INTEGRAL DESIGN OF A PHYSICS COURSE

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Abstract

This paper discusses the importance of one of the most crucial elements in science and technology education: the development of the individual capacity to cope with new problems. Also, discuss the importance of being aware of the existence of "formative objectives" and "tacit knowledge”. In the planning of a course, taking into account its aims, we need to define the explicit and implicit objectives of each topic covered. If we can find why and how the students are going to use that knowledge, and how we are going to evaluate the learning; then we can decide how, when and where see each topic; combining the theoretical and experimental resources in the best way. The problem-solving capabilities of the scientific method should be illustrated experimentally, using it to design our teaching procedures. The objectives of Physics courses are that the students learn how to use what they know to solve problems in the real world (competencies), but no one learns to do this seeing as the professor thinks on the blackboard. The program of a course uses topics as examples of reasoning. Reasoning involves the ability to use their knowledge. In writing the assessments before teaching the class, you will realize what you really want to teach. Using specialized questions can recreate the Socratic Method, which has evolved as constructivism and flipped class. How their new understanding is going to be used by the student gives an even better motivation. The best teaching tool that I know is the pleasure that comes with understanding, and what is learned with pleasure is not soon forgotten. Through experiments, demonstrations, and tips a professor can motivate learning and student competencies if one can find them.

Keywords: Physics teaching, reasoning, experiments, demonstrations.

INTRODUCTION

The definition of the objectives of science courses is part of a more general problem: the definition of the objectives of teaching in schools, colleges, and universities. These objectives are implicitly defined by that which the society is expecting from their citizens. Therefore, it is necessary to consider the situation of the country we are working in.

In the third-world countries, we prepare our technicians and engineers to consume the current technology, rather than to prepare them to develop new technologies. This is a mistake because any country needs to develop its own technology. Given the high rate of change of current technology, one of the most crucial elements in science and technology education should be the development of the individual capacity to cope with new problems. Therefore, we can define a graduate as a person capable of applying knowledge and methods in the solution of new problems. This is not a very complete definition because it does not include a description of the required skills. However, such a definition is sufficiently broad to be applied to most engineers, and scientists. It also implies the existence of a reasoning capacity for creating production procedures, designing apparatus or making contributions in pure or applied science.

Keeping in mind that we are forming professionals with the capability to solve problems, we find a very general procedure to motivate our students to learn how to apply what we are teaching correlating that knowledge with the kind of problems they are being trained to solve. According to a few students, the sense of achievement obtained after solving some problem encourages them to keep trying to learn more.

Development of a curriculum plan. In ideal conditions, the way of introducing future professionals into the problem-solving methodology, and into the necessary background of knowledge required to solve the problems, would be an interdisciplinary approach in teaching based on real problems. This approach would not divide the problems into arbitrary fashions like the courses of standard curriculum plans but would introduce a spiraling approach by starting from simple concepts and problems and then advancing into more complicated ones. However, even though this method would be an integrated approach, it presents an almost unsolvable problem: the need for teachers with a very broad experience in their professions. As we don't have them, we have developed curriculums with the desired knowledge distributed in different courses. Doing so, we lose the integration between them, but we gain in the availability of the experts as teachers. Unless we have provided some integrated courses or seminars along the way, we can only hope that after leaving the University with all the needed knowledge the student will be able to integrate it when he needs to do so in the professional practice. These integrated courses are the most difficult to teach and require very careful planning.

The Planning of a Course

The planning of a course for a well-developed curriculum needs not only the clear specification of its content but also the techniques and working methods that the student must acquire. In practice, it is very convenient to create tables in which each topic of the course content is related to working methods, and to the available resources and evaluations. Such tables should show clearly the informative as well as the formative objectives of the course.

Many curricula mention explicitly only the informative objectives; the formative ones only being mentioned as good wishes in the introductory paragraphs. And there is a very powerful reason to do that: it is very difficult to define operationally formative objectives. In the arts this is quite evident; we can teach a lot about the theory of painting, but the students themselves need to paint to learn to paint.

Similarly, we can speak of the teaching of physics, chemistry, biology as being both an art and a science. It is an Art (High et al., 1950), and everybody remembers the very few good teachers who introduced us to the pleasure of reasoning. They were really actors, and it is not easy to say why they were so good teachers. Tobin, Deacon, and Fraser (1989) have been trying to find what makes an outstanding teacher. However, even if we don't have the gift, if we enjoy our trade, learn the subject, and work hard to find the best way to communicate with the student, we may do a good job as teachers. Physics is a science, and we try to give to the students the best way to induce and deduce the relations hidden in the nature around us, without forgetting that "Doing science has many similarities with the realms of music, literature, and art- we should recognize that the practice of being a scientist is both an art and a craft" (Woolnough and Allsop, 1985).

The main formative objective can be stated as "teaching to reason", understanding "to reason" as all the mental procedures involved in the reasoning of some situation (Riveros, 2014). In analyzing some situation, we play between deductive and inductive thinking. To make deductions we need tools of algebra, derivatives, integrals, expansion in series, numerical computing, etc. To make inductions we need to know instruments, experimental techniques, graphs, data handling, statistics, etc. Even if those tools can be considered topics in other courses, here the most important point is why and how they are used to teach the topic. The topic is just a pretext to teach the reasoning involved. We are really introducing our students to The Art of Thinking.

Polanyi (1969) speaks of explicit knowledge and tacit knowledge; the explicit knowledge being articulated and cognitively assimilated into consciously formed theories, while the tacit knowledge is never consciously articulated. In solving a problem, to decide when to deduce or to induce is part of the tacit knowledge. It can be taught only by examples. As Medawar (1969) says "creativity cannot be learned perhaps, but it can certainly be encouraged and abetted". So, the best we can hope for is to create the optimum conditions so the students may think creatively. One of the best ways to do this is by asking them to solve some relevant problem as practical work.

When planning a course, the formative objectives are linked to the methods used, the decision of which one can be paired to some topic depends on the resources and the allotted time. The assessment techniques must stress the important points in the objectives to reinforce the learning procedure. Traditionally, most of the student's study to pass examinations, so they try to memorize the material covered instead of understanding it. Therefore, it is very important that the assessment covers both formative and informative objectives. Table 1 shows activities developed in the classroom and/or in the laboratory. This planning, of course, as presented in table 1, is a personal task and shows the creativity of the teacher, because he is the only one who knows the students' capabilities and the human and material resources available.

The addition of the methods column brings the tacit knowledge of the formative aims into the explicit realm, helping to clarify them. Also, we can call the topics column as the informative or immediate objectives, and the methods column as the formative or mediate objectives, emphasizing the long term of the results. Teachers have used many different teaching strategies, but it has been shown that in nearly a hundred studies, carried out and published over forty years, "that if the amount of learning is measured by final examinations, there are no measurable differences in effectiveness between different methods of college teaching" (Dubin and Taveggia, 1968).

Table 1*. The design of a course combines the allotted time for the topic, method, resources, and assessments*

Topic	**Time**	**Method**	**Resources**	**Assessments**
Chapter 1	N hours	Deductions	Lectures	Exams
Chapter 2		Induction	Discussions	Multiple choice
Newton		Derivatives	Seminars	Problems
Coulomb		Integrals	Demonstrations	Essays
Fourier		Series exp.	Experiences	Reports
Excel		Graphics	Exercises	Oral exams
		Num. solutions.	Internet	Data

The different methods include lectures, recitations, tutorials, discussions, supervised or unsupervised independent study, and some combination of them (Bauman, 1974), including the flipped class. Friedman et al. (1976), however, states that there is an improvement in the final scores if the teacher believes in the effectiveness of the new methods. Unfortunately, while most of the final examinations ask mainly about the informative objectives, it is only the teacher who can appreciate any change in the reasoning capacity of the student, if they have enough interactions. Even if this evaluation is subjective, the student and the teacher feel a sense of achievement when something is understood, and you can see the "spark" in their eyes. In any case, the main point is that the teacher needs to believe he is using the best procedures he knows.

It is not easy to integrate the planning of the theoretical and the experimental parts of a course; to be able to introduce concepts, to make inductions and deductions, to prepare lecture demonstrations, to design experiments, to know how to handle experimental data and how to write a report. And these requirements must be adjusted to the interests of the students and the teacher. Certainly, this is a very difficult requirement for most of the teachers due to their training, or to their lack of time for doing so.

This situation has traditionally produced a division in teaching between theory and laboratory work and has also created a specialization among teachers. The knowledge to be transmitted is divided between the blackboard and the laboratory according to their capabilities. Blackboard explanations may be highly efficient for transmitting the informative part of the course, including the solution of "textbook" problems. Laboratory work is more appropriate for the demonstration of phenomena, for getting the feeling of phenomena, for teaching procedures to handle experimental data, for learning the use of instruments and measurement skills, for “verification” of laws and for problem-solving activities

The laboratory in the formative aspect is important for the enlightenment of concepts, the verification or the induction of laws, and the solution of practical problems. The main point often missed, is the opportunity to teach with the example how to design an experiment to solve some problem, or how to decide when an unexpected experimental result is significant, or just a result of a malfunctioning instrument or an improper procedure.

The personal interaction between the teacher and the team of students performing an experiment, when they are trying to understand what is going on, cannot be obtained in any other way. The teacher needs to decide how much information is convenient to provide to the students without impairing their capacity to think. Too much information can reduce the experiment to a set of instructions to be followed, or if the information is very scarce the students can spend a lot of time without doing anything useful.

Despite these advantages of practical work, in many institutions, the laboratory is limited to improvised exercises that are at most at the level of qualitative demonstration experiments. In many other cases, the students receive appropriate recipes with detailed information of the steps to be followed, although the reasons for doing so are not clear, nor it is understood what the outcome will be. Another common mistake is to consider the laboratory only as a didactic help for theoretical lectures. This point of view neglects the fact that science is fundamentally an experimental activity. This mistake also disregards the possibility of working in the laboratory in the development of individual skills for solving new problems.

There have been some attempts to base the theoretical lectures on laboratory work, trying to induce the physical laws from the experiments made by the students, but in such cases, the learning process has been very slow. It is quite frequent that some students have previous ideas of what the experiment is for, and this distorts the complete induction process of getting the appropriate physical description of the phenomena.

The induction of physical laws directly from experiments is in general very unsatisfactory from the student's point of view. It is very hard to obtain a clear and direct induction of physical law, considering the available time and equipment. "Teaching theory through practical work is not an efficient way of transmitting an understanding of scientific concepts to students, indeed it can be positively harmful." (Woolnough and Allsop, 1985)

Development of Practical Activities

Knowing the specific topics and how are we going to evaluate them, we may decide the "theoretical" activities developed in the classroom, and the "experimental" ones to be made in the laboratory. The blackboard explanation (Goodwin, 1978) can be a very efficient way to fulfill the informative objectives and the deductive and or analytical side of the formative ones. On the other hand, the practical activities lead, naturally, to the inductive and or synthetical side of the formative ones. The informative objectives are those related to the characterization of the instruments, data handling and the use of statistics in the interpretation of data. So even in the laboratory, we need some blackboard activities to teach the information needed.

The range of practical activities goes from demonstrations observed by the students to experiments designed and performed by the students. A demonstration can induce a lot of thinking about what is happening and why. Demonstrations have been used to present some problems (Prigo, 1977). Homework problems involving the use of demonstration apparatus can supplement any physics course. Letting the student change the operating conditions of a demonstration can turn it into an experiment. This leaves the student with only the data handling and the interpretation work.

From the aims for the practical work we may give names to six broadly defined types of activities:

1) *Demonstrations* - Performed by the teacher, to show a phenomenon.
2) *Experiences* - Performed by the student, to get the feeling of a concept or phenomena.
3) *Quantitative demonstrations* - Performed by the teacher, producing data to be interpreted collectively or individually.
4) *Exercises* - Very simple experiments designed by the teacher so the students learn how to use an instrument, or to develop practical skills and measurement techniques.
5) *Investigations* - Realized by the students to find the answer to a question, involving theoretical models and experiment design, usually open-ended.

These six names are only a guide to help in clarifying the main aim of the activities, and it is better not to try to fulfill more than one aim simultaneously. If possible, let the students choose between two exercises, one experiment, and one or two investigations. All the activities are presented as problems to be solved in four to six hours.

Solving A Problem

The problems in the real world are not concerned with arbitrary divisions in disciplines like Physics, Chemistry, etc. Rarely can the scientific or technological problems be clearly classified in only one discipline? In general, the solution to these problems involves all our knowledge and skills.

Problem	>	Hypotesis or	>	Prediction or
		Theory		model
		^		v
Report	<	Results	<	Experiment
		^		^
	Data analysis			Instruments

***Figure 1**. A diagram to Solve A Problem*

To solve a problem. We start by formulating a problem whose solution is of interest. Then we make a hypothesis or a physics model, considering the relevant physical laws, identifying the most important variables that define the phenomena in consideration. By following a deductive process, we then make predictions about the behavior of the relevant variables describing the problem. Then we chose the equipment needed to measure the variables and decide the experimental procedure. After a preliminary trial, we decide how to make a full experiment. If the data solves the problem, we can write the report. If the data produces more questions, we start again until we solve the original question.

These predictions are deduced from the model and involve in general a mathematical relationship between the variables describing the problem. When we do not have a theoretical model, we can make a hypothesis about which we consider the pertinent variables and the relationship between them. In any case, it is then that we have an idea of what to measure, and the order of magnitude of the variables. Then, an experiment can be designed and performed to verify or modify the theoretical prediction, or to find the empirical relationship between these variables as an answer to the original problem.

For the planning of the experiment, we will require knowledge of measuring instruments as well as experimental techniques at an appropriate precision level. The next step is to assemble the instruments and to make a preliminary run on the experiment to get some data. After performing these measurements, we can analyze the data. Their interpretation should produce a conclusion validating or not the starting hypothesis as well as the accuracy and precision of the experiment. From this, we can modify the preliminary model, the instruments, the experimental procedure or the data handling. If we are satisfied with the results, then we can proceed to get the full set of data required for a valid conclusion. After all this, we can decide if the problem has been solved and the suggested hypothesis is appropriate to describe the observed phenomena. If we conclude that the initial model is not appropriate to our problem, we shall need to formulate a new one. Finally, if the problem is satisfactorily solved a written report is prepared to communicate the results in a clear manner.

We have oversimplified the situation in terms of a sequence of quasi-independent steps. The reality is more complicated and shows interconnections between all the steps. An experiment is designed considering all the knowledge available to the designer. The scheme is simple enough so that it can be used to plan the objectives of a course in the experimental sciences.

A student might be able to solve certain elementary problems after a course in one of the experimental sciences if he is able to do the following activities:

1) Given a problem, to generate a theoretical model or hypothesis, or at least to identify the relevant variables.
2) To consult the bibliography.
3) To propose an experimental procedure that would lead to the solution.
4) To choose the appropriate measurement equipment and to consult the catalogs and manuals as well as to define the general characteristics of the instruments that will be used.
5) To present the data in tables or graphics. including the estimation in precision and accuracy.
6) To interpret the results in terms of the original model.
7) To write a clear and concise report of the results, giving the answer to the original problem.

The source for the problems can be anyone available: the students own curiosity, extensions of the textbook problems, questions arising from demonstrations, any connection with a research or industrial laboratory, the teacher's creativity, etc.

The task of writing (and grading) the reports can be reduced, if the students working in pairs or triplets, produce only one report written by the student in charge of the team for that problem (Early and Stutz, 1976).

Examples of Practical Activities

1.Demonstrations - The inertia of the air. - A thin wood ruler below a sheet of paper at the edge of a table can be broken by a very fast blow to the protruding end. In a 30 cm ruler, 25 cm below the paper and 5 cm protruding into the air. The inertia of the air above the paper keeps it fixed, and the ruler is broken.

2.Experiences - The constancy of angular momentum. - Giving to the student a bicycle spinning wheel. He can move it very easily if he keeps the turning axis parallel to himself. But he will feel a big opposition to turn the axis to any other direction.

3.Quantitative demonstrations - Water drops in a parabolic stream. - Connecting a rubber hose to a constant level water reservoir, and the other end to a capillary tube (diameter = 0.5-1 mm) in contact with a loudspeaker. By applying to it a low voltage at the frequency of the line, we will get a parabolic stream because all the drops have the same initial conditions. Illuminating with a stroboscopic light at the same frequency, the drops will be completely frozen in the air. It is quite easy to measure the x and y coordinates with a ruler. The time between drops is the period of the line frequency. Smartphones takes videos and Tracker allows measuring trajectories so each student can see the drops falling on a parabolic path.

4.Exercises - To measure the speed of sound. To learn to use the oscilloscope, with two inputs, using a signal generator to produce a sound of fixed frequency, and detecting with the oscilloscope when the microphone has moved one or several wavelengths.

5.Experiments - To verify Coulomb's law. - We will need a power source to charge the balls to the same charge every time, and a way to measure the force. The main problems are the always present leakage of the charge and the redistribution of the charge on the balls when they are near. When the student understands this problem, he believes already in the Coulomb law.

6.Investigations - To measure the gold-copper ratio in a ring. - By measuring the density of the ring, it is possible to find the amount of gold, without any damage to the ring (Riveros, 1989). It is necessary to assume the additivity of the volumes of the components forming the alloy. The formative objective is to clarify the concepts of precision and accuracy in indirect measurement. The student needs to be very careful about the volume's measurement to get a density value useful to be related to the composition.

Woolnough and Allsop (1985) mention many ideas for investigations, also many toys can be used to investigate how they work; by example, it is not so difficult to measure the efficiency of a vapor boat toy (Garcia et al., 1983).

Another example of the demonstration is a light ball over one heavy ball, falling together. - The light ball reaches much higher than the heavy one. It can be explained by changing the reference system and assuming elastic collisions. A light ball on Earth bounces with the same speed and height. But if a heavy ball with speed V pushes a lighter one, then the speed of the lighter will be 2V. For the heavy ball, lighter hits it with -V and bounces with speed V, with respect to the heavy, which are 2V with respect to the ground. When the two falls together to the floor, the first one that collides is the heavy one and bounces with velocity V. For the heavy ball, the light one hits with speed 2V and bounces with 2V upwards, but with respect to the ground, it bounces with 3V speed. Solving the energy conservation and linear impulse equations, the same is obtained at the limit when the mass of the light tends to zero (Riveros, 2017).

Physics in real life. In case of an accident, we do not have time to think, we must act. Figure 2 shows an example, to avoid hitting the truck we can stop or try to avoid it.

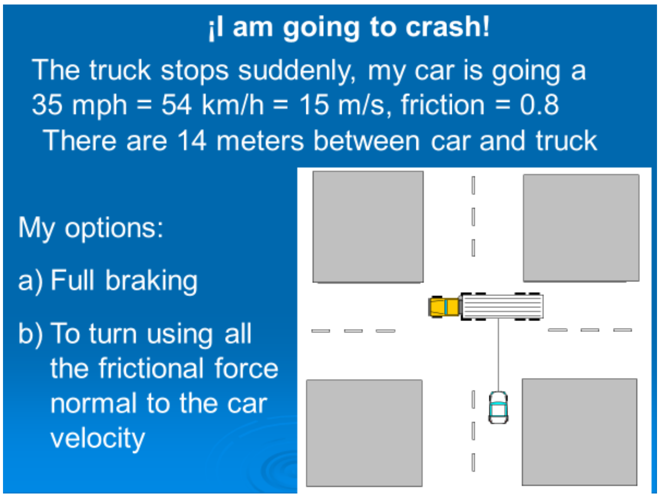

Figure 2. *The minimum radius of curvature uses the friction to change the velocity direction, speed is constant*

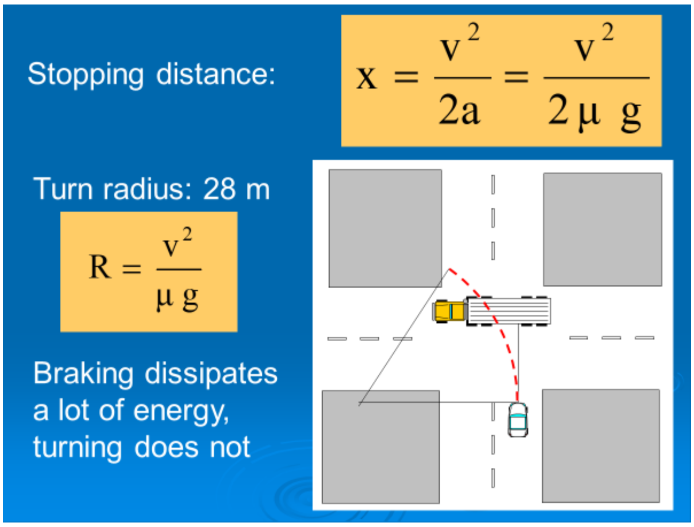

Figure 3. *The curvature radius is twice the stopping distance*

(Braking is always the best option)

The magnet in the Earth magnetic field. What is the field of a magnet in the terrestrial field? Drawing with the help of a compass, the fields shown in figure 4 for two cylindrical ceramic magnets.

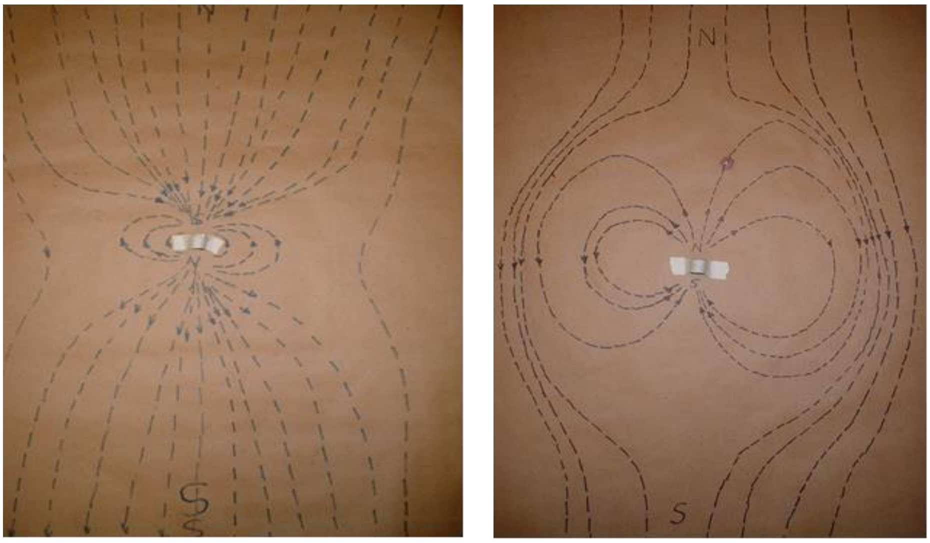

Figure 4. *The magnetic field of two cylindrical magnets, with its axis oriented in the North direction - Sur, in the left the magnet attracts the lines of the terrestrial field and in the right, the north pole of the magnet repels them.*

This experiment can be done with secondary and high school students, a compass and a magnet are required. But for undergraduate students, it can be used that the magnetic field of a point dipole of dipole moment m, in polar coordinates, is given by,

$$\mathbf{B} = \frac{\mu_0 m}{4\pi r^3}(2\cos\theta \mathbf{u}_r + \operatorname{sen}\theta \mathbf{u}_\theta) \quad (1)$$

That tells us that the field decays with the inverse of the cube of the distance to the magnet. To measure the magnetic field, we can use the Tesla meter program, free on cell phones, measuring how it changes with distance. Figure 5 shows the agreement with the theory.

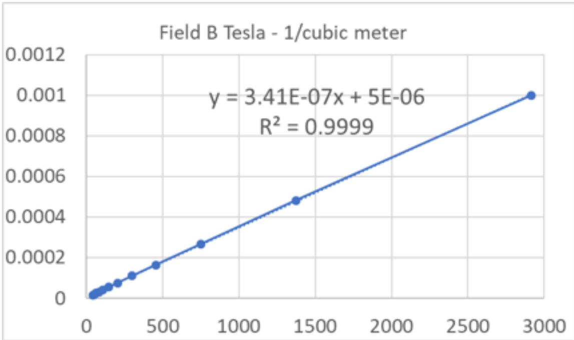

Figure 5. *The magnetic field of a magnet decays as predicted by the point-dipole approximation*

Knowing the dipolar Moment M of the magnet we can calculate the magnetic field at any point where the point dipole approximation is valid, very near the magnet the field is uniform, and we can draw field lines by calculating in Excel some lines.

We calculate for a point (x, y) the value of the magnetic field B = Bx**i** + By**j**, we can calculate an increase in the direction of the field Δs, with components Δx and Δy. If the increase in distance is small enough, it will remain on the desired line. In other words, Δx = Δs * Bx / B and Δy = Δs * By / B.

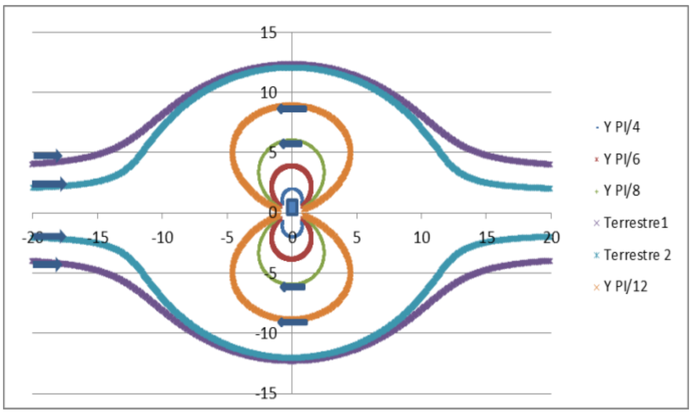

Figure 6. *Magnetic field around a magnet placed in the earth's magnetic field. The lines that come out of the magnet start in a circle with a radius of 1 cm at the angles measured in positive and negative radians. The X and Y axes are in centimeters*

Figure 7 shows the field of a magnet that attracts the Earth's magnetic field, that is, rotated 180 degrees from the previous case. The axis of the magnet is oriented North-South. Only in the region very close to the magnet does its magnetic field dominate.

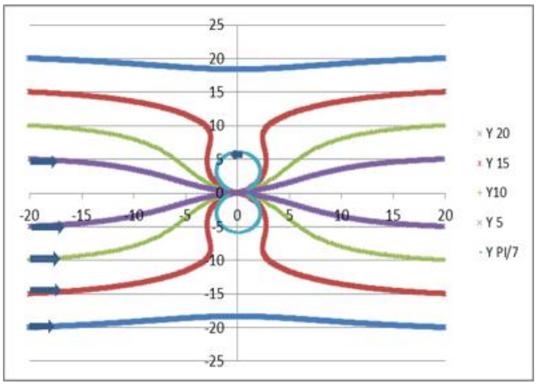

Figure 7. *The magnet attracts the terrestrial field. The lines start at the left edge at distances Y marked positive and negative. The line that starts at the magnet starts at a positive and negative PI/7 angle*

If we place the magnet with its axis oriented in the east-west direction, we obtain a completely different field, shown in figure 8.

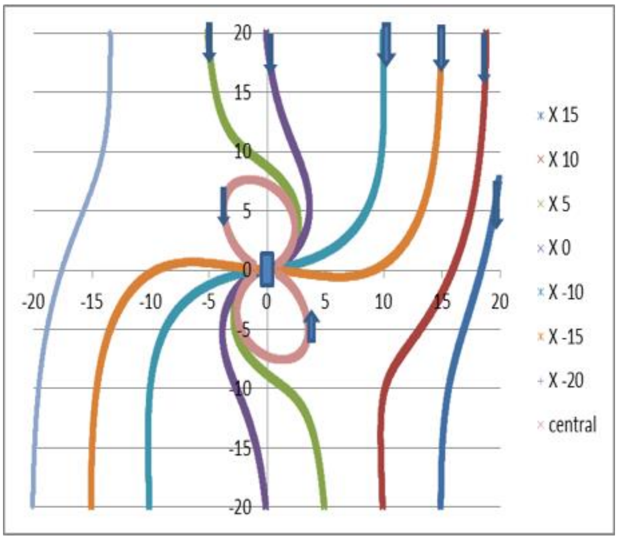

Figure 8. *Magnet oriented in the east-west direction. The lines have Y = 20 for the X shown in the figure. The central one starts at the magnet*

The figures reproduce figure 4 obtained with magnets and compasses to draw the combined magnetic field of the magnets and the Earth's magnetic field.

CONCLUSION

Teaching competencies or learning to reason, allows choosing the best teaching procedures (Riveros, 2017, Riveros, 2018).

Almost any of the usual exercises, experiments or investigations can be translated into a problem, obtaining a better motivation for the practical work. Even dull experiments like measuring "g" using a pendulum, can be exciting if the problem is a competition to find the experimental procedure with the maximum precision, with all the teams using the same rulers and chronometers.

The problems that can be solved by a science or engineering student are quite different from those that he or she will find at the professional level. Nevertheless, a careful analysis of a real problem can lead us to realize that it can be separated into an ensemble of smaller problems. Training the students in this process will allow them to tackle more difficult problems (Gomez et al., 1972; Mazur et al., 1978).

To prepare our students to solve their problems, we need to find a set of experimental problems that could be solved by the students, considering the knowledge they have, the topics to be covered in the theoretical lectures, and the available apparatus and experimental techniques. These requirements seem to be trivial but are extremely difficult to meet. Here the experiments will play the fundamental role in synthesizing knowledge and in preparing the students for his or her future professional work.

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