded in terms of the taught model in symbolic language (in the world of theory/model). Third, presenting students with an explicit theory/model, even if in the form of a ‘seed’, introduces an aspect of the status of scientific knowledge. The sequence of the three tasks seems necessary to make the students construct complex links between the world of objects/events, and the world of theory/model.

### Case 3: constructing a new concept by differentiation and relations

This case is typical of much practical work in physics teaching in the upper secondary school (Millar *et al.* submitted, Tiberghien *et al.* submitted). This situation follows the session presented in case 2. A detailed analysis of this situation has been done by K. Bécu-Robinault (1997a,b).

#### *Knowledge involved in the situation*

This situation aims to help students to construct a quantitative aspect of energy, integrating it in a relational network involving energy, power, time with power in relation to voltage and current. This requires a differentiation between energy and power, power being the "flow" of energy. This relational network is associated to several semiotic registers: series of numbers, functional relations with the rules of algebra, symbolic representation of the energy chain, and natural language. This "density" of theory, which is a characteristic of physics, is introduced through this situation. The students are expected to know the properties of energy and the energy chain. They are also expected to know, from everyday life, of the existence of apparatus for measuring energy consumption, which has to be paid for.

This situation involves constructing an understanding of power, which is complex in the sense that this physical quantity is not associated with a direct observable in the experiment. Only the relation between power, energy and time allows for the prediction of events. Thus, several steps are necessary to “stage" this knowledge.

#### *Characteristics of the design*

This situation is broken down into five parts: (1) handling and measurement, (2) data processing of two series of measurement (E, t) to find a mathematical relation, (3) assigning a name to the constant coefficient between E and t, (4) inserting power into a symbolic representation, (5) modifying the value of power by modifying the experiment.

This design differs in one sense from the previous ones, and from much practical work at this teaching level and at the university level. The resources initially provided (an experiment, with associated instructions and questions) lead the students to construct other resources such as the measurements and the data table. In this case, the students' responsibility for elaborating these resources should be carefully taken into account. If the teachers want all students to work on correct data, the guidance that is provided may be in the form of " recipes" to avoid errors. Then, in order that the students have the opportunity to be responsible for constructing their knowledge, the questions should fit with students' capabilities. Another reason to design carefully the questions associated with the resources, as has been shown (Bécu-Robinault, 1998, Sander et al. 1998, Hucke et Fisher, 1998), is that the students' activities involve only the aspects of the world which are specified in the question, and no more.

***Students' activities***

Only one important aspect is mentioned. A new type of relationship between the two worlds has to be constructed by the students: the condition of validity of a model or, more specifically in this case, of a relation between physical quantities. The example presented in figure 7 takes place during part 3 when the students have to assign a name to the constant coefficient between energy and time (from a series of measurements).
(P and M: students, dialogue turns : 497 - 505)
P: it is an average value ... which results from the division ...of the value in Joules of the energy by the time in seconds ... it is constant
M : it is a constant it is a constant value
P: ... it is a constant value all along the practical work.

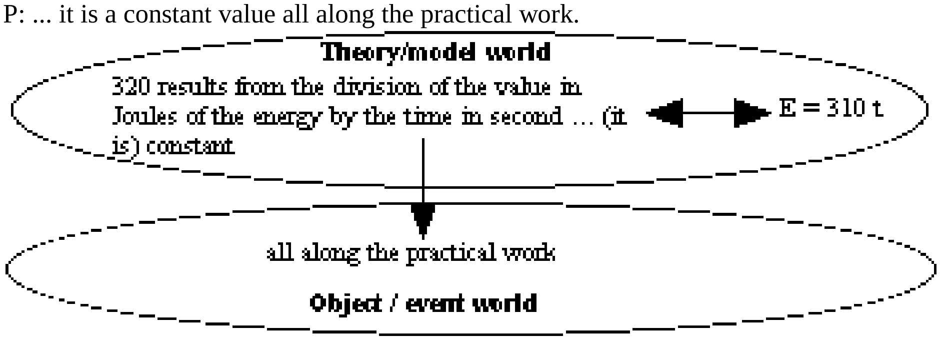



Figure 7: Extract of dialogue and its analysis with the two worlds

**Discussion on the three cases**

At a large granularity of analysis, the three situations are similar. All three take place during practical work in physics teaching, the organization of the class is in small groups (mainly pairs of students), and the teacher goes from one group to another. In each case, students have a sheet and they have to manipulate an experiment and to write in an exercise book.
However at a *fine granularity of analysis of knowledge* (Minstrell, 1992), major differences appear as is shown in table 3.

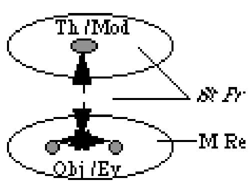
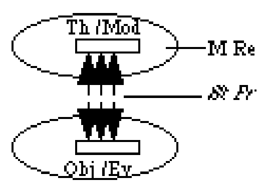
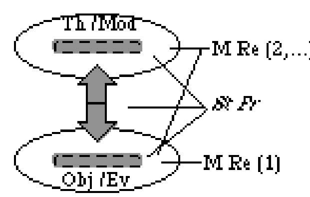
| | **Case 1: constructing a phenomenology** | **Case 2: constructing meaning for a qualitative seed of theory** | **Case 3 specifying a physical quantity and relating it to others** |
|---|---|---|---|
| Main Resources | *Material objects* which make sound, and which it is possible to touch.<br>Two short questions | A *text* giving a theory/ model Three experiments to see and touch | • An *experimental device with measurement apparatus*<br>• Technical information on setting the apparatus and reading and writing measurements<br>• A series of questions which supposes students' elaboration of resources |
| Students' activity | Transforming sense perception into concepts | Establishing links between conceptual information and the experiments | Building the relations between concepts and construct a conceptual network<br>Establishing relations between the conceptual network and the experiment |
| Intended learning | New concept of vibration which allows relations to be established between different types of objets/events (back and forth motion and sound) | Specification of the concept of energy. Elaboration of links between theory/model and objects/events. | Elaboration of the relationship : $E = P\ t$<br>Relations are made between the conceptual networks themselves, rather than individual elements in each network. |
| Worlds and their links involved in the designed situations |  |  |  |

Table 3: Specific characteristics of the three cases of teaching situations

M Re: Main resources of the situation
St Pr: Students’ productions
Arrows show the links which should be inovled in the students' activites
Th/mod : The world of theory/model; Obj/Ev: The world of objects/events

In conclusion, the analysis of knowledge in terms of modelling and of semiotic registers is a guide to designing teaching situations which actually allow the students to deal with and construct the target knowledge. This kind of research should lead to the design of teaching tools for teachers in order to help them to carry out teaching situations which are more fruitful for their students' learning.

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