KNOWLEDGE CONSTRUCTION IN PHYSICS

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For several years now, I have been observing *Natural Science* students. I noticed that their attitudes often reveal that they perceive the physics program to be a required transition to their "real training", the one they will receive in university. Others show a low evel of interest which sometimes steers them away from careers in science. They will sometimes say that they really did not like science anyway. But the question arises: have they ever really done science?

For most students, to really get into science, the teacher must create learning situations that allow them to construct their own representations of the concepts involved. However, this construction must be done in circumstances that mimic the construction of scientific knowledge. In other words, students must build their knowledge using a scientific approach; they must therefore learn how to learn.

I decided to explore an alternate route. For the past two years, I have experimented with the project method in the *Electricity and Magnetism* course[1]. This method requires students to approach science by having them construct physics-related concepts through the carrying out of a project which consists of a problem situation. However, this approach raises didactic and pedagogical questions.

From a didactic perspective, the project approach presents challenges when it comes to the choice and organization of curricular content. In fact, in a constructivist approach, concepts in physics are no longer to be presented according to the traditional organization found in instructional manuals but rather according to the requirements of the project.

Also, the project method generates in-depth reflection on the criteria used to justify the very choice of learning situations. These criteria must relate to the construction and mobilization of knowledge, in the way that is advocated in the competency-based approach. In pedagogical terms, the project method calls into question the traditional role of the teacher in the classroom by requiring that the students' conceptual frameworks be taken into account to ensure that their learning will be meaningful and long-lasting.

In this article, I will begin by describing the various situations that enable students to construct their own scientific knowledge. I will also outline the process of constructing knowledge that corresponds to the essential attitude students are expected to develop. Next, I will describe a five-step planning process in keeping with constructivist principles, while illustrating its application in the *Electricity and Magnetism* course. To conclude I will identify some of the significant implications of this process for teaching.

PROBLEM SITUATIONS IN SCIENCE

Choosing problem situations in science is a challenge because they must address general goals and promote transdisciplinarity in order to be as complete as possible. It is however possible to identify problem situations that meet these requirements with the help of technoscience. According to Jacques Desautels:

> […] problem situations in technoscience are components of social problems for which the solutions depend on the commitment of its citizens vis-à-vis the controversies they give rise to or create. (1999, p. 5)

The majority of techno-scientific problem situations are transdisciplinary. They are also in keeping with several general program objectives of the *Natural Science* program such as, *To establish connections between science, technology and the evolution of society* and *To establish one's own value system.*

Moreover, the complexity of techno-scientific problem situations allows for the development in students of two general program competencies (ministère de l'Éducation, 1998, p. 74, p. 77). These two competencies are also found in the general program objectives, and this duplication leads us to believe they are of particular importance to the program.

1 One of three required courses in physics within the pre-university *Natural Science* program.

2 Technoscience: Notion in which institutions, researchers and engineers cooperate together, so as to implement precise applications of scientific and technical resources.

1. *To deal with one or more subjects within the framework of the natural sciences on the basis of ones prior knowledge:* this competency refers to the process of live knowledge construction in actual situations. In other words, students learn how to resolve problem situations while at the same time constructing their own knowledge;
2. *To apply a scientific approach in a field specific to the natural sciences:* this competency refers to the process of knowledge construction specific to each discipline. It corresponds to the essential attitude which will be discussed later on.

THE PROCESS OF CONSTRUCTING KNOWLEDGE AND THE ESSENTIAL ATTITUDE[3]

How do we construct knowledge in any given discipline? To do physics is not to do biology and it is certainly not to do chemistry! Each discipline tackles problems in its own way. The process used to construct knowledge in a discipline corresponds to its **essential attitude**. Being trained in physics, I had an inkling of what the essential attitude of the physicist was, because it corresponds to that which I had achieved when working towards my master's degree in physics. During their studies, candidates in a master's or doctorate program must construct their knowledge. Indeed, it is often during graduate and postgraduate studies that the essential attitude is manifested in a more explicit manner.

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THE PHYSICIST AS AN EXAMPLE

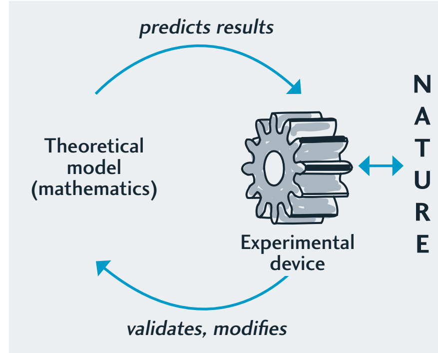
Philippe offers the following description of the essential attitude of a physicist: *For an object to attract the interest of a physicist, it must be able to be grasped through the very strict requirements of an experimental device on the one hand, and a mathematical model on the other.* (2004, p. 34)

So, faced with a phenomenon or a problem, the physicist will try to create a mathematical model in order to explain it and also to make predictions. The experimental device will then serve to establish and validate the model by establishing the laws necessary to describe the phenomenon or to solve the problem. This mathematical model will be evaluated by comparing it to experimental results.Thus, the model gives is a better grasp of nature and this allows us to further improve the model. It is this reciprocal relationship between the model and nature by means of the experimental device that allows for the evolution and, consequently the construction, of knowledge in physics. The following figure illustrates the essential attitude of the physicist.

[3] This very important concept was put forth and elucidated by Lise Lapierre within the framework of the course *Rapports aux savoirs et contenus à enseigner* (DID-868) offered through PERFORMA.

Figure 1

DIAGRAM OF THE ESSENTIAL ATTITUDE OF THE PHYSICIST



The essential attitude impacts the way we approach concepts. The choice of problem situation therefore, must not only allow the students to learn the concepts but also to grasp the essential attitude. By focusing on the process of constructing knowledge in a discipline, we can then better define the situations that support this construction.

KNOWLEDGE CONSTRUCTION WITHIN A COURSE

The process of knowledge construction described below is based on a frame of reference developed by Jonnaert and Vander Borght (1999) and on work carried out by André Giordan and Gérard De Vecchi (2002). This five-step process deals with the didactic relationship (that relates to choice of content and situations in which the content will be learned) and the learning relationship (that deals with students' diverse concepts rendered explicit in the form of formulation patterns). The resulting action plan allows the teacher to intervene effectively at various stages throughout the course.



Step 1:
Identify concepts and content

In *Natural Science*, several competencies in the program of studies include a rubric called precisions that lists the concepts the students are to learn. This rubric is fairly general and allows for some latitude in the choice and treatment of concepts. This is how learning situations can be selected and it is up to local program teams to establish their priorities and to define their orientation.

Step 2:
Establish one or more situations

This stage consists in identifying problem situations that will enable students to construct course-related knowledge. More than one situation may be necessary to "cover" the essential course content in its entirety. Such situations must call the students to action in some form of investigation, using a problem-solving approach or based on a scientific process; in short, these situations must cultivate the essential attitude.

To be authentic, meaningful as well as complete, learning situations must meet specific criteria:

- It must not be possible for students to solve the problem or bring the project to a successful conclusion based on their prior knowledge, that is, without the construction of knowledge specific to the course. The situations must therefore constitute a challenge.
- Learning situations must be techno-scientific, that is, they must focus on problematic aspects and involve the engagement of the student as a citizen.
- They must require the expression of the essential attitude of the discipline.
- They must take into account the general objectives of the program.
- As much as possible, they must call into play the prior knowledge constructed in other courses of the same discipline or better yet, of other disciplines. In short, the situation must support transdisciplinarity and the transfer of learning.

Example of a choice in the course *Electricity and Magnetism*

The project I selected was to have the students build a mini wind turbine capable of providing electricity to a 1.5 volt rechargeable battery. Faced with this challenge and some material constraints, students must use a problem-solving approach in order to create a prototype. During this process, they must collect the data, analyze the problem beginning with the concepts in question, develop a prototype, establish a mathematical model that will predict the performance of the prototype, apply this solution and then validate it using instruments of measurement. At the end of the process, they must critique their mathematical model, present the results of their project and evaluate it. This project calls into play the five criteria mentioned above and includes certain conditions. An analysis of each criterion is presented in Table 1.

Table 1

CRITERIA FOR THE CHOICE OF A SITUATION IN *NATURAL SCIENCE*

CRITERIA	JUSTIFICATIONS AND CONDITIONS
1. It must be a challenge	The students would undoubtedly be able to build a mini wind turbine without the help of the course. However, the 1.5 Volt requirement means that students must take into account several concepts and principles that they do not yet know at the beginning of the course.
2. The project must be techno-scientific	All sources of energy, even those labelled "green", have advantages, disadvantages and limitations. We have only to read the newspapers! Opting for wind-powered energy and the establishment of wind turbine parks in certain Quebec cities is causing concern in smaller municipalities. Therefore, students are called upon to take a position in this matter.
3. It must allow for the expression of the essential attitude	The realization of the project must emphasize the process used for it is this process that will enable the students to develop the essential attitude. The teacher must therefore require that the students develop a model and validate it through the use of an experimental device.
4. It must take into account the general objectives of the program	The project involves teamwork, a scientific approach, problem resolution, the presentation of results and the adoption of useful scientific work attitudes (the use of a laboratory notebook, for example). On another level, the project consists *in handling a new situation using one's prior knowledge*, which is also one of the general objectives of the program.
5. It must integrate knowledge from other courses in the program	The nature of the project makes it easy to integrate knowledge from the mechanics course. Added to this are links to the chemistry course (rechargeable battery). And a debate on the establishment of wind turbine parks can even bring knowledge from general education courses into play.

4 A prerequisite for the *Electricity and Magnetism* course.

If several situations are needed to cover the entire course content, it is not necessary for each one to adhere to all five criteria; rather it is the project as a whole that should encompass them all.

Step 3:
Make the problem-solving process explicit

At this stage, the teacher describes the problem-solving process that students should follow use. Students may not always follow the process in linear fashion. Some backpedalling may occur during the session.

The example of the *Electricity and Magnetism* course

Table 2 documents the key stages of the project and the resolution steps the students must carry out during Phase IV, as well as the concepts associated with this stage.

Table 2

STAGES OF THE PROJECT
(Phase IV: Description of The design of an alternator)

STAGES	CONCEPTS	
Phase I	Data collection	...
Phase II	Work management	...
Phase III	Design of the blades and the base	...
Phase IV	Design of the alternator 1. Choose the configuration for the rotor and stator 2. Choose the materials: a. type of magnet b. size of coils c. diameter of wires d. number of rotations of the wire, etc. 3. Predict the performance of the alternator using a mathematical model 4. Adjust the choice of parameters according to the results of the mathematical model	• Magnetic field • Magnetic induction • Magnetic flux • Magnet motor force • Reluctance • Faraday's Law o Electromotive force o Electrical resistance • Lengthr • Surface section • Resistivity • Magnetic circuit • Counterelectromotive force • Single-phase current • Three-phase current
Phase V	Design of the rechargeable battery circuit	...
Phase VI	Application of the adopted solution	...
Phase VII	Validation of the solution	...
Phase VIII	Presentation of the results	...

The students should not be expected to carry out these stages intuitively. Rather, the teacher should guide them methodically throughout the process. This is part of what they have to learn.

Step 4:
Define a conceptual framework

Throughout the process described in the preceding stages, the students must construct their own representations of several concepts and phenomena. To this end the teacher can work out the sequence in which these concepts appear at each stage. This construction by the teacher must also show the connection between the various concepts.

This sequence is presented as a **conceptual framework** which is the result of an in-depth analysis of the subject matter taught.

In a conceptual framework:

> the components of the learning object are presented as statements (complete sentences) and are organized within a network. (Jonnaert and Vanderborght, 1999, p. 303)

Figure 2 (see page 23) introduces the conceptual framework of Phase IV *The design of the alternator*. Each box in this figure presents a concept formulated as a statement by the teacher.

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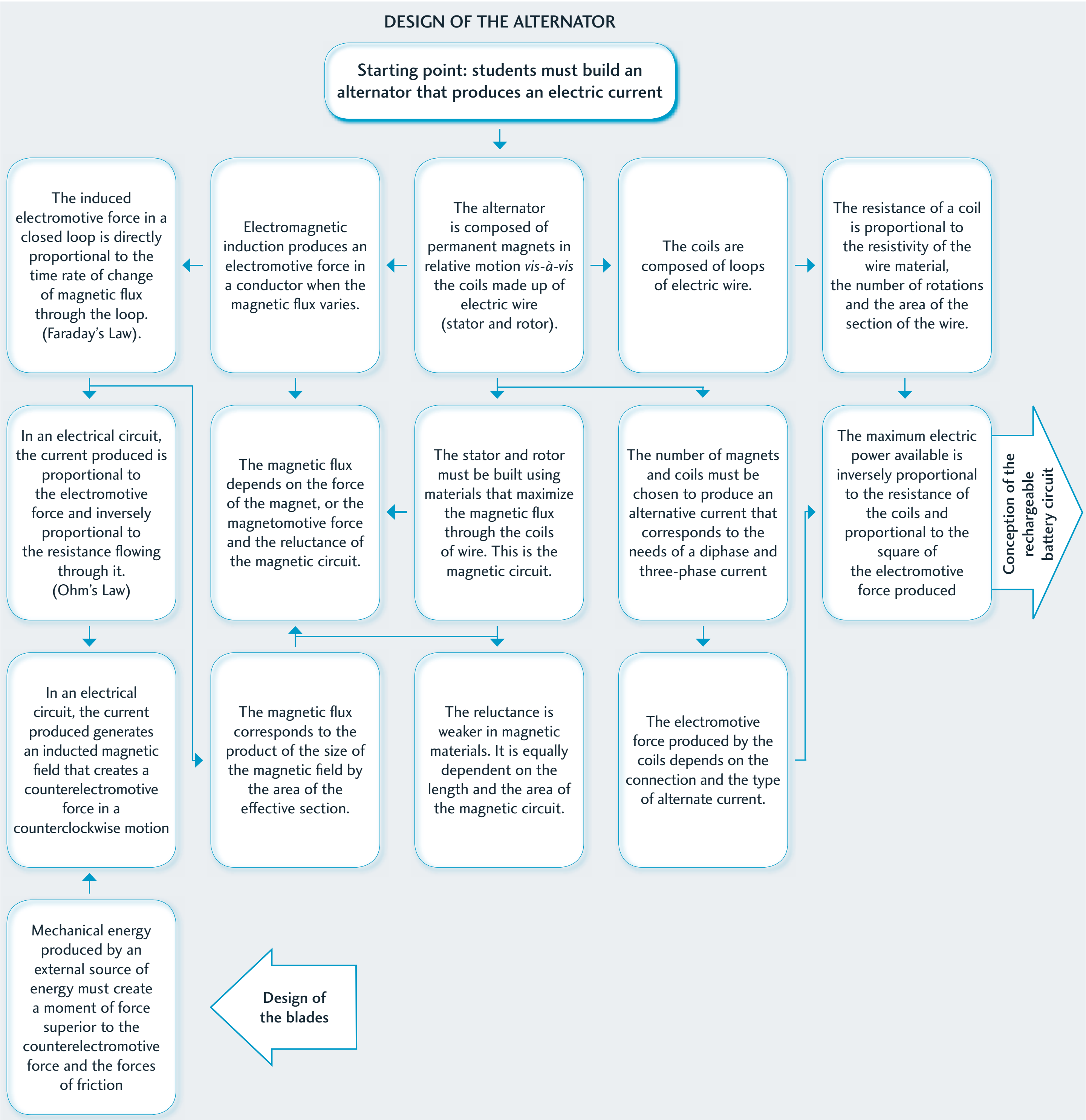
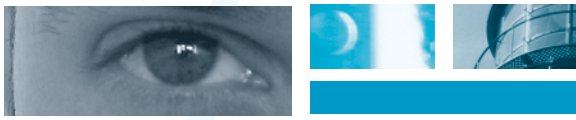
The framework thus introduces the statements, the connection between the statements and the link to other stages in the problem-solving process. It therefore makes it possible to highlight key concepts that must be exploited in the project. It also serves as "geographical map" or "blueprint" for the concepts.

Figure 2

CONCEPTUAL FRAMEWORK FOR THE DESIGN STAGE OF AN ALTERNATOR





Step 5:
Analyze students' concepts

Students use their prior knowledge to carry out the project. This prior knowledge consists of well-anchored concepts that have served the students well, at least up to the start of the course.

The teacher can formulate these concepts as statements called levels of formulation. According to De Vecchi and Giordan, a level of formulation means:

> a statement that corresponds to a specific threshold; a level of abstraction expressed through a global statement that the learner is expected to produce (and not simply recite by rote). (De Vecchi and Giordan, 2002, p. 201)

A level of formulation can also be considered to be a stage in the construction of a concept by the students. They are taught to modify their concepts through the resolution of a problem situation, that is, by moving from an ill-suited concept to one that is better adapted.

The statements appearing in the conceptual frameworks correspond to the targeted level of formulation at end of the course. However for each concept, the teacher must state the intermediary levels of formulation. Table 3 provides an example of this. I was inspired by Marcel Thouin (2001) in my description of the first level of formulation in the concept of the magnetic circuit; I then used my own experience to describe the second level; and the third level corresponds to the level targeted at end of course. For each level of formulation, a development mechanism is outlined and it shows how students will be able to construct the scientific concept.

Table 3

LEVELS OF FORMULATION RELATIVE TO MAGNETIC CIRCUITRY

LEVELS OF FORMULATION	DEVELOPMENT MECHANISMS
An obstacle made from a piece of cardboard and an obstacle made from a metal plate have the same influence on the behaviour of a magnet.	**Analogy with other phenomena: light, sound, etc.** The students believe that only the thickness of an obstacle influences the magnetic field.
Metal lets the magnetic field "pass through" more easily.	**Reference: one's experience.** One can see that a magnetic object stuck to a magnet becomes a magnet itself and attracts other magnetic objects.
Lines of magnetic fields are deviated by a magnetic object (ferromagnetic or paramagnetic) just as a conductor causes the deviation of lines in a magnetic field. The magnetic object can be considered to be a circuit (magnetic).	**Broadening of the concept.** Analogy between an electrical circuit that includes a battery (magnet) and a wire (magnetic object). Both systems show correspondence. The strength of the battery (electromotive force) corresponds to the strength of the magnet (magnetomotive force). The resistance of the wire corresponds to the reluctance of the magnetic object.

Students have an impressive number of differing concepts. Nevertheless, these concepts can be grouped together based on common features and we can also refer to the history of scientific concepts in order to categorize them. By reading books on the history of science, it is easy to locate old concepts that are still firmly anchored in today's students.

IMPLICATIONS FOR TEACHING

This process of knowledge construction gives rise to a certain number of important implications for teaching that I will only touch on briefly here. Having to choose a problem situation for purposes of constructing concepts alters the role of teachers in the classroom. From transmitters (of knowledge), they become mediators; that is to say, the ones who facilitate the students' construction of concepts used in the course.

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In addition, the organization of course content differs from that of course manuals because it is based on the demands of the problem situation. The use of a conceptual framework, therefore, allows for the establishment of a "blueprint" or a "geographical map" of the concepts. Thanks to this tool, teachers are able to monitor the students throughout their problem-solving process. In this way, they can foresee and adapt strategic interventions to the needs of the students and their concepts.

The description of levels of formulation is very useful for teachers because they can then develop strategies that help students face specific inconsistencies.

Only if this condition is respected, can students make modifications to their own concepts. Consequently, it becomes important to bring out these concepts by suggesting various activities where students can articulate their concepts. It then becomes possible to identify concepts in the classroom and to establish a strategy which is appropriate both for the group and for individual students. Becoming aware of the students' concepts leads teachers to be more vigilant relative to their problem-solving approaches and also to their conceptual learning processes.

CONCLUSION

Experimenting with the project approach in one of my courses led me to raise questions about the choice and organization of curricular content to teach, about the choice of learning situations and about the role of the teacher. My research has not yet led me to a completely satisfactory theoretical framework, one that can validate the various aspects of my practice in this field. Therefore, it remains for me to complete the construction of this didactic and pedagogical theoretical framework for application in the project approach.

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