EPISTEMOLOGY OF A PHYSICS LABORATORY ON ELECTRICITY AND MAGNETISM

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EPISTEMOLOGY OF A PHYSICS LABORATORY

ON ELECTRICITY AND MAGNETISM

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Following previous experience and research which indicated the need of providing students with a heuristic device to help them in the understanding and description of the structure of knowledge of laboratory experiments, this study investigated some of the factors involved in providing students with Gowin's epistemological framework (Vee) through an introductory college laboratory physics course at Federal University of Rio Grande do Sul (UFRGS), in Brazil.

An evaluation of students' receptivity and performance in understanding and using the Vee in a physics laboratory context was the main objective of this study. In the process of establishing answers to the basic research question of this study, we differentiated the students' performance in three levels of achievement: (1) the classification of the parts of the structure of knowledge involved in a laboratory experiment, and the understanding of their functions; (2) the description of relationships among these parts; (3) the application of the epistemological framework to new problems and situations of a laboratory experiment.

This study was carried out through two research runs and involved roughly 80 students per run from a course population

which ranged from 270 to 370 students. The students' performance was evaluated through five written tests concerning five laboratory experiments on electricity and magnetism. Students also answered a final questionnaire.

In addition to the five laboratory tests, three different formative evaluation strategies (clinical interviews, group discussions, and written feedback) were used in order to evaluate the students and to provide them feedback in the achievement and use of the epistemological framework.

The use of the three strategies generated an additional research question concerned with the differences that could arise among the three strategies in terms of students' performance and receptivity to the Vee.

The main findings of this study are:

1. From the first to the fifth laboratory experiment and test, there was a progressive improvement in the students' understanding of the epistemological framework (Vee), in applying the Vee to the description of the structure of knowledge involved in a laboratory experiment, and in conducting new experiments in order to analyse physics phenomenon(a) and to establish knowledge claims.

2. The methodological domain of the Vee (experiment) was more easily understood and described than the conceptual one.

3. Students' main difficulties in the conceptual domain came from their (a) lack of mastery of the theoretical background of the experiment, (b) difficulties in expressing relationships

among concepts, and (c) lack of knowledge about the nature, structure and functions of a theory and its component parts. These difficulties also represented obstacles in the description of the constant interplay between the conceptual and the methodological domains.

4. Students' main difficulties in the methodological domain came from their lack of skills in the graphic representation and analysis of data.

5. The students' receptivity to the use of the Vee was good (about 75% of the possible maximum by using the Likert's scale).

6. Among the three experimental groups using the three different formative evaluation strategies, there was no significant differences in terms of students' performance, receptivity to the Vee, and receptivity to the strategies.

One important aspect of this study was the deep and clear communication, between the author (teacher) and the students, which was made possible by the use of the "Vee language" in the analysis of the structure of knowledge involved in laboratory experiments.

The evidence that the Vee has an excellent structure, a strong communication power and it is likely to improve abilities in scientific inquiry, are the most important findings of this research study.

BIOGRAPHICAL SKETCH

Carlos Ernesto Levandowski was born in Porto Alegre, RS, Brazil, on March 17, 1938.

In 1955, he entered the Varig Brazilian Airlines School and became an electrician of aircraft; he worked in Varig from 1956 to 1960. He completed his secondary education in 1960. From 1961 to 1963, he worked in television repairs.

In 1962, he was admitted to the Faculty of Philosophy, Sciences and Letters of the Federal University of Rio Grande do Sul (UFRGS), Brazil, where he graduated in Physics in 1966 From 1964 to 1968, he taught physics and mathematics in several Brazilian public and private secondary schools.

In 1969, he started his research and teaching activities as a full-time instructor of physics at the Institute of Physics and at the School of Engineering of UFRGS. He received his M.Sc. degree in Physics from this University in December 1975. He was promoted to the position of Assistant Professor in December 1977.

The author began studying for his Ph.D. degree at Cornell University in January 1978. In December 1979, he went to Brazil in order to carry out this research study in the UFRGS educational context. In March 1981 the author returned to Cornell in order to fulfil the requirements for the Ph.D. degree in Science Education. Back to Brazil, the author will resume his position at UFRGS, where he is presently an Assistant Professor of physics.

He is married to former Eloa Graciano Casagrande and has two children, Lauro and Luisa.

To my wife Eloa,

to my son Lauro,

and to my daughter Luisa.

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Chapter I

INTRODUCTION

There is a persistent discussion and concern about the deficiencies and problems of the introductory physics laboratory. Many teachers have put much time and efforts into improving the laboratory experience of their students. In spite of these efforts, the results are, in many cases, disappointing. Almost all physics teachers feel that the laboratory is a good thing, but if asked to justify this feeling they may have difficulties and they may disagree concerning the laboratory goals and procedures. The high cost of the implementation and maintenance of a laboratory, and the teacher's efforts, must be satisfactorily justified.

In which aspects can laboratory best contribute to a student's education? What are the educational objectives of the laboratory and how can they be achieved? What should be taught to students? Our answer would be that, in addition to teaching them laboratory skills, physics concepts and certain attitudes, students ought to be taught how to learn. That is, students should be taught how to learn from nature without the assistance of either a laboratory guide or a teacher, because it is this ability that the students would be most likely to retain after their course work is completed.

Physics has been defined to be both a body of knowledge and a process of inquiry. This process of inquiry ought to be taught to students in a laboratory context because it will probably increase their ability in learning from nature on their own. One of the major mistakes made by teachers in laboratory teaching is to assume that the students know how to learn from nature when students actually do not know it. How can this process of inquiry be taught to them ?

During the last twelve years I have been teaching introductory physics courses to engineering students at the Federal University of Rio Grande do Sul (UFRGS), in Brazil. During most of this time I taught the Physics II course, which is concerned with electromagnetism and thermodynamics.

Physics II is the second one of a sequence of three one--semester courses in General Physics. Its content is taught at the level of "Fundamentals of Physics" by Halliday and Resnick (1974) and the prerequisites are one semester of calculus (derivatives and integrals) and one semester of physics (mechanics). The total course time is 90 hours: 6 hours per week, during 15 weeks. Enrollment ranges from 250 to 400 students each semester.

The research findings of a study carried out by Moreira (1977) provided evidence that, in the Physics II laboratory context, some students were unable to learn the educative materials presented.

Moreira designed a five-item laboratory test based on Gowin's (1970) "five questions" to evaluate the students' performance in four laboratory experiments of the Physics II course. These "five questions" (described in Section II-3) were devised by D.B.Gowin as a method for the critical analysis of documented claims. They ask about the telling question(s), the key concepts, the method(s) of inquiry, the findings, and the value of documented claims.

In Moreira's research, Physics II students were asked about the basic question(s), the key concepts, the basic phenomenon(a), the method, and the results of each one of four laboratory experiments. His findings were rather surprising because, in spite of being able to perform the experiments according to the directions given in the laboratory guides, the students obtained poor mean scores in the identification of basic phenomenon(a) and in the description of the method and results of each experiment. In the description of the method, for example, the scores were systematically around 50% of the maximum. Students rarely described the method as a systematic procedure; most students simply gave answers like "experimental method" or "scientific method".

It is to these type of findings, established in the Physics II laboratory context but very probably valid for several other laboratory courses, that our research study is directed. We think that the Physics II laboratory work has not been often effective and its potential has not been duly explored. Even more, facing this problem, we assume that it was in part happening because the students were not provided with an epistemological framework that could guide them to the understanding and description of a laboratory experiment. In other words, we assume that the laboratory work has not been often effective because, in part, the students do not know how to learn from nature, they do not know about processes of inquiry and, consequently, they do not understand and know how to describe the structure of knowledge involved in a laboratory experiment.

Therefore, we decided to provide the Physics II students with an epistemological framework in order to improve their understanding of and ability to describe the structure of knowledge of a laboratory experiment.

For reasons that are explained in the next chapter, we chose Gowin's Epistemological Vee (Gowin, 1981)[(1)] as a suitable and useful framework for the purpose of this study.

An evaluation of students' performance in the understanding and use of Gowin's epistemological framework (the Vee) was the main objective of this research. That is, this study intended to investigate the students' conceptions and misconceptions, main difficulties and abilities, as well as feelings in the comprehension and use of the epistemological framework in the Physics II laboratory context.

The basic research questions of this study were:

(I) To what degree are students able to acquire an epistemological framework and to use it as a device for:

(a) The understanding and description of the relation

[(1)] Gowin's Vee is described in Section II-3 and in Appendix A, and illustrated in Figure 1.

between physics and nature, that is, between the physicist's description of nature and the phenomenon(a) or event(s) studied ?

(b) The recognition of physics as being both a body of knowledge and a process of inquiry ?

(II) What are the students' difficulties in these (above described) processes of acquisition and use of the epistemological framework ?

In the process of establishing answers to the basic research questions of this study, we differentiated the students' performance in three levels of achievement:

1. The classification of the parts of the structure of knowledge involved in a laboratory experiment;
2. The description of relationships among these parts;
3. The application of the epistemological framework to new problems and situations of a laboratory experiment.

Students' understanding and use of the epistemological framework was evaluated through five written tests concerning five laboratory experiments of the Physics II course. In addition to these five laboratory tests, three different formative evaluation [2] strategies were used in order to provide the students with feedback in their achievement and use of the epistemological framework. These three formative evaluation strategies also served as three different channels of information for research purposes. The three strategies

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(2) A concept analysis of formative evaluation is presented in Appendix B.

were named Clinical Interviews (C.I.), Group Discussions (G.D.), and Written Feedback (W.F.), and they are described in Section III-3. These three formative evaluation strategies were also used to promote the sharing of meanings between students and the teacher (researcher). This is coherent with Gowin's Triadic Model of Teaching (See Section II-4) which was used as a reference by this author (researcher) in the organization and elaboration of instructional activities and materials.

The use of the three formative evaluation strategies generated a third research question of this study:

(III) What differences would arise among the students involved with each one of the three formative evaluation strategies, C.I., G.D., and W.F., in terms of:

(a) students' performance in each one of the three levels of achievement proposed in the research questions I and II already stated ?

(b) students' receptivity to the epistemological framework as expressed both during the course and as reflected in a final attitude questionnaire ?

This research study was carried out through two research runs: a pilot run and a second research run. The pilot research was carried out during the first semester of 1980 (from March to June). After that, the instructional, evaluative, and research materials, as well as the design of the experiment, were improved for the second research run from August to November of 1980. Each run lasted about 15 weeks and involved five laboratory experiments on electricity and magnetism performed by roughly 80 students of the Physics II course at UFRGS, in Brazil.

In the next chapter the theoretical background of this study is presented. It contains a literature review on objectives of introductory physics laboratory, a description of Gowin's epistemological framework, a description of the theoretical frameworks for teaching and evaluation used in this work, and a moral justification for this research study.

Chapter III describes the objectives, the research design, and the work conditions of this study. It also describes the formative evaluation strategies, and the performed instructional, evaluative and research activities.

Chapter IV presents the analysis of the laboratory experiments, the instruments of research measurements, the data collection procedures, the analysis of data, and the results of this research study about students' understanding and use of an epistemological framework in a physics laboratory context.

Chapter V summarizes the study and presents some interpretations of the research findings with their possible implications for laboratory instruction.

Chapter II

THEORETICAL BACKGROUND

II-1 Objectives of the Laboratory Course

Having in mind the problem that the Physics II laboratory work usually was not effective, we reviewed some literature related to objectives which are more frequently proposed for introductory physics laboratories at the college level.

We found out that the objectives stated by Nedelsky (1949, 1958, 1965), and frequently used by other researchers as a reference, would be appropriate to the specific laboratory context of this study. According to Nedelsky's ideas, the central objective of introductory laboratory instruction is:

> A. Relation between Physics and Reality: To increase the student's understanding of the relation between theoretical science and nature, that is, between the physicist's description of nature and nature itself - between physics and reality.

In addition, he proposes three subsidiary objectives of laboratory instruction, which are:

> B. Comprehension of Concepts.
> C. Ability to use Instruments[1]
> D. Certain Attitudes and Habits (Nedelsky, 1958).

The central objective of the laboratory course, as stated by Nedelsky, seeks to find a way in which students can

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[1] Which we prefer to designate as: Development of Laboratory Skills

understand meaningfully the relation between physics and nature. It seems that current teaching practices do not provide students with the kind of experience needed for achieving this goal, but instead, according to Nedelsky:

> "Science courses stuff their students with facts instead of giving them understanding and teaching them how to learn, yet it is the last two abilities that the students would be most likely to retain and use after their course work is completed." (Nedelsky, 1965, p. xi).

Nedelsky has further clarified his objectives as:

> "Understanding of experiment means understanding the total process by which a scientist, starting from known concepts and generalizations, adds to them, makes them more general, or otherwise modifies them through experimentation. The core of this understanding (in physics) is therefore an understanding of the relation between verbal--mathematical science and phenomena." (Nedelsky, 1965, p. 23).

Michels (1957) and Nedelsky (1958), as well as others, have defined physics to be both "a body of knowledge and a process of inquiry". This definition is still leading some science course objectives (Klopfer, Chapter 18 in Bloom et al., 1971).

This concept of science as "a body of knowledge and a process of inquiry" seems to have guided all the structuralism of the sixties (Bruner, 1960; Phenix, 1962; and Schwab, 1962) in curriculum planning. As Bruner, in "The Process of Education Revisited" (1971), has summarized:

> "The prevailing notion was that if you understood the structure of knowledge, that understanding would then permit you to go ahead on your own; you did not need to encounter everything in nature in order to know nature, but by understanding some deep principles you could extrapolate to the particulars as needed. Knowing was a canny strategy

> whereby you could know a great deal about a lot of things while keeping very little in mind. ... It was this point of view that emerged from the famous Woods Hole conference on improving education in science (the impetus and inspiration for 'The Process of Education')." (Bruner, 1971).

We accepted the objectives described before as appropriate to our Physics II laboratory context. We thought that we should contribute to the students' understanding of the "relation between physics and nature" and the recognition of physics as "a body of knowledge and a process of inquiry".

II-2 <u>The Need of an Epistemological Framework</u>

Epistemology, or Theory of Knowledge, called Gnosiology by some European writers, is the study of the nature and validity of human knowledge. "Knowledge", used in this study, refers to the "results or products of inquiry".

In other words, Epistemology is the study or a theory of the nature and the grounds of knowledge especially with reference to its limits and validity.

Zais (1976, p. 111) defined epistemology as the "philosophical problem that deals with the nature of knowledge and the nature of knowing. It asks the questions: What is true? How do we know the truth? And how do we know that we know?"

Typically, epistemologists examine the degrees of certainty and probability in knowledge and the difference between knowing (with certainty) and believing (without being certain). The epistemologist wants to provide knowledge about knowledge. This can be used to provide a basis for wise action, security, and truth. Two competing traditional epistemological orientations are Rationalism, which stresses the role of reason in providing certainty, and Empiricism, which stresses the role of sense perception. Gowin's (1981) view follows modern philosophy which emphasizes the constant interplay between the conceptual and the methodological domains of the structure of knowledge.

Taking those laboratory objectives considered before, and facing the problem that the Physics II laboratory work usually was not effective and its potential was not duly explored, we assumed that this was in part happening because the students usually were not provided with an epistemological framework that could guide them to the understanding and description of a laboratory experiment.

So, the next step of our work was the selection of an epistemological framework to guide us, teachers and students, in the achievement of those objectives.

II-3 Selecting the Epistemological Framework

For reasons that will be explained in this section, we chose Gowin's Epistemological Vee (Gowin, 1981) as a suitable and useful framework for the purpose of this study.

Before the Vee, Gowin devised the "five questions" (Gowin, 1970) as a method for the critical analysis of documented claims. Gowin's "five questions" are:

(1) What is (are) the telling question(s)?
(2) What are the key concepts?
(3) What are the methods of inquiry?
(4) What are the knowledge claims?
(5) What are the value claims?

In analysing a research paper, the telling question is the question that tells about the phenomenon being investigated, and probably something will be found out by answering this question. The key concepts are the basic concepts, from the field of study related with the paper, that are involved in the telling question and in the research project itself. The methods of inquiry are the sequence of steps, the techniques of investigation, the devices that were used to answer the telling question, i.e., to go from the telling question to the knowledge claims. The knowledge claims are answers to the telling questions, and the value claims are concerned with the significance, usefulness, and importance of the knowledge claims.

Gowin's Epistemological Vee (Gowin, 1981) came after the "five questions" (Gowin, 1970). The Vee is a method for the analysis of the knowledge claims (products of inquiry); that is, the Vee is a heuristic device for the analysis of the structure of knowledge as a product of disciplined inquiry. Here, structure of knowledge is defined as: the parts of knowledge and the way these parts are related to each other.

Gowin's Epistemological Vee is schematized in Figure 1. The V-shape serves to emphasize that both sides, the conceptual and the methodological, are brought to bear on objects and events in the process of knowledge production. The Vee points towards the events and objects which indicate the phenomenon(a) of interest and the source(s) of evidence.

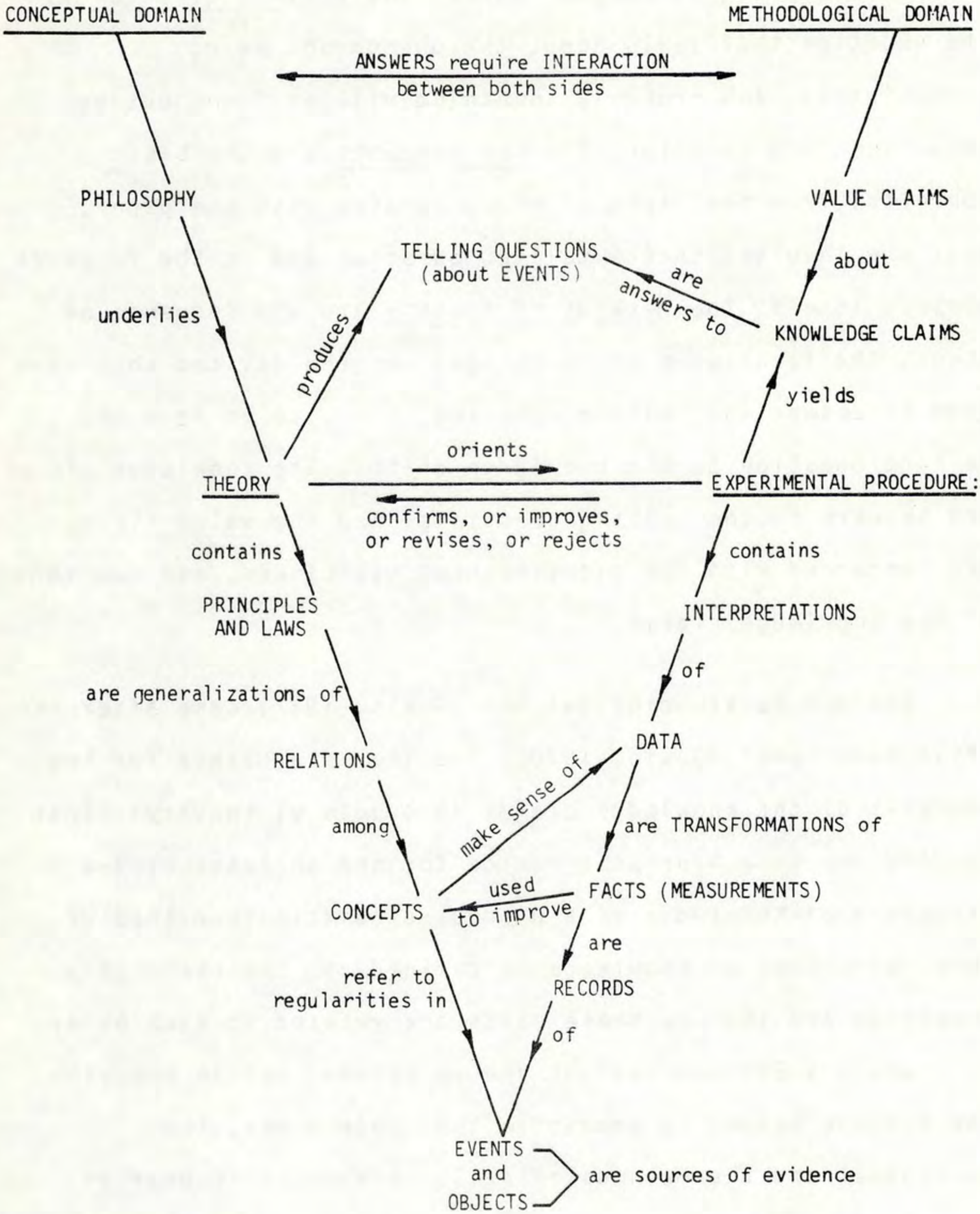

Figure 1. Gowin's Epistemological Vee. Some parts and relationships among the parts of the Structure of Knowledge. (After Gowin, 1981, and adapted from Buchweitz, 1981).

The telling question, in the center of the Vee, indicates the problem to be solved and the kind of knowledge claim that will be made. The telling question not only asks but also tells something; it belongs to both sides of the Vee, and it helps to clarify "what is going on" in the entire process of knowledge (product of inquiry) production.

The left side of the Vee, the conceptual (theoretical) domain, is composed of concepts, concept definitions, conceptual structures, principles, laws and philosophies. Gowin defines a concept as a regularity in events or objects coded (designated) by a sign or symbol.

Considering the telling question(s), the events and objects, the conceptual domain guides the methodological one to decide what records of events to take; how to take them; what transformations to make; how to interpret the data (the transformed records of events); and, finally, what knowledge and value claims to make. Everything done in the methodological side is guided by concepts, theories and philosophies of the conceptual side. In turn, new knowledge claims sometimes lead to new concepts, altered concepts or, occasionally, to new theories and philosophies. In short, there is a constant and active interplay between the two sides of the Vee. Knowledge, therefore, undergoes a continuous revision.

In Educating (D.B.Gowin, 1981) the reader can find clear operational definitions and explanations for each term (part) of the Vee, and also for the relationships among these parts which describe the structure of knowledge.

Appendix A reproduces in English the instructional units about Gowin's Epistemological Vee that were presented in Portuguese to the Brazilian students of the Physics II course.

So far, the only definition of understanding that we have presented is that given by Nedelsky relating to what he perceives understanding to mean in the context of a laboratory experiment. At this point, we intend to introduce Gowin's view of understanding and, at the same time, to provide an opportunity to increase the reader's comprehension of the Vee.

Both Gowin and Nedelsky are concerned with what is most worthwhile for the student: "understanding" and "ability to learn". Moving along the Vee, Gowin points out that:

> "Part of the structure of knowledge is the relation between descriptions and explanations. As we move up the right side of the Vee, we begin to see the connectedness between events, records, facts, data, generalizations, and explanations. At the top of the view should be understanding (interpretation). We want to know the significance of our knowledge claims. And that leads us directly into value claims". (Gowin, 1981, Chapter 4).

He goes on to say that:

> "(a) understanding comes from accepting the reasons given in the explanation,
> (b) the explanation is of the summarizing generalization,
> (c) which in turn is expressed through concepts,
> (d) which signify regularities in facts (records of events),
> (e) which serve as evidence for the argument,
> (f) and which facts are linked to records and events.

Gowin continues, always taking the Vee as a framework, and presents his criteria of excellence for "understanding":

> "In a sense, the farther we move away from events along this linkage the more interesting the narrative becomes, and the greater possibility that our understanding is increased. The amount of confidence we have in our understanding is a

> function of the tightness of the links shown by the Vee. If we can reliably move from one link to the next and back again, then we may hold our understanding with confidence". (Gowin, 1981, Chapter 4).

We see coherence between Nedelsky's ideas (about objectives, learning and understanding in the laboratory context) and Gowin's points of view. Their ideas can be matched to form a fruitful theoretical frame of reference for instructional purposes.

For these reasons, we selected Gowin's Vee as an appropriate epistemological framework to guide students to the understanding and description of a laboratory experiment. We considered that the Vee is likely to help teachers and students to develop the ability to learn and to increase the understanding of the relation between physics and nature, as well as to see physics as a body of knowledge and a product of disciplined inquiry through experiments in the laboratory setting.

II-4 Theoretical Framework for Teaching and Evaluation

We strongly defend the use of a "formative evaluation" system in order to improve the teaching process, and to generate fruitful data for research purposes.

The concept of "formative evaluation" was introduced by Scriven (1967) and refined by Bloom (1971) through the use of the mastery learning approach. For the purpose of this study, formative evaluation means the use of some evaluative activities while the teaching learning process is taking place with the objective of improving this process through feedback. It is also antecipated that formative evaluation will help to make the process of teaching more effective, long before any summative (final) evaluation takes place. Formative evaluation yields feedback and facilitates assessment of students' understanding and enables the teacher to take decisions soon enough to correct deficient teaching methods and promote more meaningful learning. In Appendix B we present a conceptual analysis of "formative evaluation".

In relation to "teaching", we decided to use another Gowin's model as a theoretical framework. Gowin (1981, Ch. 3) sees teaching as a triadic (three-way relation) episodic exchange of meanings of pieces of knowledge between teacher and student, and the occurence of successful teaching as the achievement of shared meaning between them.

The teacher introduces some instructional materials to the student who tries to understand the meaning of these materials. Then, teacher and student develop a kind of communication, the object of which is to analyse the instructional materials by giving reasons, weighing evidence, justifying, explaining, concluding, and so forth. As a result, the student gets some meaning that he/she shares with the teacher; at the end of this process, if both teacher and student agree, congruence is obtained and the result is shared meaning. When shared meaning is achieved, an episode of teaching has happened. In short: "teaching is the achievement of shared meaning". Gowin's model for teaching is schematized in Figure 2.

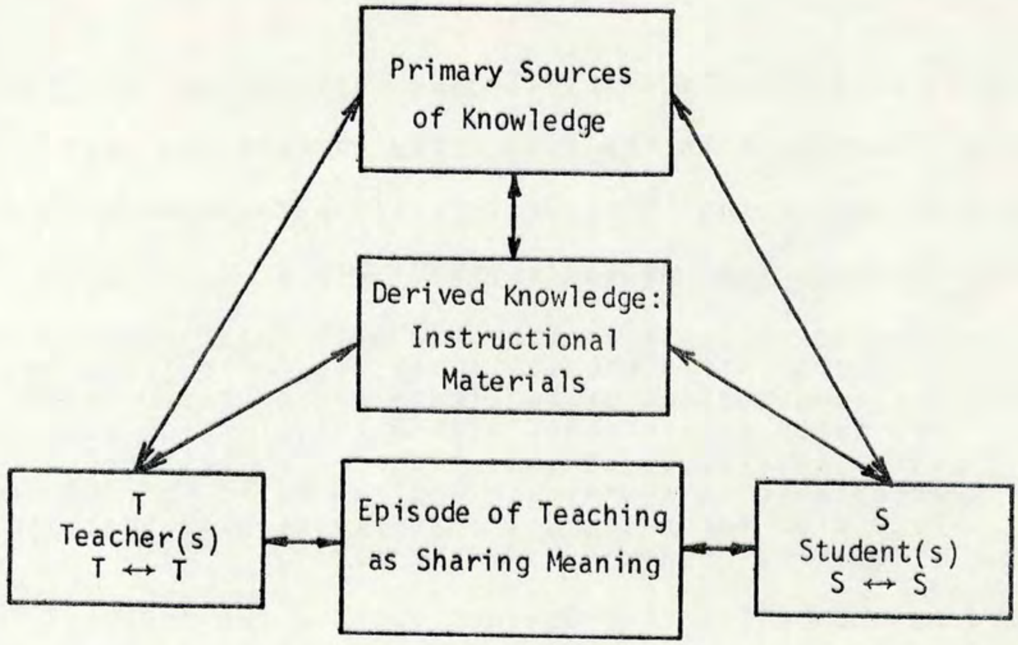

Figure 2. The Relationships Involved in the Process of Teaching. (Adapted after Gowin, 1981).

We see Gowin's model of teaching as coherent with the use of a formative evaluation approach because feedback is provided through the sharing of meanings between teacher and students.

According to Gowin, after the achievement of some initial shared meaning, the student is then ready to decide to learn or not because learning is a responsability of the individual; learning is not a responsability that can be shared. Gowin defines learning as "the active re-organization of the old pattern of meaning that the student brings to the teaching situation". And he clarifies that: "The re-organization of meaning is under the voluntary control of the learner ... according to his or her own interest".

II-5 Moral Justification for the Research Study

By providing the students with the Epistemological Vee for the purpose of use in the laboratory context, we were deliberately intervening in students' life because we wanted them to learn something. As Gowin (1970) wrote:

> "The moral justification for this intervention (of teachers into students' lives) is to be found in the human values of knowledge and truth. Unless the teacher intervenes with material which purports to be knowledge, and knowledge which has some acceptable test of truth applied to it, a necessary condition for the moral justification of teaching is missing" (Gowin, 1970, p. 327).

Based on the belief that Gowin's Vee has the necessary requisite of providing instructional material with "some acceptable test of truth", either by itself or through the analysis of physics knowledge claims, we assumed that it could and should be taught to the Physics II students.

Above all, our particular philosophy (world view and system of values) led us to contend that: it is not possible to teach science effectively without a minimum of epistemological meanings conveyed to both teachers and students, for sharing, in addition to the subject matter content. This means that a good science teacher needs training not only in his/her field of expertise, but he/she also needs to understand the overall epistemology of science in order to become able to teach both the subject matter and its epistemology.

Usually, students have little more than just an intuitive and preliminary knowledge of scientific and epistemological thought. To develop in his/her students an awareness of both fields of thought, the subject matter field and the epistemological one, is one of the teacher's most challenging tasks. In a sense, we agree with Gowin's assertion: "Helping others to reach understanding through clear relations of the structure of knowledge is a pedagogical value of the highest order". (Gowin, 1981, Chapter 4).

In summary, we believed as morally justified our intervention in students' lives by providing them with an epistemological framework (Gowin's Vee) through the use of an instructional approach based on Gowin's Triadic Model of Teaching and on formative evaluation strategies. Formative evaluation, which is compatible with Gowin's model of teaching, takes place during the evolving state of instruction and provides kinds of evidence that would be most useful for data collection and remedial intervention designed to improve the teaching process.

Chapter III

THE RESEARCH STUDY

III-1 Objectives of the Research Study

Through the use of an introductory college level physics laboratory course in electromagnetism, the aim was to find answers to the following main questions:

(I) To what degree are students able to acquire an epistemological framework and to use it as a device for:

(a) The understanding and description of the relation between physics and nature, that is, between the physicist's description of nature and the phenomenon(a) or event(s) studied ?

(b) The recognition of physics as being both a body of knowledge and a process of inquiry ?

(II) What are the students' difficulties in these (above described) processes of acquisition and use of the epistemological framework?

In the process of collecting data in order to establish answers to the basic research questions stated above, at first we differentiated the students' performance in two levels of achievement:

First Level - Classification (of the parts of knowledge)

1. To what degree are students able to acquire an epistemological framework and to use it as a device to:

1.1 - Identify the basic phenomenon(a) under study?

1.2 - Name the key concepts involved in the experiment with a brief verbal and/or mathematical description (or definition) of each one?

1.3 - Indicate the basic question(s) to be answered through the experimental procedure?

1.4 - Indicate the records (measurements) made?

1.5 - Recognize the transformations and interpretations of the facts (records of the events) produced along the experiment?

1.6 - Report the results (knowledge claims, conclusions) of the experiment?

1.7 - Point out value claims for the knowledge claims as well as for the whole laboratory experiment ?

<u>Second Level</u> - <u>Description of Relationships</u> (among the parts of knowledge)

2. Using the epistemological framework, how well are students able to:

2.1 - Represent through verbal and/or mathematical expressions the relationships among concepts, by considering the telling question(s), the main events, and the methodological structure involved in the laboratory experiment? (Left side of the Vee, or verbal-mathematical physics).

2.2 - Indicate the experimental procedure (method) performed in the laboratory experiment, that is: how events, records, transformations, interpretations, and knowledge claims are related? (Right side of the Vee, or experimental physics).

2.3 - Describe the continuous interplay between the conceptual structure (2.1, above) and the methodological structure (2.2, above) in the creation of new knowledge claims? (Relation between physics and nature).

2.4 - Represent (having the Vee as a reference) a general view of a concept-methodological structure of the laboratory experiment? (Relation between physics and nature; physics as a body of knowledge and product of disciplined inquiry).

We had in mind a third level that, probably, could be achieved only by some more clever students:

Third Level - Application (of the structure of knowledge)

3. Applying the epistemological framework, how well are students able to:

3.1 - Analyse and provide an experimental solution to problems (questions) which are similar in structure to examples (situations) which they have previously met in a laboratory experiment? (Estimate the outcome of a new situation in the same experiment).

3.2 - Suggest an experimental solution to a problem (question) for a situation not analogous to any single example (situation) previously seen in the laboratory experiment? (Project and execute a simple experiment to obtain knowledge claims).

III-2 Population and Work Conditions

Engineering students taking the Physics II course (Electromagnetism and Thermodynamics) at the Federal University of Rio Grande do Sul (UFRGS), Brazil, constituted the population of this study.

Physics II is the second one of a sequence of three one--semester courses in General Physics. Its content is taught at the level of "Fundamentals of Physics" by Halliday and Resnick (1974) and the prerequisites are one semester of calculus (derivatives and integrals) and one semester of physics (mechanics). During a term of 15 weeks, the course meetings consist of three sections per week, lasting two hours each. Some sections have morning classes, while others meet during the afternoons or evenings. Enrollment ranges from 250 to 400 students each semester. As a teacher I was in charge of two course sections each one having about 40 students. The research being reported here was carried out with the students of these two sections.

This research study dealt specifically with the laboratory activities related to five experiments of electricity and magnetism performed in five classes, lasting two hours each.

The nearly 80 students received the following written research materials: instructions about the epistemological framework, laboratory guides, and laboratory tests.

The instructions about the epistemological framework aimed:

(a) to guide the students in the understanding and description of the laboratory experiments (classifying and relating the parts of the structure of knowledge);

(b) to help the students to gain comprehension of the "relation between physics and nature";

(c) to assist the students to see "physics as a body of knowledge and a product of disciplined inquiry".

Appendix A presents the instructional units about the epistemological framework provided to the students who performed the five laboratory experiments. Laboratory instructions (see Appendix C) were prepared to guide students in performing these experiments.

A written test about the use of the epistemological framework in the laboratory experiments was administered after each one of them. These tests (presented and analysed in Chapter IV) were individually answered and were supposed to provide evidence about the student's level of understanding of the epistemological framework applied to the description of the structure of knowledge of each experiment.

The criteria used in assessing the student's understanding of the epistemological framework through the laboratory tests were based upon previously prepared answers by the researcher and upon a Vee of each experiment (see example in Appendix D). In addition, a concept map (see example also in Appendix D) illustrating the conceptual structure of each laboratory experiment was drawn in order to assist the researcher in carrying out the evaluation of the tests. These maps had also been used as a guide in the preparation of the laboratory guides.

A zero to a maximum of 10 points scale was used to score each laboratory test, which was separated into its several component parts in order to increase the range of the evaluative discrimination.

III-3 The Formative Evaluation Strategies

In addition to the laboratory tests, three different formative evaluation strategies were used in order to evaluate and provide feedback to the students in the achievement of the three levels proposed in the research questions (see Section III-1), and also to get more information (data) for research purposes.

The three formative evaluation strategies were named:

1. Clinical Interviews (C.I.).
2. Group Discussions (G.D.).
3. Written Feedback (W.F.).

To meet administrative and time constraints, just one of these three strategies was used with each student, i.e., each one of them received just one of the three possible treatments for feedback.

The rationale of the first two strategies, the C.I. and the G.D., used to provide feedback and sharing of meanings, are presented in Appendices E and F, respectively. They are briefly described now.

Strategy One - Clinical Interviews (C.I.)

Thirty minutes were set aside for each student (of the C.I. experimental group) to discuss individually with the researcher the results of each laboratory experiment: his/her laboratory test, his/her understanding of the epistemological framework applied to the experiment, and so forth. In this case, feedback was provided in the form of oral explanations, recommendations and support.

Strategy Two - Group Discussions(G.D.)

An informal 45 minutes discussion between the teacher and a small group of students (about 5 students showed to be an appropriate number) revolved around the previous experiment(s), laboratory test(s), and the epistemological framework.

We anticipated practical conditions to perform individualized clinical interviews only with a small number of students during the course. We also recognized that these two strategies, the C.I. and even the G.D., which requires only small groups instead of individual assistance, could not be incorporated into the regular instructional practices being used in the Physics II course context at the time this study was conducted. Consequently, we decided to develop a third additional strategy for feedback and sharing of meanings which could be more easily generalized in our "traditional" instructional context. The description of this third strategy, which we called Written Feedback Strategy, is presented next.

Strategy Three - Written Feedback (W.F.)

In this treatment, each W.F. student got back his/her laboratory test corrected in the same way as the tests of the C.I. and the G.D. students were corrected; that is, the teacher (author) used the same correction criteria for the three experimental groups. The W.F. students received back their tests with additional written comments and requirements for written remedial work concerned with the students' incorrect answers. After doing this individual additional written work, each student returned it to the teacher for control and approval. That is, emphasis was placed on written communication between teacher and student for the purposes of feedback and sharing of meanings.

We assumed that these three instructional and evaluative strategies would be capable of providing feedback and to favour sharing of meanings between students and the teacher (researcher) because the strategies seemed to be coherent with the Gowin's Triadic Model of Teaching and with the concept of formative evaluation.

In summary, we used these three different formative evaluation strategies with the purpose of:

(a) providing methodological improvement: different sources (kinds, channels) of information, gathering additional data to answer the research questions through formative evaluation processes, in order to increase the validity of the research findings;

(b) enhancing the sharing of meanings between teacher and student through feedback;

(c) satisfying administrative and time constraints.

III-4 The Additional Research Question

It was our understanding and feeling that having a "control" group "without an epistemological framework" and/or "without a formative evaluation strategy" would not provide any methodological advantage in order to answer the specific proposed research questions. As Cronbach (1963) already pointed out:

> "The aim to compare one course with another should not dominate plans for evaluation. To be sure, decision makers have to choose between courses, and any evaluation report will be interpreted in part comparatively. But formally designed experiments, pitting one course against another, are rarely definitive enough to justify their cost. ...
> Since group comparisons give equivocal results, I believe that a formal study should be designed primarily to determine the post-course performance of a well described group with respect to many important objectives and side effects."

On the other hand, we assumed that the Written Feedback Strategy could be more easily incorporated into the Physics II course context as well as in other introductory physics courses of General Physics at UFRGS This led us to think that a comparison among the three groups, with different formative evaluation treatments (strategies), in terms of student's achievement and use of the epistemological framework (Gowin's Vee), would be more valuable. That is, mainly because we believed that the research findings could be more readily subsumed into the lore and practice of laboratory instruction we decided to analyse and compare the efficiency of these three feedback strategies. Therefore, the use of the three strategies (for research, evaluative, instructional, administrative and methodological purposes) generated the third research question of this study:

(III) What differences would arise among the students involved with each one of the three formative evaluation strategies, C.I., G.D., and W.F., in terms of:

(a) students' performance in each one of the three levels of achievement proposed in the research questions I and II already stated ?

(b) students' receptivity to the epistemological framework as expressed both during the course and as reflected in a final attitude questionnaire ?

III-5 Samples and Design

As we mentioned before, this research study was carried out through two research runs: a first (pilot) run and a second research run. Each run lasted approximately 15 weeks and involved five laboratory experiments on electricity and magnetism performed by nearly 80 students of the Physics II course.

We emphasize that the pilot research run was quite worthwhile because it permitted the detection of several instructional, evaluative, and research shortcomings in time to correct deficiencies and promote improvements for the second research run. These shortcomings and improvements are described in this Chapter III.

During the first and second research runs, nearly 270 and

370 students were respectively enrolled in 6 and 9 sections of the Physics II course. As a teacher, the author was in charge of two course sections with approximately 50 students per section in each semester; however, only about 40 students per section actually attended the classes and answered the written tests.

Students of the course sections used in the experiment were not randomly selected because students are free to enroll in any of the sections of Physics II, but once they are enrolled no changes can be made. At registration they are not aware of which teacher will be in charge of a certain course section; the major factor determining students' preference for a certain section is, in general, their own scheduling convenience.

During the pilot research, the two sections were divided into three experimental groups. All the 37 students of the first section received the written feedback (W.F.) treatment with emphasis on written communication between student and teacher. Students from the other section were, in turn, randomly divided into two groups with which the other two treatments (C.I. and G.D.) were used. Figure 3 shows how the students of these three experimental groups were selected for the pilot study.

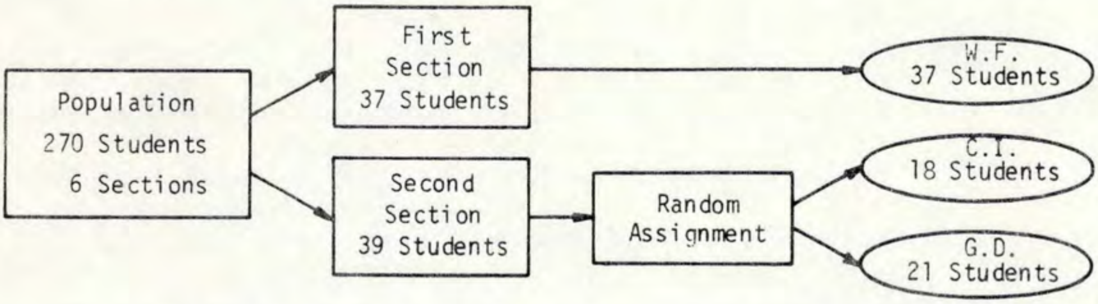

Figure 3. The Selection of the Three Experimental Groups for the Pilot Research Study.
Key: W.F. = Written Feedback Strategy
C.I. = Clinical Interview Strategy
G.D. = Group Discussion Strategy

The three formative evaluation strategies used to stimulate feedback and sharing of meanings, were already presented, described and justified in Section III.4. The main differences among these three experimental treatments are concerned with the kind of feedback that each group received after performing the laboratory experiments and tests:

- the G.D. group was divided in two sub-groups, each one with about 10 students, for the purpose of group discussions lasting about 45 minutes per sub-group, three times along the semester;
- the C.I. students were excused from the class planned for group discussions, but they were required to participate in individualized clinical interviews, lasting half an hour per student, during the same week of group discussions (three times along the semester);
- the W.F. group was also excused from the class planned for the group discussions, but W.F. students received back

their laboratory tests with comments and individualized remedial written work requirements; this was done with emphasis on written communication, so that no more than fifteen minutes per student per test were taken from the teacher (researcher).

With the sample design used in the pilot research run, we had difficulties to manage the group discussions within the limited period of 45 minutes because the number of nearly 10 students per sub-group ended up as being too large. For this reason, in the second research run, we changed the system of selecting three experimental groups: we randomly selected the three experimental groups from each one of the two course sections. Figure 4 schematizes this selection approach that permitted group discussions with smaller groups (5 or 6 students per sub-group), and also allowed to increase the number of students (from 18 to 25 students) of the clinical interview strategy because in the pilot research the C.I. strategy showed to be the most fruitful source of research information.

In addition, through this kind of sample selection used in the second research run, as said before, we got three randomly selected experimental groups from each of the two course sections. Therefore, a sample selection improvement was made: in the pilot run a course section provided the written feedback group with no randomization while in the second run all groups were randomly selected.

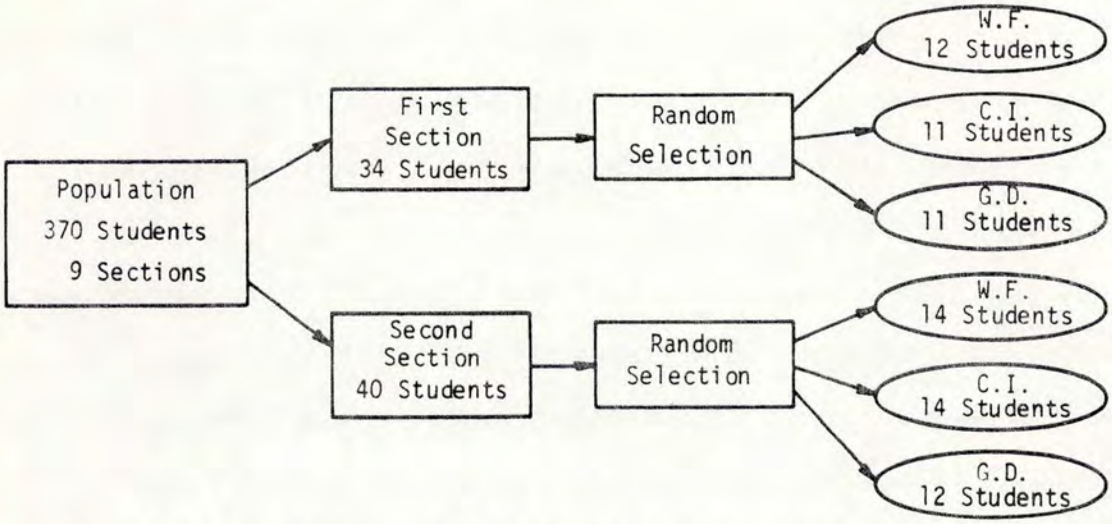

Figure 4. The Selection of the Three Experimental Groups for the Second Research Run.
Key: W.F. = Written Feedback Strategy
C.I. = Clinical Interview Strategy
G.D. = Group Discussion Strategy

III-6 Performed Instructional, Evaluative and Research Activities

In both the pilot and the second research studies, students took part in the following main activities relative to the research:

(a) studying instructional units about an Analytical Method (The Gowin's Questions and Epistemological Vee);

(b) performing laboratory experiments oriented by laboratory guides;

(c) answering laboratory tests;

(d) participating in only one type of three formative evaluation activities to get feedback;

(e) answering a final questionnaire.

III-6.1 The Instructions about the Epistemological Framework

In both research runs, students received written instructions (accompanied by nearly 60 minutes of oral explanations) about an "Analytical Method" (that is, the Epistemological Framework or the Gowin's Vee) for the purpose of students' use in the five laboratory experiments, and the corresponding tests, of the Physics II course.

In the pilot research run, we divided these written instructions about the "Analytical Method" in two instructional units: the first one concerned with "the six questions" (adapted from Gowin's five questions), and the second one with the Vee. Both units were complemented with applications to the classical "Hooke's Law Experiment".

Specifically, the following "six questions" were introduced, explained and examamplified through the first instructional unit in the pilot run:

(1) What is (are) the observed event (s), i.e., the phenomenon(a) that is (are) being studied?
(2) What is (are) the telling (basic) question(s) of the experiment?
(3) What are the key concepts?
(4) What is the experimental procedure (method)?
(5) What are the knowledge assertions (affirmations)?[1]
(6) What are the value assertions (affirmations)?

Then, in the pilot study, the Vee was introduced later through a second instructional unit and before the third

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(1) Just to clarify: in the last two questions, Portuguese terms which correspond to the English words "assertions" and "affirmations" were used because they provide the best translation to the Portuguese of the term "claims" originally introduced by Gowin (1970).

laboratory experiment.

By separating the instructions about the Analytical Method in two parts, the "six questions" and the Vee, we were intending to allow the students to proceed slowly in the understanding and use of the Method in the description of the structure of a laboratory experiment. This approach showed to be not efficient: students lost the opportunity to get earlier the general overview of the laboratory structure which is provided by the Vee. We realized that it is more fruitful to introduce the Vee at the beginning of the course, that is, through the first instructional unit, because students have an early opportunity to acquire a general view of the structure of a laboratory experiment. This was evidenced by information that we got through feedback from the formative evaluation activities and it was quantified through students' answers to an item of the Final Questionnaire. At the end of the pilot research run, we included the following assertion, asking for students' opinion (agreement or disagreement):

> "If the Vee had been given at the very beginning of the course and elaborated since the first laboratory experiment, I would have progressed more in the understanding and use of the Analytical Method".

Sixty six students answered this question, providing the following frequencies: 19 strong agreements and 28 simple agreements, totalizing 47 agreements; 4 strong disagreements and 7 simple disagreements, totalizing 11 disagreements; 8 students expressed no opinion. In summary, at the end of the pilot research run, 47 students (out of 66) agreed that the Vee should have been given earlier, i.e., before the third laboratory experiment and test.

As a consequence, at the very beginning of the second research run we introduced a first instructional unit already including the Vee. This unit was complemented by a second one including an example of application of the Vee to the classical "Hooke's Law Experiment". In addition, a short third written unit was given after the first laboratory test in order to clarify and revise the main aspects of the Vee where the students showed misunderstanding. These three instructional units about the Analytical Method (the Vee) are in Appendix A.

This approach for the instructional units showed to be appropriate as the reader can see through the data analysis presented in the next chapter. By now, we will just present the evidence provided by students' opinion, at the end of the second research run, to the following statement:

> "It would be more fruitful if the Vee had been introduced slowly in the course and had begun to be elaborated by the students only at the third laboratory experiment and test".

Fifty students opined and the frequencies were: 5 strong agreements and 11 simple agreements, totalizing 16 agreements; 7 strong disagreements and 22 simple disagreements, totalizing 29 disagreements; 5 students with no opinion. In brief, only 16 students (out of 50) found the instructional approach as unfitting.

Additional considerations relative to the instructional units, used, respectively, in the first and second research runs, are made in the next chapter.

III-6.2 The Laboratory Experiments and Tests

In both research runs, nearly 80 students from the three experimental groups (taken from the two course sections) performed five laboratory experiments and tests. The five experiments were named:

L_1 - Experimental Study of a Simulated Electrostatic Field
L_2 - Linear and Nonlinear Resistors (Ohm's Law)
L_3 - Resistor and Capacitor in Series Circuit
L_4 - Experiments of Magnetism (Projection of Ealing Film-loops)
L_5 - Electromagnetic Induction

Special laboratory guides (see Appendix C) were prepared for use in each laboratory experiment, excluding the L_4 which consisted of film-loop projections. All students received the same laboratory guides.

Each laboratory guide consisted of a brief introduction, a theoretical background of the experiment, and a discussion of possible practical difficulties. Next, suggestions were given for an experimental procedure requiring performance and answers to some questions concerning the application of the previous instructions. Finally, the laboratory guide instructed students on what they should present at the end of the experiment: tables of measurements, graphs, numerical computations, and answers to some final questions.

About one week before the laboratory class, students received in advance the corresponding guide, as well as practical orientations for the next experiment; therefore, they had opportunity to get a general and preliminary overview of the next lab.

Let us now describe how the laboratory experiments and tests were carried out.

A. The First Three Laboratory Experiments and Tests

In both research runs, the first three experiments were performed by students working in groups of 4 students/group as it is usual in the "traditional" laboratory classes of the Physics II course. Each group worked in a separate laboratory table provided with laboratory kit.

In the pilot study, after one and a half hour of laboratory work, oriented by the laboratory guide, the teacher and a teaching assistant, each student had half an hour for a brief individual test in which he/she was asked to apply the epistemological framework to the analysis of the experiment. The accomplishment of these tests at the final 30 minutes of the two-hour laboratory class indicated two main shortcomings:

(a) students had not enough time to perform the experiment;

(b) the testing time was also unsatisfactory for a complete evaluation of students' learning.

Let us detail this last aspect. In the pilot study, to ensure that each student's answers to the test questions were his/ /her own, we elaborated four different versions of the first two tests; therefore, each student was not stimulated to share answers with his/her neighbours. This also permitted to reduce each test size to fit in the limited time of 30 minutes. Of course, there was a disadvantage: each student had not an opportunity to answer all the questions involving the use of the Analytical Method (epistemological framework); consequently, he/she lost part of the educative experience that he/she could have got by answering all the questions. This shortcoming was in part reduced by giving the students a second test (in the second laboratory work) with questions different from those of the first one. For these reasons, in the third test used in the pilot run we changed the testing approach: the third test was the same for all the students and it was applied during a period of 45 minutes taken from a lecture which came one or two days after the laboratory work. This approach also provided more time to the students to carry out the third lab experiment. However, a different kind of disadvantage might have resulted from the time gap between the actual laboratory work and the corresponding laboratory test (one or two days, depending of the course section), as well as from the additional testing time (45 minutes) which was used in detriment of the lecture.

In the second research run, for the first three experiments, this more appropriate (although still imperfect) approach of laboratory testing separated from the laboratory work was repeated mainly to meet time, administrative and evaluative constraints. It allowed the elaboration of just one refined type of test instead of four different test versions for a same experiment; in addition, all students answered the same type of test in each one of the first three laboratory experiments. Consequently, we also got a bigger test sample size which ended up as an improvement in terms of statistical analysis. Also, only in the second research run, students of the two course sections had a common two-hour lecture per week; therefore, three times along the semester (for the first three tests), it was possible to take 45 minutes from one of that lectures for a common laboratory test individually answered but performed at the same time by all the students.

B. The Fourth Laboratory Experiment and Test

In the fourth laboratory experiment, each course section was divided into five groups, with nearly 7 students/group, for the projection of five Ealing film-loops (about magnetism experiments) specified in Appendix C. Each group received a projector and a film-loop for analysis using the Analytical Method (epistemological framework).

In the pilot run, each group answered a same test, i.e., each group of nearly 7 students worked all together elaborating a Vee for a specific film. At the end of the class each group projected and explained to the other group the film they had analysed.

In the second research run, the program for the fourth laboratory was approximately the same but with three main modifications: (a) the test was revised and refined, (b) each student answered his/her own test, and (c) the teacher (researcher) projected and commented each film in terms of the Vee at the end of the class, i.e., after the laboratory test.

C. The Fifth Laboratory Experiment and Test

The fifth lab had very different approaches in the two research runs. First, in the pilot run, the fifth lab was carried out like the first three labs: 4 students working together as described before. However, in the second research run, the fifth lab content was divided into three different parts (relative to three different events or phenomena) and each student worked alone with no lab guide but with a lab test for one specific event. These three specific events are described and analysed in the next chapter (see also the three versions of the fifth test in the next chapter). Our objective, with this approach for the fifth lab in the second study, was to test each student in the proposed third level of achievement of the epistemological framework: "application" of the epistemological framework to a new situation in order to obtain knowledge claims (see the "Third Level" of achievement specified in Section III-1).

To permit this kind of individual work, the two hours of the laboratory class were divided into four periods of 30 minutes and a group of nearly 7 students/group was scheduled to each period; thus, each student had a maximum of 30 minutes to work with the lab equipment (focusing and analysing one of three specific events) and an additional half an hour for completing his/her lab test but without the use of the equipment now already being in use by another colleague. The three different lab tests were distributed at random at the beginning of the lab work. This approach for the fifth lab worked quite well and allowed individual work and testing of the third level of achievement as the reader will see in the next chapter.

We were positively surprised with the students' enthusiasm with this fifth lab approach; they liked the work conditions and the new challenging situation that required individual thought and application of the epistemological framework (See students' opinions in the Appendix G).

III-6.3 The Development of the Formative Evaluation Activities

In Section III-3, we described and justified the use of the three instructional and formative evaluation strategies, namely: Individualized Clinical Interviews (C.I.), Group Discussions (G.D.), and Written Feedback (W.F.). As said before, each student participated in only one of these three strategies.

In both research runs, the C.I. and the G.D. strategies were used three times during the course: initially, after the first lab and test; second, after the third lab and test; finally, before the fifth (last) lab and test. The W.F. approach was used after each laboratory test except the fifth one (when students answered the Final Questionnaire).

Each one of the three clinical interviews lasted 30 minutes and the time period of each group discussion session was 45 minutes. Each one of the additional written communications(four times along the course), through the corrected lab tests, which represented the W.F. treatment, took us an average time of 15 minutes per test (student).

The number of students assigned to each one of the three treatments is specified in Section III-5. The objectives of each set of C.I., or G.D., or W.F. activities are presented in the next chapter together with the data analysis of students' participation in each treatment.

III-6.4 The Final Questionnaire

In both research runs, after the fifth (last) lab test, students answered a Final Questionnaire. The aim of this questionnaire was to collect students' opinions and final critical comments relative to their participation, difficulties, and learning insights in the understanding and use of the epistemological Vee that they had just finished to work with in the Physics II laboratory context. The content and the analysis of students' answers and opinions expressed in the Final Questionnaire are presented in the next chapter.

Chapter IV

DATA ANALYSIS

IV-1 Introduction to the Data Analysis

In this chapter we will present mainly the analysis of data of the second research run because, as we pointed and commented earlier in Chapter III, several shortcomings happened in the first (pilot) research run. These shortcomings, which were corrected in the second research run, were the following:

a) the three experimental groups were not all randomly selected (as mentioned in Section III-5);

b) the number of 10 students per sub-group was too large for the purpose of group discussions (as pointed also in Section III-5);

c) the separation of the instructional units about the Analytic Method in two parts (the "six questions" and the Vee) was not an efficient approach for the Physics II course context with only five laboratory experiments (See Section III-6.1);

d) the accomphishment of the two first laboratory tests at the final 30 minutes of a two-hour laboratory class caused two main shortcomings: the students had not enough time to perform the experiment, and the testing time was also unsatisfactory for a more complete and worthwhile evaluation of students' learning (as commented in Section III-6.2, A);

e) the fourth laboratory test was answered by sub-groups of nearly 7 students working all together and, consequently, each student did not answer alone his/ /her own test (See Section III-6.2, B);

f) the evaluative approach of the fifth laboratory test did not permit testing each student in the proposed third (higher) level of achievement: application of the structure of knowledge to a new situation in order to obtain knowledge claims (See comments in Section III-6.2, C).

These shortcomings of the first (pilot) research run were eliminated in the second run as explained in the same sections of Chapter III pointed above. In addition, in the second run there was a general improvement in the content of the instructional units about the Vee, in the content of the laboratory guides, in the discriminative power of the laboratory tests, in the formative evaluation activities, and in the final questionnaire.

Taking into account all these reasons mentioned earlier, we will direct this chapter mainly to the analysis of data collected in the second research run; however, when analysing the answers given by students to the final questionnaire, we will also include and analyse the ones given by students of the first research run. This will permit the reader to get an additional overview of the pilot research run and to perceive some of the improvements made in the second run. Indeed, we conclude this introduction to the data analysis emphasizing that, coherent with the concept of formative evaluation

(Section II-4 and Appendix B), the pilot research run was quite worthwhile mainly because it permitted detection of those shortcomings in time to correct deficiencies and promote improvements in the research design, materials and activities for the second research run.

IV-2 Data Analysis of the First Laboratory Experiment and Test

In the second research run, anticipating the first laboratory experiment and test, the students received the first two instructional units about the Analytic Method (Gowin's Epistemological Vee) that are shown in Appendix A. In order to discuss and clarify the content of these written instructions about the Vee, two periods of half an hour each one (in two different days) were used from the lectures. The students also received the laboratory guide of the first experiment (Appendix C) in advance. Appendix D shows the Vee and concept map that were used as a reference for the construction of the first laboratory guide and test as well as for the evaluation of the students' performance in the first test.

Table 1 shows the 10 questions included in 6 items of the first laboratory test; the means and standard deviations of answers given by 74 students to the questions are indicated. The results and some statistics of the first test are summarized in Table 2.

Table 1. First Laboratory Test. Questions are about the "Experimental Study of a Simulated Electrostatic Field" laboratory experiment. The means and standard deviations of answers given by 74 students to the questions are indicated.

Question	wrong — correct (0 .5 1.0) Mean	SD
1. a) Indicate the basic electric event (phenomenon) which you made happen in this lab experiment.	.43	.42
b) Why did we use the term "simulated" in the title of this experiment?	.30	.42
2. Mention one of the basic (telling) questions that you answered when you performed this experiment.	.74	.40
3. With regard to the theoretical (conceptual) background of the experiment:		
a) Indicate the key concepts (the fundamental concepts) involved in the experiment.	.58	.28
b) Show briefly how these key concepts are logically and mathematically related among themselves.	.34	.28
4. Concerning the experimental procedure:		
a) Measurements: Indicate the measurements (records of events) that you made, i.e., what did you measure?	.77	.32
b) Transformations: Describe how you transformed the measurements, i.e., what did you make with the measurements? (Indicate how the conceptual domain oriented you on these transformations).	.68	.36
c) Interpretations: Indicate how you interpreted the data (the transformed records) in order to obtain an answer to the basic question which you mentioned in the item 2 before. (Show how the theory guided you on these interpretations).	.52	.46
5. Express the knowledge claim you established as the answer to the basic question which you indicated in the item 2 before.	.50	.45
6. What is a possible value claim for a) the knowledge claim that you indicated in the question 5 above? b) the whole experiment you performed?	.51	.40

Table 2. Data of the First Laboratory Test.

Question		% of the scores of 74 students			Mean Score	Standard Deviation
Item	Content	0 Wrong	0.5 (±)	1.0 Correct	Difficulty and Discrimination Levels	
1.a	Event	45	24	31	0.43 difficult	0.42 good
1.b	The term "simulated"	63	14	23	0.30 very difficult	0.41 good
2	Basic (Telling) question	19	15	66	0.74 very easy	0.40 good
3.a	Key concepts	9	65	26	0.58 easy	0.28 intermediate
3.b	Relationships among concepts	37	59	4	0.34 very difficult	0.28 interme.
4.a	Measurements (Records of events)	8	30	62	0.77 very easy	0.33 good
4.b	Transformations of measurements	15	35	50	0.68 easy	0.36 good
4.c	Interpretations of data	39	18	43	0.52 intermediate	0.46 good
5	Knowledge claims	39	22	39	0.50 intermediate	0.45 good
6	Value claims	31	35	34	0.51 intermediate	0.41 good

Total Mean: 5.4 *.

Standard Deviation of the Total Mean: 1.9.

Reliability Coefficient of the Test: 0.67**.

Standard Error of the Measurement: 1.1.

*Maximum value of the Total Mean = 10.0 .

**Calculated by a Kuder-Richardson formula (Ebel, R.L., 1972, p.419).

In Tables 1 and 2 we can observe that:

a) the group of students had poor means (less than 0.50) in questions 1.a, 1.b, and 1.c, that is, in the identification of the basic event (phenomenon), in the elucidation of the term "simulated"[1] used in the tittle of the experiment, and in the description of the relationships among concepts;

b) the group of students got intermediate means (nearly 50% of the maximum score) in the questions 3.a, 4.c, 5, and 6, that is, in the identification of the key concepts, in the interpretations of data, and in the expression of knowledge and value claims;

c) the group of students obtained higher means in questions 2, 4.a, and 4.b, that is, in mentioning a telling (basic) question, in indicating the measurements, and in describing the transformations of measurements.

In the question concerning the identification of the basic event, 45% of the 74 students received a zero (minimum) score because they gave wrong or incomplete answers such as: "electrostatic field", or "production of an electric field", or "study of electric lines of force (or of electric equipotential lines)". In the same item asking the

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(1) The electrostatic field is "simulated" because it is not actually static: there are weak electric currents due to the motion of ions in the water layer (as explained in the Considerations of Practical Nature of the first laboratory guide shown in Appendix C). These currents permit measurements by the voltmeter.

identification of the basic event, we intentionally asked about the term "simulated" used in the title of the experiment, in order to stimulate students' attention to the actual event(2). This clue, however, did not help students much because they also got very poor scores in the question: 63% of the 74 students gave wrong explanations, and only 23% of the students actually knew the reason of being of the term "simulated".

In the formulation of a telling question of the first experiment, it was particularly surprising to us to see nearly 19% of the students proposing "Are the electric lines of force perpendicular to the equipotential lines?" as a telling (basic) question. This cannot be a telling question of the first experiment because the experimental procedure followed by the students did not permit a check on this perpendicularism already known from the theory. In other words, the performed experimental procedure did not provide separately the two families of lines, the equipotential lines and the lines of force, for posterior superposition in order to verify the existence (or non existence) of the perpendicularism between the two families.

In the description of the relationships among the key concepts (represented through a concept map in Appendix D), only 4% of the 74 students obtained the maximum grade and 37%

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(2) In the Vee of the first experiment (Appendix D) we describe the basic event: electric potential difference from an electric power supply producing an electric field which produces weak ionic currents in a tank with a fine layer of water.

received the minimum (zero) score. Indeed, the students' difficulty in the description of the concept relationships remained, to a certain extent, during the next four laboratory experiments as the reader will see in the analyses of the other tests.

Concerning the interpretations of data (question 4.c), 57% of the students did not obtain the maximum grade because they confused the interpretations of data with the transformations of measurements, or because they tried to interpret the data without the correct use of the theoretical background. Other students obtained the minimum score in the question because they were not specific in their answers: they indicated general interpretations or knowledge claims not based on data.

The students' main mistakes in questions 5 and 6, namely the statements of knowledge and value claims, were: to provide a knowledge claim to an incorrect telling question and to repeat a knowledge claim already stated through other words as being a value claim (without any connotation of importance or usefulness for the results or for the whole experiment). Actually, also in the pilot research run students had difficulties in stating value claims and philosophies and, consequently, in the second research run we gave up asking them what philosophy (world view and system of values) was underlying the theory, the experiment, and the value claims.

Table 2 shows the difficulty and the discrimination levels of the questions of the first test. The criteria which we used to estimate the difficulty level of each question (difficulty for the group of students) is shown in Table 3.

Table 3. The criteria used to estimate the difficulty level of each question of the laboratory tests.

Mean Score of the Question	Difficulty Level
Higher than 0.70	Very easy
Between 0.55 and 0.70	Easy
Nearly 0.50	Intermediate
Between 0.35 and 0.45	Difficult
Lower than 0.35	Very Difficult

The criteria which we used to estimate the discrimination level of each question was mainly based on the numerical value of the standard deviation of the mean of each question; the criteria is presented in Table 4.

Table 4. The criteria used to estimate the discrimination level of each question of the laboratory tests.

Standard Deviation of the Mean Score of the Question	Discrimination Level
Higher than 0.30	Good
Between 0.20 and 0.30	Intermediate
Lower than 0.20	Poor

According to these criteria, e.g., the students had very much difficulty in answering the questions 1.b (the term "simulated") and 3.b (relationships among concepts). These criteria also indicate, e.g., that the questions 3.a (key concepts) and 3.b (relationships among concepts) had intermediate discrimination because the standard deviations of the means of these two questions were not quite high (0.28).

Table 2 also shows the total mean score of the first test, 5.4, and its standard deviation, 1.9. It also shows the reliability coefficient(3) of the test, 0.67, and the standard error of the measurement(4), 1.1. The latter statistics permits us to say that, under a confidance of 68%, the true score of a student, for example, who received a grade 5.0 would be between 3.9 and 6.1 .

Table 5 shows the key concepts of the first experiment as indicated by the students.

The very low number of indications to the "electric current" concept is coherent with the very poor grades obtained by the students in the first two questions, i.e., in the identification of the basic event and in the elucidation of the term "simulated" of the title. In order to answer correctly these two questions, it is necessary, at first, to perceive the electric current as a very fundamental concept of the experiment and 61 out of 74 students did not perceive it.

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(3) Calculated by a Kuder-Richardson formula (Ebel, R.L., 1972, p. 419).

(4) See Ebel, R.L., 1972, pp. 423-424.

Table 5. Key concepts indicated by 74 students in a question of the first laboratory test about the "Experimental Study of a Simulated Electrostatic Field" laboratory experiment.

Key Concepts and Number of Indications from 74 Students	
Electric Potential or Electric Potential Difference	61
Electric Field	59
Lines of Force	39
Equipotential Lines	30
Electric Charge	24
Lenght or Distance	18
Electric Force	15
Electric Current	13
Electric Flux	11
Resistance or Resistivity	7
Vector	2
Symmetry	1
Work	1

It was particularly surprising to this author to see the low number of indications of some very fundamental physics concepts. Concepts such as "lines of force" (39 indications) and "equipotential lines" (only 30 indications out of 74 students) were quite important concepts for the experiment but they received low number of indications. Even more, how can we explain why 13 students (out of 74) did not indicate the concept of electric potential (or electric potential difference), or why 15 students did not mention the concept of electric field? They were very key concepts of the first experiment.

Most concepts indicated by the students and shown in Table 5 are actually key concepts. However, we consider that the concept of electric flux (11 indications) is not quite fundamental for the first experiment. The concept of work (just one indication), of course, is not a key concept. The concepts of resistance or resistivity (7 indications) are actually key concepts because they are associated with the concept of the electric current of the water layer. Finally, we consider that the concepts of vector and symmetry are more mathematical than physics concepts.

In the following section we describe the first clinical interviews, group discussions, and written feedback that were performed having the first test results as a main reference. Then, we complete the analysis of students' performance in the first test and we infer some reasons why students gave poor number of indications for some very fundamental concepts of the first laboratory experiment.

IV-3 The First Set of Formative Evaluation Activities

As we mentioned earlier in Section III-3, three different instructional strategies with formative evaluation were used in addition to the laboratory tests: the Clinical Interview (C.I.), the Group Discussion (G.D.), and the Written Feedback (W.F.) strategies. The objective of these strategies was to evaluate and provide feedback to the students in the understanding and use of the Analytic Method (Vee), and also to get additional information for instructional and research purposes.

The rationales for the clinical interviews and the group discussions (Appendixes E and F), as well as the students' performance in the first laboratory test, were the main references for the development of the first set of C.I., G.D., and W.F. activities.

Each C.I. lasted 30 minutes and was individually conducted with 24 students; just one student of the C.I. group dropped out of the Physics II course.

Four G.D. sessions, with 5 students per session and lasting 45 minutes each one, were conducted with a total of 20 students. By the time of the first group discussions, 3 out of the 23 students of the G.D. experimental group had already dropped out of the course.

The W.F. communication was developed with 25 students and, as we mentioned in Section III-6.3, each W.F. took us an average time of 15 minutes per test (student). At that time of the first W.F., just one student of the W.F. experimental group had dropped out of the course.

Next, we summarize some information and key regularities detected by the first set of formative evaluation activities; they are concerning the students' conceptions, misconceptions, feelings, and patterns of thinking in the understanding and use of the Vee in the laboratory context.

IV-3.1 Analysis of the First Clinical Interviews

The following inferences about students' performance in the understanding and use of the Vee could be made with the help of information collected by the first set of clinical interviews:

a) The students asserted that they would need more time and practice to acquire understanding and mastery in the use of the Vee.

b) Most students perceived that an improvement in their sense of critical appraisal was needed.

c) Most students had insufficient understanding of the theoretical background (left side of the Vee) when performing the experiment, although they had received the laboratory guide in advance and also lectures concerning the same theory.

d) We can also infer that most students were not used to answering the kind of question requiring the indication of key concepts.

e) Most students actually did not know how to connect the theoretical and the experimental domains of the structure of the first laboratory experiment (left and right sides of the Vee).

f) Most students did not know how to identify the event correctly because they were not used to verifying what was being measured and how it was being measured. This analysis could help the students because the measurements are records of the events.

g) The students had an additional difficulty in the correct identification of the event because they did not know the working system of a voltmeter which needs an electric current in order to indicate an electric potential difference between two points of a water layer.

h) Many students obtained a poor grade in the first test mainly because they made a chain of mistakes originated in the formulation of a wrong telling (basic) question at the beginning of the test. For example, one student indicated the worthless question: "Is the voltage constant along an electric equipotential line?". Other students, as mentioned before in Section IV-2, wrongly indicated the question "Are the lines of force perpendicular to the equipotential lines?" that was not answered by the first experiment.

i) Several students indicated a small number of concepts because in the question of the test it was not specified the number of key concepts that should be indicated. For this reason, in the following two tests, we required the indication of eight key concepts because we found this number (eight) as appropriate for the theoretical background of the two following experiments.

j) Most students were not used to expressing relationships among concepts via several ways such as mathematical equations, definitions, and logical relationships given by practical rules, principles, and laws.

k) Some students indicated a knowledge claim completely dissociated from the telling question that they had indicated before in the test. In other words, they lost the objective of the experiment by not connecting the answer (knowledge claim) with the initial telling question.

IV-3.2 Analysis of the First Group Discussions

As we mentioned before, a week after the first laboratory test, four group discussions (G.D.) sessions were conducted with 5 students per session lasting 45 minutes each one.

The group discussions were performed with the purpose of sharing meanings and feedback for both students and teacher (researcher).

For development of the first group discussions, the main references were the first laboratory test and the equipment and materials of the first experiment.

Now, we briefly describe the content of each one of the four group discussion sessions.

1. In the first session the discussions evolved around:

   1.a. The existence of the electric field $\vec{E}$ producing electric forces $\vec{F} = q\vec{E}$ on the ions of charge q of the water and ionic currents in the fine layer of water.

   1.b. The basic event of the experiment and, consequently, the ionic currents and the working system of the voltmeter.

1.c. The perpendicularism between the lines of force and the equipotential lines that was already known from the theory; the $V_B - V_A = -\int_A^B \vec{E}.d\vec{\ell}$ and the $\vec{E} = -\vec{\nabla}V$ equations were reviewed.

2. In the second session the group discussion developed about:

   2.a. The meaning and power of a concept and what concepts were the most fundamental in the first experiment.

   2.b. The relationships among the concepts.

   2.c. The perpendicularism between the lines of force and the equipotential lines (as in the item 1.c).

   2.d. The reasons why the electric potential is constant or the electric field equals zero inside a metallic cylindrical tube placed in the water layer.

3. In the third session, students preferred to discuss:

   3.a. The value, significance, and utility of the Analytic Method (Vee).

   3.b. The structure and organization of a laboratory experiment and of the Analytic Method.

4. In the fourth session, the following aspects were discussed:

   4.a. The basic event of the first experiment (as in the item 1.b).

   4.b. What content already known from the theory was or was not verified practically by the first laboratory experiment.

Analysing the content of the group discussions, which was chosen spontaneously by the students at the moment of the session, we can see that the content reflects the students' main difficulties in the first test, that is, difficulties in the correct description of the event, the working system of the voltmeter, the theoretical background (concepts and relationships among concepts), and the purpose of the experiment. The content selected by the students in the third session also reflects students' interest in aspects of value, structure, and organization of both the Vee and the laboratory experiment.

The information collected by the group discussions (concerning the students' needs, difficulties, and misconceptions) confirmed, in great part, the one collected by the clinical interviews and by the written feedback which we describe next.

IV-3.3 Analysis of the First Written Feedback

The written Feedback (W.F.) of the first laboratory test was carried out with 25 students. Each student received back his/her test corrected by the same criteria as the tests of the C.I. and G.D. students were corrected; however, additional written comments and requirements for written remedial work were made such as the completion of an answer to a certain question, the elucidation of a given answer, and the correction of a wrong answer.

Now, we describe how the 25 students of the W.F. experimental group performed the written feedback of the first test.

Through the first written feedback, the 25 students identified, and/or described, and/or explained:

1. The event:

   Completely correct: 5 students but one of them included measurements and transformations (out of place in the question which was concerned only with the event).

   Completely incorrect: 3 students.

   Partly (about 50%) correct: 3 students; one of these students provided a general description without indicating the main source of evidence.

2. The term "simulated":

   Completely incorrect: 9 students.

   Completely correct: 6 students; one of them complemented his answer with a correct explanation about the working system of a voltmeter.

   Partly (about 50%) correct: 2 students.

3. The telling (basic) question:

   Completely correct: 5 students. About 50% correct: 1.

   Completely incorrect: 1.

4. The key concepts:

   Completely correct: 5 students.

   Not completely correct: 4 students; 3 of them missing the concept of electric current and one student indicating some concepts with no importance.

5. The relationships among concepts:

   Not completely correct because still missing very important relationships: 9 students.

Completely correct: 8 students.

Very poorly: 4 students; one of these students indicating some relationships with no importance and another student indicating very particular relations as being general ones.

6. The measurements:

   Completely correct: 4 students.

   Partly (about 50%) correct: 3 students; 2 of them without specifying where the electric potential difference was measured and the other using just the term potential instead of potential difference.

7. The transformations of measurements:

   Completely correct: 8 students.

   Completely incorrect: 4 students; 2 of them without indicating how the theoretical information (that the lines of force are perpendicular to the equipotential lines) had oriented the transformations.

8. The interpretations of data:

   Completely correct: 5 students.

   Partly (about 50%) correct: 4 students; one of them confusing interpretations with knowledge claims.

9. The knowledge claims:

   Completely correct: 5 students.

   Completely incorrect: 2 students; one of them still without knowing that it is an answer to a question. About 50% correct: 1 student indicating more than was asked and answered through the experiment.

10. The value claims:

    Completely incorrect: 13 students; 7 of them still without knowing to express a value; 2 of them confusing value claims with theoretical aspects; 2 of them writing too much but without expressing a value for the knowledge claims or for the whole experiment. Completely correct: 8 students.

It was particularly surprising to us to observe that, even with a second opportunity through the written feedback, a significant number of students did not perform an acceptable written review in the three questions concerning the term "simulated" (9 students), the relationships among concepts (13), and the value claims (13). We have to emphasize that students performed the written feedback out of the class, with free amount of time to perform the written revision, and they could consult their books, notes, and colleagues. Considering the above information, we can conclude that a significant percentage of students had actually very much difficulty in answering these three questions, or that they were not sufficiently motivated to perform the work.

The information obtained by three different channels (the C.I., the G.D., and the W.F.) permitted us to comprehend some of the students' basic difficulties in the understanding and use of the Vee in the first laboratory experiment and test. This information provided material for the elaboration of a third instructional unit about the Analytic Method that is shown at the end of the Appendix A. Coherent with a formative evaluation approach, this third instructional unit aimed to help students to overcome their difficulties and misconceptions in the understanding and use of the Vee that were detected through the first test and the first set of formative evaluation activities.

At the end of this chapter, we intend to make a final comparison of the total time involved in the development of the three formative evaluation strategies. Then, we conclude this section by showing the approximate total time used to carry out each one of the three formative evaluation activities after the first test:

- Clinical interviews:
  23 students x 30 minutes/student (interview) = 11.5 hours.
- Group discussions:
  4 sessions x 45 minutes/session = 3.0 hours.
- Written feedback:
  25 students x 15 minutes/student = 6.25 hours.

At the end of the first set of formative evaluation activities (and still now), this researcher had the impression that the highest amount of information for research and for instructional feedback (for the teacher) resulted from the clinical interviews. A possible factor that determined this accepted (by the researcher) higher amount of information could be the higher amount of total time used for the clinical interviews in comparison with the ones of the two other strategies.

IV-4 Data Analysis of the Second Laboratory Experiment and Test

A week before the second laboratory experiment and test, in the second research run, the students received the third instructional unit about the Analytic Method, which is presented in the final part of the Appendix A, as well as the laboratory guide of the second experiment (Appendix C).

Figure 5 shows a Vee for the second laboratory experiment.

Table 6 shows the 10 questions included in the six items of the second laboratory test. This table also indicates the means and standard deviations of answers given by 67 students to the questions. Table 7 summarizes the results and some statistics of the second test. Table 8 shows the key concepts of the second experiment as indicated by the students in the question 3.a of the second test.

In Table 6 we can observe that the students obtained high means in all questions except in the question 3.b, which asked students to write a definition which they had considered the most important one in the experiment. This students' difficulty deserves some comments that we will present later.

The questions of the second test are very similar to the ones of the first test, i.e., we just changed two questions of the first test: first, we excluded the question about the term "simulated" (which has no meaning in the second experiment) and, second, instead of asking directly the relationships among concepts we asked a definition and the Ohm's Law which, of course, relate concepts.

Comparing Tables 6 and 7 with Tables 1 and 2 we can see that there was an improvement in students' understanding and use of the Vee from the first to the second test. This improvement happened in the proposed (in Section III-1) first

TELLING (BASIC) QUESTION:
Does each resistor (common resistor, light bulb, NTC and LDR resistor) follow Ohm's Law?

CONCEPTUAL

PHILOSOPHY:
Scientific knowledge about nature lies in observation and experiment based on theories that organize our facts, reasoning, deepening our understanding.

THEORY:
Theory of electrodynamics.

PRINCIPLES AND LAWS:
Ohm's Law: $R = \frac{V}{I}$ = constant when the temperature T is constant.

DEFINITIONS:
Electric resistance R, current I, potential difference V, field; linear resistor, conductor, etc.

RELATIONSHIPS AMONG CONCEPTS:
See the Theoretical Background of the second laboratory experiment in Appendix C.

KEY CONCEPTS:
See Table 6 and add the concepts of speed, metallic conductor, ion, and linearity.

INTERPLAY

METHODOLOGICAL

VALUE CLAIMS:
The whole experiment allows the training of some basic laboratory skills.
The knowledge claims show that Ohm's Law is a very particular law.

KNOWLEDGE CLAIMS:
The resistor is (is not) linear and the temperature is (is not) constant; therefore the resistor follows (does not follow) Ohm's Law.

INTERPRETATIONS:
Graphical analysis (R is or is not linear). If R is linear and T is constant, the resistor follows Ohm's Law.

TRANSFORMATIONS:
Tables, V vs. I graphs, calculations of R = V/I and of average R.

OBSERVATIONS:
Changes of temperature T and/or luminosity.

MEASUREMENTS:
10 records of electric potential differences and the corresponding electric currents across each resistor. Direct measurements of electric resistances R with a ohmmeter.

EVENT:
An Electric potential difference (V) applied on a resistor (common, or light bulb, or NTC, or LDR) establishes a direct electric current I.

Figure 5. A Vee for the "Linear and Nonlinear Resistors (Ohm's Law)" laboratory experiment.

Table 6. Second Laboratory Test. Questions are about the "Linear and Nonlinear Resistors (Ohm's Law)" laboratory experiment. The means and standard deviations of answers given by 67 students to the questions are indicated.

Question	wrong — correct (0 .5 1.0) Mean	SD
1. Indicate the basic electric event (phenomenon) which you made happen in this lab experiment.	.89	.20
2. Mention one of the basic (telling) questions that you answered when you performed this experiment.	.92	.17
3. With regard to the theoretical (conceptual) background of the experiment:		
a) Indicate eight key concepts (eight concepts which you consider the fundamental) involved in the experiment.	.78	.24
b) Write the definition which you consider the most important in this experiment.	.34	.37
c) Enunciate the Ohm's Law. Be very precise.	.73	.41
4. Concerning the experimental procedure:		
a) Measurements: Indicate the measurements (records of events) that you made, i.e., what did you measure?	.97	.14
b) Transformations: Describe how you transformed the measurements, i.e., what did you make with the measurements? (Also indicate how the conceptual domain oriented you on these transformations).	.82	.24
c) Interpretations: Indicate how you interpreted the data (the transformed records) in order to obtain an answer to the basic question which you mentioned in the item 2 before.	.93	.17
5. Express the knowledge claim you established as the answer to the basic question which you indicated in the item 2 before.	.76	.30
6. What is a possible value claim for a) the knowledge claim that you indicated in the question 5 above? b) the whole experiment you performed?	.80	.28

Table 7. Data of the Second Laboratory Test.

Question		% of the scores of 67 students			Mean Score	Standard Deviation
Item	Content	0 Wrong	0.5 (±)	1.0 Correct		
1	Event	0	22	78	.89	.20
2	Basic (Telling) question	0	16	84	.92	.17
3.a	Key concepts	0	45	55	.78	.24
3.b	Definition	49	33	18	.34	.37
3.c	Ohm's Law	21	12	67	.73	.41
4.a	Measurements (Records of events)	1	3	96	.97	.14
4.b	Transformations of measurements	1	33	66	.82	.24
4.c	Interpretations of data	0	15	85	.93	.17
5	Knowledge claims	6	36	58	.76	.30
6	Value claims	5	31	64	.80	.28

Total Mean: 7.9*

Standard Deviation of the Total Mean: 1.2.

Reliability Coefficient of the Test: 0.51**.

Standard Error of the Measurements: 0.82.

* Maximum value of the Total Mean = 10.0

** Calculated by a Kuder-Richardson formula (Ebel, R.L., 1972, p. 419).

Table 8. Key concepts indicated by 67 students in a question of the second laboratory test about the "Linear and Nonlinear Resistors (Ohm's Law)" laboratory experiment.

Key Concepts and Number of Indications from 67 students	
Electric Potential or Electric Potential Difference	67
Electric Resistance	67
Electric Current	67
Temperature	57
Electric Field	41
Light	34
Resistivity	27
Electric Charge	26
Energy	10
Conductivity	10
Heat	9
Time	8
Power	7
Conductor	4
Resistor	3
Work	3
Force	3
Electric Polarization	2
Current Density	1
Photon	1
Temperature Coefficient of Resistivity	1

level of achievement of the epistemological framework, i.e., in the classification of the parts of the structure of knowledge of a laboratory experiment.

Of course, we do not contend that the increase in the total mean score of the second test in comparison with the one of the first test, that is, 7.9 minus 5.4, reflects the amount of improvement. This claim cannot be made because of three main reasons. First, the two tests refer to two different laboratory experiments. Second, two out of 10 questions were different in the two tests and contributed with 0.43 in favour of the total mean of the second test. Third, because 8 out of 10 questions of the first two tests were practically the same, the increase in the total mean score not only reflects students' growth in the understanding and use of the Vee but also reflects a higher familiarity of the students with the questions in the second test. This higher familiarity was surely very helpful to the students and must be emphasized mainly because a non-traditional laboratory test was in use.

Even considering the interference of these three factors, i.e., the differences between the two experiments, the contribution of the two different questions for the increase of the mean of the second test, and the higher familiarity of the students with the questions in the second test, we contend that there was an improvement in students' capacity to classify the parts of the structure of a laboratory experiment. We do not know the amount of this student improvement but we are quite sure that it happened in the second laboratory experiment and test in relation to the first one.

This improvement of the students does not surprise us because we already expected it. In Section II-2 we assumed that the Physics II laboratory work usually was not effective and its potential was not duly explored because, in part, the students usually were not provided with an epistemological framework that could guide them to the understanding and description of a laboratory experiment. We intentionally provided students with an epistemological framework (the Vee) in order to allow their improvement in that understanding and description.

In addition, according to Gowin's triadic model for teaching (described in Section II-4), we think that by giving our meanings through instructional materials about the Analytic Method (the Vee) to the students and receiving their meanings through the laboratory work, the tests, and the formative evaluation activities, an exchange of meanings probably occurred. However, because there is not a necessary causal relationships between teaching and learning(5), we concentrated our effort in the organization of instructional and evaluative conditions that could maximize the probability of students' learning by using formative evaluation approaches.

Let us now return to the students' difficulty in writing a definition (Question 3.b of the second test). The

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(5) Learning is an idiosyncratic process, under the responsibility of the learner, or, as Gowin (1981) says, "learning is a responsibility that cannot be shared".

definition could be the one of the meaning of the electric resistance, or the electric current, or others. In Table 7 we can observe that 49% of the students obtained the zero (minimum) score in this question 3.b. Based on information that we collected later through the second set of formative evaluation activities (performed between the third and the fourth laboratory experiments) we can infer that, at the time of the second test, the students' difficulty in the identification and statement of a definition reflected that:

a) the training in the identification and statement of definitions was lacking to the students;
b) the students had difficulty in expressing relationships among concepts (that also may be expressed by a definition);
c) the students misconceived the definition of electric resistance as being the Ohm's Law, i.e., they wrongly used the general definition of electric resistance as being the Ohm's Law(6) and, consequently, they did not use the definition of electric resistance as an answer to the question 3.b of the second test; in other words, they gave in question 3.c the answer that they should give in question 3.b;
d) the students thought that a concept could not be a

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(6) See the article "Ohm's law and the definition of resistance" by Colm T.O'Sullivan, 1980, Physics Education, Vol. 15, pp. 237-239. It is concerned with the confusion created when attempts are made to give a precise definition of electrical resistance and at the same time to introduce Ohm's law.

definition or defined, i.e., because they indicated the concept of electric current, e.g., in question 3.a of the second test, they thought that they could not define electric current in the question 3.b.

This latter students' misconception reflects that the students did not know one of the most important things we do with key concepts in physics and other fields of study, that is, to give concept definitions. As Gowin says:

> "Concept definition is similar to operational definition. The similarity is found in the relation between words and events. Basically to define a concept is to show the way the key term points to the regularities in the phenomena of interest, the selected events." (Gowin, 1981, Chapter 4).

Let us now analyse some statistics shown in Table 7. If we apply to the questions of the second test the same criteria, specified in Tables 3 and 4, that we used in Section IV-2 to decide about the difficulty and discrimination levels of the questions, we will obtain:

Difficulty level of the questions of the second test:

9 very easy questions;
1 very difficult question (the question 3.b requiring a definition).

Discrimination level of the questions of the second test:

3 questions with poor discrimination;
5 questions with intermediate discrimination;
2 questions with good discrimination (the questions 3.b and 3.c).

We can see that, applying those criteria, most questions were very easy for the students and that three questions had a poor discrimination level because three standard deviations of the means were quite low. We can say that the group of students became more homogeneous in the second test than it was in the first one. Consequently, the reliability coefficient of the second test (0.51) is lower than the one of the first test (0.67). According to the theory of statistics, this reflects that the group became actually more homogeneous. Scores obtained from heterogeneous groups are likely to be more reliable than scores obtained from homogeneous groups; that is, the more variable the scores obtained from a test, the higher its reliability is likely to be[7].

We infer that the group of students became more homogeneous as an effect of the formative evaluation approach which was used. Because reliability is lowered by the use of formative evaluation approaches (which tend to yield more homogeneous groups) there is a classic claim in statistics stating that the concept of reliability is incompatible with the concept of formative evaluation. In our research, we see the decrease of the reliability coefficient (from 0.67 to 0.51) as a possible additional index measuring the effects of the formative evaluation activities which were developed between the first two tests.

Let us see the key concepts indicated by the students (Table 8). The concepts with the maximum number of indications (67) are actually key concepts. The same we can say about the

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(7) A worthwhile analysis on test reliability is presented in "Essentials of Educational Measurement", by Robert L. Ebel, 1972, Ch. 15.

other indicated concepts except the concept of electric polarization (2 indications) which we consider with no importance for the second experiment. However, we are again surprised with the low number of indications that some very important concepts received from the students; such is the case of the concept of temperature: 10 (out of 67) students missed this important concept. Even more, these same 10 students also missed the concept of heat. This shows that these 10 students were not mastering the theoretical background of the second experiment mainly because temperature is a key concept present in the Ohm's Law which had the most important role in the experiment.

A second written feedback was carried out after the second test by 12 students. From 23 students of the written feedback experimental group which had taken the second test, only 12 students actually needed and performed the feedback; the other 11 students had had only minor mistakes and did not need it. From the 12 students, 10 made a very good written review of the test but one student still did not know how to express the Ohm's Law and another student still confused the concept of linear resistor with the concept of ohmic resistor, i.e., he still did not know that a resistor is ohmic when linear at constant temperature.

The second set of clinical interviews and group discussions were carried out after the third laboratory test. The data collected through these interviews and group discussions will be presented and analysed later in Section

IV-6. Now, let us analyse the third laboratory experiment and test.

IV-5 Data Analysis of the Third Laboratory Experiment and Test

As in the first two experiments, a week before the third laboratory experiment and test the students received the corresponding laboratory guide (Appendix C).

Figure 6 shows a Vee for the third laboratory experiment.

Table 9 shows the 7 questions included in the four items of the third laboratory test. This table also indicates the means and the standard deviations of the scores obtained from the answers given by 68 students to the questions. Table 10 summarizes the data of the third test. Table 11 shows the key concepts of the third experiment as indicated by the students in the question 2.a of the third test.

In Table 9 the reader can observe that modifications were made in the structure of the third test in comparison with the one of the first two tests. These changes were made mainly because, at the time of the third test, we were already satisfied in great part with the students' performance in the first level of achievement of the epistemological framework (Vee), that is, in the classification of the parts of the structure knowledge of a laboratory experiment. Consequently, we decided to evaluate students' performance mainly in the second level of achievement, that is, in the description of relationships among the parts of the structure of knowledge. Therefore, the third test contains questions which require

TELLING (BASIC) QUESTIONS:
a) What is the numerical value of the capacitative time constant RC?
b) Does the charging (discharging) process of a capacitor with the time follow the function (equation) foreseen by the theory?

CONCEPTUAL	INTERPLAY	METHODOLOGICAL
PHILOSOPHY: Scientific knowledge about nature lies in observation and experiment based on theories that organize our facts, reasoning, deepening our understanding. THEORY: Theory of electrical circuits. Theory of differential equations. PRINCIPLES AND LAWS: Conservation of charge (energy). Continuity of electric current. Kirchhoff's second law (loop theorem). DEFINITIONS: Electric resistance R, electric current I, capacitance C, capacitative time constant RC, RC-series circuit, etc. RELATIONSHIPS AMONG CONCEPTS: See the theoretical Background of the third laboratory experiment in Appendix C. KEY CONCEPTS: See Table 9.	INTERPLAY ↔	VALUE CLAIMS: The whole experiment allows the training of some basic laboratory skills and illustrates very well the constant interplay between the conceptual and the methodological domains. The establishment of the RC numerical value provides a better understanding of the meaning of this capacitative time constant. KNOWLEDGE CLAIMS: a) RC numerical value equals ... ... second in the charging (discharging) process. b) The charging (discharging) process of a capacitor with the time obeys the exponential function (equation) foreseen by the theory. INTERPRETATIONS: a) In the charging (discharging) process, the RC constant is the time that the capacitor needs to achieve 63% (37%) of its maximum (initial) charge or voltage. b) Graphical analyses. c) Analysis of the (straight) line on a mono-logarithmic V vs. t graph.

TRANSFORMATIONS:
Tables, V vs. t graphs, graphical determinations of RC, calculations of RC, determination of the declivity of the V vs. t straight line on a mono-logarithmic graph.

OBSERVATIONS:
Comparisons between the charging and discharging processes. Readings of the internal resistance R of the voltmeter and of the capacitance C indicated by the manufacturers.

MEASUREMENTS:
10 records of V and t (the electric potential difference accross the capacitor and the corresponding time), both for the charge and the discharges processes.

EVENT:
Charging and discharging processes of a capacitor in a RC - series DC circuit.

Figure 6. A Vee for the "Resistor and Capacitor in Series Circuit" laboratory experiment.

Table 9. Third Laboratory Test. Questions are about the "Resistor and Capacitor in Series Circuit" laboratory experiment. The means and standard deviations of answers given by 68 students to the questions are indicated.

Question	wrong (0) — .5 — correct (1.0) Mean *	SD
1. Express one of the knowledge claims that you established as an answer to a basic (telling) question by performing this experiment.	.93	.18
2. With regard to the theoretical (conceptual) domain of the experiment:		
a) Indicate eight physics key concepts (eight physics concepts which you consider the fundamental) involved in the experiment.	.86	.14
b) Write mathematical equations, i.e., formulas which relate the concepts which you indicated in the item above.	.74	.26
c) Write three physics definitions which you consider the most important in this experiment.	.42	.31
d) The differential equation of the RC series circuit may be obtained either by applying a physics principle or by direct application of a physics law of electric circuits. Mention this principle and this law.	.34	.40
3. Considering the experimental procedure, you registered the variations with time of the potential differences across the capacitor in both the charge and the discharge processes and then you transformed these records (measurements) by making calculations and sketching graphs. Explain how you interpreted the data (the transformed records) in order to obtain the knowledge claim which you expressed in the item 1 before. It is very important to mention and explain the theory which oriented your interpretations.	.62	.29
4. Express two reasons (objectives) which led us to represent the discharge process with time of the capacitor on a semi--logarithm graph (mono-logarithm paper).	.62	.26

* All the seven questions have the same maximum score value which was normalized to 1.0 .

Table 10. Data of the Third Laboratory Test.

Question		% of the scores of 68 students					Mean** and Standard Deviation	
Item	Content*	Wrong 0	.25	.5	.75	Correct 1.0		
1	Knowledge Claim	1	1	3	12	83	.93	.18
2.a	Key concepts	0	0	3	50	47	.86	.14
2.b	Relationships among concepts	3	7	19	32	39	.74	.26
2.c	Definitions	17	31	28	12	12	.42	.31
2.d	Principle & Law	50	9	15	7	19	.34	.40
3	Interpretations	6	16	22	35	21	.62	.29
4	"Two reasons"	4	2	60	7	27	.62	.26

Total Mean: 6.5***.

Standard Deviation of the Total Mean: 1.4.

Reliability Coefficient of the Test: 0.57****.

Standard Error of the Measurement: 0.95.

* The question content is completely described in Table 9.

** All the seven questions have the same maximum score value which was normalized to 1.0 .

*** Maximum value of the Total Mean = 10.0 .

**** Calculated by a Kuder-Richardson formula (Ebel, R.L., 1972, p. 419).

Table 11. Key concepts indicated by 68 students in a question of the third laboratory test about the "Resistor and Capacitor in Series Circuit" laboratory experiment.

Key Concepts and Number of Indications from 68 Students	
Electric Potential or Electric Potential Difference	67
Capacitance	67
Electric Current	65
Resistance	64
Electric Charge	60
Time	56
Electromotive Force	40
Electric Field	23
RC-Circuit	20
Resistivity	8
Energy	7
Conductivity	6
Electric Polarization	2
Capacitor	2
Power	1
Work	1
Resistor	1

answers mainly concerning the relationships among concepts (the four questions formulated in the item 2), and the relationships among the parts of the structure of knowledge as well as between the two sides of the Vee (the last two questions in the items 3 and 4).

Let us now make a parenthesis. With the last question we intended to evaluate the students' understanding of two objectives (reasons) which should have led them to represent the discharging process of the capacitor with time on a semi-logarithmic graph: first, to determine the capacitative time constant RC by other graphical method and, second, to verify if the discharging process actually followed the equation foreseen by the theory. From students' scores shown in Table 10 we conclude that the students were not quite sure about these two objectives.

In the correction of students' answers to questions of the third test, we used five discriminative indexes (0 for wrong, 0.25, 0.50, 0.75 for partially correct, and 1.0 for correct answers, as shown in Table 10) instead of only three (0 for wrong, 0.50 for partially correct, and 1.0 for correct answers) which we had used in the correction of the first two tests. Using five instead of three discriminative levels, we intended to improve the discriminative quality of our corrections in evaluating students' performance through the third laboratory test.

In tables 9 and 10 we can observe that the students obtained poor mean scores in the questions 2.c and 2.d, that is, in writing three physics definitions and in mentioning a principle and/or a law used in the establishment of the differential equation of the RC-series circuit.

The definitions which the students tried to express when answering the question 2.c were the definitions of:

electric current (37 out of 68 students),
electric resistance (34), capacitance (30),
capacitative time constant RC (17),
RC - series circuit (6), and electromotive
force (1).

In the question 2.d, the students should have mentioned the Conservation of Charge (or Energy) Principle, or the Principle of Continuity of Electric Current, and the Kirchhoff's Second Law (the loop theorem). However, they obtained poor scores in question 2.d: 50% of the 68 students received a zero (minimum) score and only 19% obtained the maximum grade in this question as shown in Table 10.

Let us analyse the key concepts indicated by the students in Table 11. The concepts with higher number of indications are actually key concepts. This indicates that students at this time had acquired training in the identification of the correct key concepts of an experiment. From the concepts which were indicated by the students, we consider electric polarization as not a quite important concept for the third laboratory and should not have received even the only two indications.

Let us analyse some other statistics shown in Table 10. Applying to the questions of the third test the same criteria used in the analyses of the first two tests (Tables 3 and 4), we obtain the following difficulty and discrimination levels:

Difficulty level of the questions of the third test:

3 very easy questions (the first three questions);

2 easy questions (the last two questions);
1 difficult question (the one requiring definitions);
1 very difficult question (the one requiring the principle and the law).

Discrimination level of the questions of the third test.

2 questions with poor discrimination (the first two questions);
3 questions with intermediate discrimination (the questions 2.b, 3 and 4);
2 questions with good discrimination (the questions 2.c and 2.d).

We can infer that the low standard deviations and, consequently, the poor discrimination levels of two (out of seven) questions is an effect of a higher homogeneity of the group of students. However, the two questions which required the three definitions, the principle and the law, were the most difficult for the students' answering and also had the better discrimination levels; therefore, the group of students seemed to be more heterogeneous when answering these two questions (2.c and 2.d).

Comparing the Tables 2, 7 and 10 we can observe that four statistics of the third test, that is, the total mean and its standard deviation, the reliability coefficient, and the standard error of the measurement, have all numerical values between the ones of the first two tests; this is shown in Table 12.

To compare and analyse just the statistics shown in Table 12 could lead us to wrong conclusions mainly because the three laboratory experiments were different and also because the structure of the third test is different from that of the first two tests, although the similarity of 4 questions (out of 7) of the third test with 4 questions of the first and second tests.

Table 12. The Numerical Value of Some Statistics of the First Three Laboratory Tests.

Statistics	Laboratory Test		
	1st.	2nd.	3rd.
Total Mean	5.4	7.9	6.5
Standard Deviation of the Total Mean	1.9	1.2	1.4
Reliability Coefficient	0.67	0.51	0.57
Standard Error of the Measurement	1.10	0.82	0.95

A more valid and secure analysis may be made by comparing two statistics of questions which were similar in the three tests. This analysis can be made through Table 13 and Figure 7.

In Table 13 we can observe that 10 questions were similar in two (or three) of the first three laboratory tests. The students' means in these 10 questions concerning parts of the Vee are presented in Figure 7.

Table 13. Means and Standard Deviations of the Means of Questions of the First Three Laboratory Tests.

Question about the	Test Mean Score			Test Standard Deviation		
	1st.	2nd.	3rd.	1st.	2nd.	2rd.
Event	.43	.89	-	.42	.20	-
Term "simulated"	.30	-	-	.42	-	-
Basic (Telling) question	.74	.92	-	.40	.17	-
Key concepts	.58	.78	.86	.28	.24	.14
Relationships among concepts	.34	-	.74	.28	-	.26
Definition(s)	-	.34	.42	-	.37	.31
Ohm's Law	-	.73	-	-	.41	-
Principles and laws	-	-	.34	-	-	.40
Measurements	.77	.97	-	.32	.14	-
Transformations	.68	.82	-	.36	.24	-
Interpretations	.52	.93	.62	.46	.17	.29
Knowledge claims	.50	.76	.93	.45	.30	.18
Value claims	.51	.80	-	.40	.28	-
"Two reasons (objectives)"	-	-	.62	-	-	.26

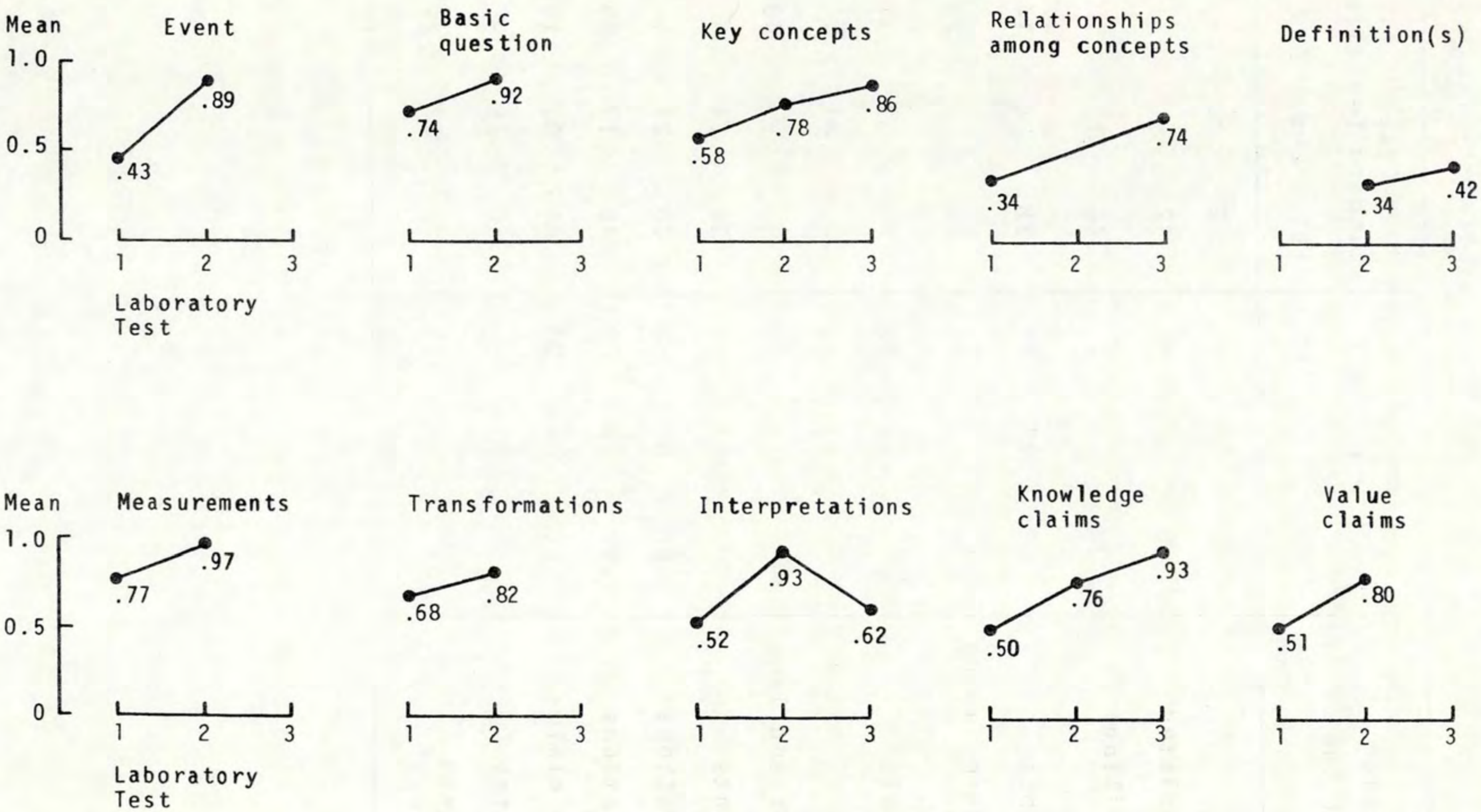

Figure 7. Means of the questions which were similar in laboratory tests.

In this figure we can see that an increase happened in the means of all the questions, except in the mean of the question concerning the interpretations of data. In this question the mean decreased in the third test but, even so, to a value (0.62) higher than the one of the first test (0.52). However, we consider that, among the three first laboratory experiments, the interpretations of data required in the third experiment are the most difficult to carry out, and that the ones of the second experiment are the easiest. If we accept these considerations as valid, we can infer from the means in this question about interpretations (see Figure 7) that there was also an improvement in the students' ability to analyse and interpret experimental data.

In Table 13 and Figure 7 we can also observe that, at the time of the third laboratory test, students still had difficulties in the statement of definitions.

On the whole, through the data summarized in Table 13 and Figure 7, we can observe that, at the time of third laboratory experiment and test, most students already had improved their understanding of the epistemological framework and their ability to use it in the analysis of a laboratory experiment.

Let us now analyse the second set of formative evaluation activities.

IV-6 The Second Set of Formative Evaluation Activities

The students' performance in the first three laboratory tests was the main reference for the development of the second set of clinical interviews and group discussions which were organized and carried out in a manner similar to that one of the first set.

The second set of written feedback was developed in two parts: initially, after the second test (see Section IV-4) and, posteriorly, after the third test.

Let us now summarize the information collected through the second set of formative evaluation activities.

IV-6.1 Analysis of the Second Set of Clinical Interviews

As in the first set, each clinical interview of the second set lasted 30 minutes and was individually conducted with 19 students. Five students out of the remaining 24 students of the clinical interview (C.I.) group did not appear for the scheduled interview and they did not give us any convincing excuse. We believe that these 5 students were not actually motivated for the interviews at that time of the second set.

The following information was collected through the second clinical interviews:

a) Most students did not know how to identify and to state definitions.
b) The students had difficulty in expressing a definition correctly. In trying to define resistance, for example, about 30% of the 19 students wrongly wrote that the resistance was directly proportional to the voltage.

c) About 50% of the 19 students misconceived the definition of electric resistance as being Ohm's Law.

d) About 50% of the 19 students thought that a concept could not have a definition, and that a definition could not become a concept

e) Most students did not know the nature, the structure, and the functions of a theory and its component parts, that is, the concepts, definitions, concept definitions, assumptions, relationships among concepts, laws and principles.

f) Most students did not know the main functions and purposes of a theoretical model which are: to describe and explain phenomena, to predict natural outcomes, and both to make happen and control events.

g) Most students did not know that a law (or a principle) fulfills two main functions: first, it summarizes many regularities in events and so makes for economy of thought, because if one knows the law (or principle) one does not need all events; second, it enables one to predict further events, because it tells one that if a phenomenon is an instance of a law, it will behave as the law (or principle states.

h) Most students did not perform quite well the interpretations of data of a laboratory experiment because they did not master the theoretical background of the experiment.

i) Few students took time describing the measurements and the transformations of records (which were not asked in the third test) in addition to describing the interpretations

(which were asked)

j) About 30% of the 19 students described the interpretations of data very poorly mainly because in their descriptions they moved far-away from the basic (telling) question

k) Most students had difficulties in performing and analysing the third experiment because they lacked training (1) in the graphic representation of data, (2) in the drawing of a "best-fit" curve through the data points, and (3) in interpreting the curve as satisfying or not satisfying an equation

IV-6 2 Analysis of the Second Group Discussions

A week after the third laboratory experiment, four group discussion (G.D) sessions were conducted with about 4 students per session, each lasting 45 minutes

From the 20 students that had participated in the first group discussions, 17 students also participated in the second ones, 2 students dropped out of the Physics II course, and just one student was absent and he did not present us any convincing excuse.

Now, we will briefly describe the content of the second set of group discussions:

a) Discussions concerning the theoretical domain (left side of the Vee) of an experiment. That is, discussions concerned with the physics definitions, concepts, relationships among concepts, laws, and principles, which were involved in the theoretical background of the second and third experiments.

b) Discussions about the meanings and functions of concepts, definitions, principles, laws and theories.

c) Discussions about the nature, the structure, and the main functions of a theory.

d) Discussions about the general structure of the Vee.

e) Discussions about the construction and the analysis of graphs mainly with the purposes of establishing a law or of trying out the validity of a theoretical equation.

f) Discussions about the several possible types of curves (equations) and the use of a more appropriate graph paper for the graphic construction and analysis of each curve.

IV-6.3 Analysis of the Second Set of Written Feedback

As we mentioned earlier, the second set of written feedback was carried out in two parts. The first part (carried out by 12 students after the second test) was already described at the end of the data analysis of the second test (Section IV-4).

The second part of the second set of written feedback was developed after the third test. Fifteen students (out of the 25 students who had answered the third test) actually needed and performed the written feedback; the other 10 students had had just minor mistakes and did not need any written revision of the third test. The performed written revisions were mostly well done and mainly concerned with the last four questions of the third test, that is, with the relationships among concepts, the definitions, the principles and laws, the interpretations of data, and the two reasons for the graphical representation of the discharging process of the capacitor with time in a mono-logarithm paper.

We must emphasize that the third written revision was very well performed by most students. This contrasts mainly with the results of the first written feedback which showed that, even with a second opportunity, a significative number of students had not performed an acceptable written review in some questions (See the Section IV-3.3)

From the information collected through the second set of formative evaluation activities we may conclude that, at the time of the third test, the students' main difficulties to perform a better analysis of the laboratory experiment (using the epistemological Vee as a reference) were mainly determined by students' three deficiencies:

1. Most students came in the laboratory class without an acceptable understanding of the theoretical background of the experiment.
2. Most students did not know the nature, the structure and the functions of a theory and its component parts.
3. Most students showed lack of knowledge and training in the graphic representation as well as in the graphic analysis of data.

We should have elaborated written instructional units in order to minimize the students' deficiencies 2 and 3 pointed above, but we did not make it. However, we used every opportunity from the Physics II theoretical classes to introduce some key ideas concerning the nature, structure and functions of a theory and its parts as well as to illustrate some basic techniques about graphic representation and analysis of data.

Accepting the existence of deficiency 1, i.e., that a better understanding of the theoretical background of the experiment is lacking for most students when they come in the laboratory class, we suggest a possible remedial solution: the use of a pretest preliminary to the laboratory work. Through this pretest, a minimum performance level concerning the theoretical background of the experiment would be required from each student as condition to perform the laboratory work. Otherwise, we think that a significant number of students do not even read the theoretical background provided in advance by the laboratory guide.

We did not put this remedial solution into practice in this study but it could be tried out in other research run.

We conclude this analysis pointing out that the second set of formative evaluation activities probably would produce better results if they had been developed before (instead of after) the third laboratory experiment and test. However, this anticipation was not possible mainly because of course constraints determined by the fact that the second and the third experiments were respectively concerned with two successive chapters of the textbook (Chapters 27 and 28, by Halliday, 1974). The content of these two chapters had to be studied in two successive weeks through the theoretical classes and the two laboratory experiments. Consequently, the available course time was reduced and did not permit the antecipation of the second set of group discussions and interviews. Even so, we consider as worthwhile, to both students and teacher (researcher), the feedbacks and sharing of meanings carried out through the second set of formative evaluation activities

To make possible a final comparison of the total time involved in the development of the three formative evaluation activities, let us conclude this section by estimating the approximate total time used to carry out each one of the three formative evaluation strategies in the second set of activities

- Clinical interviews:
  19 students x 30 minutes/student (interview) = 9.5 hours.
- Group discussions:
  4 sessions x 45 minutes/session = 3.0 hours
- Written feedback:
  a) First part: 12 students x 15 minutes/student = 3.0 hours,
  b) Second part: 15 students x 15 minutes/student = 3.75 hours.
  Total time for the second set of written feedback = 6.75 hours

Let us now analyse the fourth laboratory experiment and test.

IV-7 Data Analysis of the Fourth Laboratory Experiment and Test

As mentioned earlier in Section III-6.2,B, in the fourth laboratory class of the Physics II course the students did not carry out an actual laboratory experiment because this class was used for the projection and analysis of five

Ealing film-loops (about experiments of magnetism) specified in Appendix C. These film-loops are silent 8 mm films, each one has a time duration of about 3 minutes, and its projection may be repeated easily for a better understanding.

Section III-6.2,B describes the two different approaches used in the two research runs for the development of this fourth laboratory class. In the second research run (when the data to be analysed here were collected) each one of the two course sections involved in this study was divided into five groups, with 6 or 7 students/group. Each group received a projector and a film loop for analysis using the Analytical Method (Gowin's Epistemological Vee). After projecting and analysing a film-loop during the first 45 minutes of the 2-hour class, each student had the next 45 minutes to answer his/her own test. After the students completed their answers to the test, the teacher (author) projected and commented on each film in terms of the Vee during the last 30 minutes of the class.

Table 14 shows the 5 questions included in the first five items of the fourth laboratory test. This table also indicates the means and standard deviations of the scores obtained from the answers given by the students to each one of these five questions. The number of students who worked in each one of the five films is also indicated.

The item 6 of the Table 14 shows the mean grade (and its standard deviation) obtained from the grades assigned by the students to the quality of each film-loop. This quality refers to one of the possible objectives of the film-loops

Table 14. Fourth Laboratory Test Questions are about the "Experiments of Magnetism (Projection of Ealing Film-loops)" laboratory class The means and standard deviations of answers given by the students to the questions are indicated.

Question, Film, and Number of Students per Film	Question Value, Means and Standard Deviations	
1 What are the <u>knowledge claims</u> that you can establish from the analysis of the lab activities presented in the film?	wrong — correct 0 1 2 3	
	Mean	**SD**
Film I: "The Magnetic Field"* N_1 = 13 students	2.21	.44
Film II: "The Field from a Steady Current".* N_2 = 13 students	2.21	.86
Film III: "Field: The Force on a Current".* N_3 = 13 students	1.64	.58
Film IV: "Field vs. Current".* N_4 = 13 students	1.92	.62
Film V: "Field vs. Distance".* N_5 = 13 students	2.46	.46
2. Indicate the <u>physics key concepts</u> (the physics concepts which you consider the fundamental) involved in the lab activities presented in the film.	wrong — correct 0 .5 1.0	
	Mean	**SD**
Film I:	.81	.17
Film II:	.81	.20
Film III:	.76	.17
Film IV:	.77	.17
Film V:	.61	.20

* The films are best identified in Appendix C.

(Continue)

Table 14. (Continued)

3. Write down the maximum number of independent logical <u>relations among the concepts</u> which you indicated in the item 2 before. These relations can be expressed in form of practical rules, definitions, principles, laws and mathematical equations. (You are allowed to consult your book and notes to answer this item).

wrong — correct: 0 — 1 — 2

	Mean	SD
Film I:	1.39	.47
Film II:	1.00	.54
Film III:	1.29	.39
Film IV:	1.15	.51
Film V:	1.04	.22

4. Describe the <u>experimental procedure(s)</u> presented by the film to illustrate the knowledge claims which you have indicated in the item 1. In other words, describe the observations (or measurements), the transformations (when they are shown), and the interpretations (of observations or data) which were developed in order to get the answers to the basic questions. Always (whenever possible) indicate how the theory oriented these several stages of the experimental procedure(s).

wrong — correct: 0 — 1 — 2 — 3

	Mean	SD
Film I:	2.79	.41
Film II:	2.86	.36
Film III:	1.79	.77
Film IV:	1.92	.44
Film V:	1.92	.72

(Continue)

Table 14. (Continued)

5. One of the film objectives is to illustrate experimental procedures permitting to establish knowledge claims. Perform a critical analysis of the film; that is, point out some strenghts (positive aspects) and some weaknesses (deficiencies, imperfections), considering the film objective indicated above.		wrong — correct 0 .5 1.0	
		Mean	**SD**
	Film I:	.89	.30
	Film II:	.86	.26
	Film III:	.81	.20
	Film IV:	1.00	.00
	Film V:	.90	.17
6. Considering the film objective pointed in item 5, assign a grade to the film on the scale below. 0 stands for poor (minimum) quality and 4 stands for high (maximum) quality. Minimum Grade — Medium Grade — Maximum Grade 0 1 2 3 4		**Mean**	**SD**
	Film I:	3.00	.53
	Film II:	2.86	.74
	Film III:	2.79	.67
	Film IV:	2.85	.77
	Film V:	2.92	.48

which is the one of illustrating experimental procedures in order to permit the establishment of knowledge claims.

In Table 14 the reader can observe that modifications were made in the structure of the fourth test in comparison with the one of the first three tests. These changes were determined mainly by two reasons: first, to fit the test for the analysis of a film (instead of an actual experiment) and, second, to continue the evaluation of students' performance mainly in the second level of achievement of the Vee, that is, in the description of relationships among the parts of the structure of knowledge.

Not all the five questions of the fourth test had the same maximum score value (as happened in the first three tests) because they require answers with different extent of writing and different levels of knowledge and understanding The maximum score value of each question, corresponding to a completely correct answer, is indicated in Table 14.

To facilitate the reading, the analysis, as well as comparisons with statistics of other tests, the maximum score values of the questions were all normalized to 1.0. That is, the means of the questions and their standard deviations were all expressed in terms of a same maximum value 1.0. Table 15 shows the normalized values as well as other statistics of the fourth laboratory test.

Let us now analyse some statistics shown in Table 15. Applying to the questions of the fourth test the same criteria (specified in Table 3) used in the analyses of the first three tests, we observe in Table 15 that most questions had an easy or a very easy level of difficulty for the students' answering. Only in the third question (concerning the relationships among concepts), Films II and V, we observe two means (0.50 and 0.52) which indicate an intermediate difficulty level for the students.

Table 15. Data of the Fourth Laboratory Test.

Question		Means** and Standard Deviations				
Item	Content* / Film*	I	II	III	IV	V
1	Knowledge claims	.74 .15	.74 .29	.55 .19	.64 .21	.82 .15
2	Key concepts	.81 .17	.81 .20	.76 .17	.77 .17	.61 .20
3	Relationships among concepts	.70 .24	.50 .27	.65 .20	.58 .26	.52 .11
4	Experimental procedure	.93 .14	.95 .12	.60 .26	.64 .15	.64 .24
5	Critical analysis	.89 .30	.86 .26	.81 .20	1.00 .00	.90 .17
6	Didactic quality of the film	.75 .13	.72 .19	.70 .17	.71 .19	.73 .12
Total Mean***		8.10	7.74	6.29	6.77	6.93
Standard Deviation of the Total Mean		.99	1.31	1.29	.74	.96
Reliability Coefficient of the Test		.47	.38	.38	.00	.08
Standard Error of the Measurements		.72	1.03	1.01	.74	.92

* The question contents, the films, and the number of students per film are specified in Table 14.

** The six questions have different maximum values (see Table 14) which here were all normalized to 1.0 .

*** Maximum value of the Total Mean = 10.0 .

Concerning the discrimination levels of the questions, if we use the criteria specified in Table 4 we can conclude from Table 15 that there are thirteen values of standard deviation indicating an intermediate discrimination level; that is, 13 (out of 30) standard deviations of question means have values between 0.20 and 0.30. The other seventeen questions (out of 30) have standard deviations of the question means which indicate a poor discrimination level for the questions. We consider these low numerical values of seventeen standard deviations of the question means as being a consequence of a high homogeneity of the group of students when answering the fourth test. This homogeneity was increased by students' discussions during the projection and analysis of each film. These discussions happened few minutes before the students received the test for individual answers and, surely, share of meanings were carried out through these discussions and, consequently, the group became more homogeneous. This permits us to say that an integration of the students' ideas concerning the understanding and use of the epistemological framework (Vee) was made possible through the fourth laboratory class.

Table 15 also shows the relatively low numerical values of the standard deviations of the total means and of the reliability coefficients of the tests; these low values confirm that the group of students was actually very homogeneous when answering the fourth test.

The item 6 of the Table 15 indicates the mean grades assigned by the students to the didactic quality (see item 5 in Table 14) of the films; these mean grades resulted between 70% and 75% of the maximum value.

Table 15 also indicates the total mean and the standard error of the measurement of the test scores in each film.

Let us now analyse Table 16 which shows the key concepts indicated by 65 students in the second question of the fourth test. We can see that some concepts were quite fundamental in certain film(s) but, otherwise, they were not fundamental in other(s), e.g., electric current which was not a key concept only in the Film I, or weight which was a fundamental concept only in the Film III.

The totals shown in Table 16 permit us to see the total number of indications per film and the total number of indications that each concept received in the set of five films. For instance: the Film II received the higher number of 130 indications, and the concept of magnetic field was the most indicated (64 out of a maximum of 65 indications).

We conclude this analysis of the fourth class and test emphasizing something which we already mentioned before in this same section: we consider that the main role of this fourth class was the one of making possible an integration of the students' ideas concerning the understanding and use of the epistemological framework (Vee). This integration was made possible through sharing of meanings carried out during the projection and analysis of the films, having the Vee as a reference, preliminar to the fourth laboratory test. The projection of the films with teacher (author)'s comments in terms of the Vee, during the last 30 minutes of the class, reinforced that integration.

Table 16. Key concepts indicated by the students in a question of the fourth laboratory test about the "Experiments of Magnetism (Projection of Ealing Film-loops)" laboratory class.

	Number of Indications from						TOTAL
	Film*	I	II	III	IV	V	
Key Concept	No. of Students	13	13	13	13	13	65
Magnetic Field		13	13	12	13	13	64
Magnetic Force		12	9	12	10	10	53
Electric Current		1	13	13	13	12	52
Magnetic Flux		9	4	13	2	8	36
Distance or Length		9	3	3	8	13	36
Electric Charge		0	10	8	7	3	28
Magnetic Lines of Induction		11	10	1	1	2	25
Magnetic Torque		3	6	8	7	1	25
Electric Field		0	9	5	5	5	24
Electric Potential Difference		0	12	1	8	1	22
Magnetic Dipole Moment		4	5	2	6	2	19
Electric Resistance		0	6	1	4	2	13
Time		0	3	1	5	1	10
Weight		0	0	10	0	0	10
Electric Force		0	6	0	1	2	9
Magnetic Poles		7	0	0	0	0	7
Electromotive Force		0	5	2	0	0	7
Magnetic Permeability Constant		1	2	1	2	1	7
Energy		0	2	0	0	5	7
Area		2	0	3	1	0	6
Vector		1	0	1	4	0	6
Velocity		0	5	0	0	1	6
Mass		0	0	4	0	0	4
Earth Magnetic Field		0	0	0	3	1	4
Work		0	3	0	0	0	3
Electric Lines of Force		0	3	0	0	0	3
Acceleration of Gravity		0	0	3	0	0	3
Angular Displacement		0	0	0	2	1	3
Electric Flux		0	1	0	0	0	1
TOTAL		73	130	104	102	84	493

* The films are identified in Table 14 and in Appendix C.

IV-8 The Third Set of Formative Evaluation Activities

The third set of clinical interviews, group discussions, and written feedback, was carried out after the fourth test.

The third interviews and group discussions were mainly directed to collect information that could help us in the elaboration of a final questionnaire. That is, the last interviews and group discussions were mainly used to collect information about students' receptivity concerning the use of the Analytic Method (epistemological Vee). This information was posteriorly used as the main reference in the construction of the final questionnaire through which we aimed to quantify that students' receptivity. The final questionnaire is presented and analysed in Section IV-10.

Respectively 22 and 16 students participated in the individualized interviews and in the group discussions (four sessions with nearly 4 students/session). Respectively 2 and 3 students were absent from the interviews and the discussions. They were not the same absentees in the anterior and similar activities, and they did not present us any convincing excuse.

The written feedback was carried out by 11 students who performed written reviews in the fourth test. These written reviews were mainly concerned with the third question of the test which refers to relationships among concepts. The other 11 students (from the total of 22 students of the written feedback group who answered the test) did not carry out the written revisions because they had had just minor shortcomings in their tests.

To permit a final comparison of the total time involved in conducting the three formative evaluation activities, let us conclude this section by showing the approximate total time used to carry out the third set of these activities:

- Clinical interviews:
  22 students x 30 minutes/student (interview) = 11.0 hours.
- Group discussions:
  4 sessions x 45 minutes/session = 3.0 hours.
- Written feedback:
  11 students x 15 minutes/student = 2.75 hours.

Let us now analyse the fifth (last) laboratory experiment and test.

IV-9 Data Analysis of the Fifth Laboratory Experiment and Test

As mentioned earlier in the Section III-6.2,C, in the second research run, the fifth laboratory test was used to test each student in the third level of achievement of the epistemological framework which was proposed in section III-1, that is, application of the Analytic Method (Vee) to a new laboratory situation in order to establish knowledge claims.

To permit this kind of evaluation, the fifth laboratory content (see Appendix C) was divided into three different parts (relative to three different events or phenomena) and each student worked alone without a laboratory guide but with a laboratory test concerning one specific event.

The students of the second research run did not receive a laboratory guide but through the theoretical classes (lectures combined with recitations) they had received in advance the theoretical background of the experiment. This theoretical background was mainly concerned with the Faraday-Lenz's Law (Chapter 31 of the textbook by Halliday and Resnick, 1974), and it is briefly described in the Appendix C. The laboratory guide of the fifth experiment (Electromagnetic Induction), shown in the Appendix C, was provided only to the students of the first (pilot) research run.

A brief demonstration by the instructor with the apparatus available to the students illustrated how to generate the three basic events which were the subjects of investigation. (For sketch of apparatus, see Appendix C).

To make possible the student's individual work, the two hours of the laboratory class (plus an additional half an hour for students who could come 30 minutes earlier to the class) were divided into five periods of 30 minutes. Then, a group of nearly 7 students/group was scheduled to each one of the first four periods; thus, each student had a maximum of 30 minutes to work with the laboratory equipment (focusing and analysing one of the three specific events) and an additional half an hour for completing his/her laboratory test but without the use of the equipment now already being in use by another colleague.

One out of the three different types of laboratory tests was distributed at random to each student at the beginning of his/her laboratory work.

Table 17 shows the 6 questions of the fifth laboratory test. This table also indicates the three different events (which originated the three different types of test), the number of students per type of test, the maximum score value of each question, and the question means and their standard deviations. The six questions of the fifth test had not the same maximum score value because they required answers with different difficulty levels.

To facilitate statistical analyses and comparisons with other laboratory tests, the maximum score values of the questions were all normalized to 1.0. Table 18 shows these normalized values as well as other statistics of the fifth laboratory test.

Table 18 also shows, for each one of the three different types of test, the total mean and its standard deviation, the reliability coefficient of the test and the standard error of the measurements of the test scores.

Let us now analyse some statistics shown in Table 18.

Applying the criteria specified in Table 3 (concerning the difficulty levels of the questions) to the data of the Table 18, we conclude that 13 (out of 18) questions were quite easy for the students' answering and that 5 (out of 18) questions were easy ones. These five easy questions were concerned with the experimental procedure (question 2, in the Events II and III), the knowledge claims (question 3, Event II), and

Table 17. Fifth Laboratory Test. Questions are about the "Electromagnetic Induction" laboratory experiment. The means and standard deviations of answers given by the students to the questions are indicated.

Considering the physics event (phenomenon):

Event I: "Electromagnetic Induction Changing with the Inductive Magnetic Field Intensity",

Event II: "Electromagnetic Induction Changing with the Distance between the Inductive (Primary) and the Induced (Secondary) Coils",

Event III: "Electromagnetic Induction Changing with the Relative Angular Position between the Inductive (Primary) and the Induced (Secondary) Coils",

answer the following questions:

Question, Event, and Number of Students	Question Value, Means, and Standard Deviations	
1. State a <u>basic (telling) question</u> relative to this event.	wrong 0 .5 1.0 correct	
	<u>Mean</u>	<u>SD</u>
Event I (N_1 = 24 students):	.74	.39
Event II (N_2 = 21 students):	.98	.06
Event III (N_3 = 22 students):	.93	.09

(Continue)

Table 17. (Continued)

2. Project and carry out an <u>experimental procedure</u> in order to get an answer to the basic question which you indicated in the item 1. Describe the experimental procedure, i.e., the relationships among the performed observations, measurements, transformations, and data interpretations

wrong correct
0 1 2 3

	Mean	SD
Event I:	2.67	.69
Event II:	1.81	.63
Event III:	2.00	.60

3. Express the <u>knowledge claim</u> that you obtained as the answer to the basic (telling) question.

wrong correct
0 1 2

	Mean	SD
Event I:	1.56	.72
Event II:	1.22	.48
Event III:	1.64	.40

4. Indicate the <u>physics key concepts</u> (the fundamental physics concepts) involved in the experiment.

wrong correct
0 .5 1.0

	Mean	SD
Event I:	.77	.15
Event II:	.84	.14
Event III:	.81	.18

(Continue)

Table 17. (Continued)

5. Write down the maximum number of independent logical relations among the concepts which you indicated in the item 4. These relations can be expressed in form of practical rules, definitions, principles, laws, and mathematical equations. (You are allowed to consult your book and notes but indicate only the relations which were actually involved and that constituted the theoretical basis of the experiment).

   wrong — correct: 0 1 2

	Mean	SD
Event I:	1.47	.33
Event II:	1.15	.47
Event III:	1.24	.39

6. Point out any kind of difficulties, imperfections, and deficiencies which you faced by planning and executing this experiment; suggest remedial solutions for them.

   wrong — correct: 0 .5 1.0

	Mean	SD
Event I:	.78	.28
Event II:	.87	.17
Event III:	.82	.22

Table 18. Data of the Fifth Laboratory Test.

Question		Means** and Standard Deviations		
Item	Content* / Event*	I	II	III
1	Basic (Telling) question	.74 .39	.98 .06	.93 .09
2	Experimental procedure	.89 .23	.60 .21	.67 .20
3	Knowledge claims	.78 .36	.61 .24	.82 .20
4	Key concepts	.77 .15	.84 .14	.81 .18
5	Relationships among concepts	.74 .17	.58 .24	.62 .20
6	Critical analysis	.78 .28	.87 .17	.82 .22
Total Mean***		7.97	6.86	7.42
Standard Deviation of the Total Mean		1.92	1.45	1.30
Reliability Coefficient of the Test		.76	.68	.67
Standard Error of the Measurements		.94	.82	.75

* The question contents, the events, and the number of students per event are specified in Table 17.

** The six questions have different maximum values (see Table 17) which here were all normalized to 1.0 .

*** Maximum value of the Total Mean = 10.0 .

the relationships among concepts (question 5, Events II and III). Considering this analysis and observing the total means of the tests for the three different events, we may conclude that the Event II provided the most difficult type of test. This conclusion is valid in terms of research sample because the three different types of test were distributed at random and, consequently, the three groups of students (who answered respectively the three types of test) were probably equivalent groups (samples).

We consider that the Event II was the most difficult for the students' analysis, and the test results may reflect this intrinsic difficulty. In Event II students had more difficulties than in the other two events in trying to find the "best-fit" equation which could represent the curve that they had sketched using the records. In Event II, the inductive (primary) coil behaved like a magnetic dipole, that is, the inductive coil produced a magnetic induction with magnitude inversely proportional to r^3, where r is the distance from the center of the coil.

Let us make another comment concerning the Event III. In analysing the Event III, the students' main difficulties came from the fact that the magnetic field of induction (produced by a primary coil) was not an uniform field. Consequently, when the relative angular position of the induced (secondary) coil was changed by a complete turn, the magnitude of the electromagnetic induction did not follow an exact cosine function (foreseen by the

theory, through the Faraday-Lenz's Law, in the specific case of an uniform and constant magnetic field of induction).
In practical terms: the graph of the induced electric current versus the cosine of the angular position of the two coils did not show an exact straight line because the plane of the turns (of the induced coil) was changing inside a non-uniform magnetic field of induction.

Let us now return to the analysis of the data shown in Table 18. We can observe that, in spite of the students' good ability to answer the questions of the fifth test, there still remained some difficulty in the expression of relationships among concepts; this difficulty in the mastery of the theoretical background of an experiment is evident in all the five experiments, and must be claimed.

Some students' difficulties in planning and developing an experimental procedure, in order to analyse an event and to establish knowledge claims, was already anticipated because we were requiring the students' performance in the highest level of achievement. These difficulties happened, as we can observe in Table 18 (mainly in question 2, in the Events II and III) but not to an extent that could result in discouragement; on the contrary, we were positively surprised with a students' satisfactory performance in the fifth laboratory experiment and test.

We contend that this students' satisfactory performance was possible, in great part, because the students were provided with an epistemological framework which guided them in the planning, execution, and analysis of the experiment. That is, the students had such clear ideas about the structure of knowledge of a laboratory experiment (through the epistemological Vee) that, even facing a situation not analogous to any one previously seen in the laboratory context, they were capable of projecting and executing an experiment to obtain knowledge claims. Even more, they liked this kind of work and the challenging situation that required individual thought and application of the epistemological framework.

Let us return to the Table 18. Using the criteria specified in the Table 4, we obtain the following discrimination levels for the questions:

> 7 questions with poor discrimination levels (3 of them were concerned with the indication of key concepts);
> 9 questions with intermediate discrimination;
> 2 questions with good discrimination (the questions 1 and 3 in the Event I).

We observe that the questions of the fifth test, as a whole, had a better discrimination level than the question of the fourth test. In addition, because the group of students was not quite homogeneous when answering the fifth test (which was evaluating student in the highest level of achievement of the Vee for the first time in the course) the standard deviations of the total means were higher than for the fourth test. These two factors, the better discrimination of the questions and the higher standard deviations of the total means of the fifth test, determined higher values for the reliability coefficient of the fifth test that the ones of the fourth test. (The reader may compare the mentioned statistics in the Tables 15 and 18).

The reliability coefficients of the fifth test have higher values than the ones of all the other first four tests. (Compare the reliability coefficients shown in the Tables 2, 7, 10, 12, 15, and 18). This reinforces the consideration that the fifth test was actually measuring a different kind of achievement relative to the use of the Vee. That is, the student group became less homogeneous in responding to this test. We can plausibly conclude that this different kind of achievement is in the realm of the third achievement level which we hoped to assess. (See in page 76 our previous comments concerning the relationship between group homogeneity and reliability coefficient).

We can infer that, by providing students with an instructional approach to facilitate sharing of meanings and feedback, and repeating the evaluation of the students in the same highest level of achievement of the Vee through a sixth laboratory experiment and test, the group of students would increase in its homogeneity. Consequently, the values of the reliability coefficients would probably decrease to values lower than the ones of the fifth test, as a result of the instructional approach which had been carried out.

Let us now analyse the key concepts indicated by 67 students in the fourth question of the fifth laboratory test; they are shown in Table 19. Some concepts were more

Table 19. Key concepts indicated by the students in a question of the fifth laboratory test about the "Electromagnetic Induction" laboratory experiment.

Key Concept	Event*	I	II	III	TOTAL
	No. of Students	24	21	22	67
Electric Current		24	17	21	62
Magnetic Flux		20	19	22	61
Magnetic Field		20	20	20	60
Electric Resistance		19	16	15	50
Electric Potential Difference		22	12	15	49
Electromotive Force		20	13	13	46
Electric Field		11	12	14	37
Time		10	12	15	37
Distance or Length		2	19	8	29
Induced Electric Current		7	10	4	21
Electromagnetic Induction		11	3	3	17
Induced Electromotive Force		5	6	4	15
Area		1	5	9	15
Electric Charge		4	4	6	14
Magnetic Lines of Induction		4	2	1	7
Inductance		4	2	1	7
Number of Turns		2	1	1	4
Angular Displacement		0	0	4	4
Energy		0	1	3	4
Work		0	0	3	3
Joule Heating		1	0	2	3
Magnetic Permeability		2	0	1	3
Power		2	0	0	2
Internal Electric Resistance		1	1	0	2
Electric Resistivity		1	0	1	2
TOTAL		193	175	186	554

Number of Indications from: Event I, II, III, TOTAL.

* The events are identified in Table 17.

fundamental in a certain event than in the other two, and this is reflected by the students' number of indications. The concept of distance (or length), e.g., was more fundamental in the Event II; or, another example, the concept of angular displacement which was more fundamental in the Event III. By the way, we were negatively surprised with the low number of indications that some key concepts received from the students. That is the case of very fundamental concepts (for the events being analysed) such as: electric field, induced electric current, induced electromotive force, and angular displacement (this latter particularly in the Event III).

We conclude this analysis of the fifth laboratory experiment and test rewarded by the satisfactory (for a first experience) students' performance in the highest level of achievement of the epistemological framework, that is, in the application of the epistemological Vee to new laboratory situations in order to plan and execute an experiment to obtain knowledge claims (products of inquiry obtained through a structured process of investigation). However, at the same time, we conclude this analysis sorrowful because we had not opportunity to carry out a sixth laboratory experiment plus testing through which we could try to confirm some of our initial findings in that highest level of students' achievement of the epistemological framework (Vee).

IV-10 Data Analysis of the Final Questionnaire

In both research runs, one week after the fifth (last) laboratory test, students answered a Final Questionnaire. The aim of this questionnaire was to collect students' opinions and final critical comments relative to their participation, difficulties, and learning insights in the understanding and use of the epistemological Vee that they had just finished to work with in the Physics II laboratory context.

The questionnaire of the first research run, in particular, provided information which was used as a reference when modifications were made for improvement in the research and instructional programs for use in the second research run.

The questionnaire of the second research run also helped in the answering of the additional research question stated in Section III-4. That is, the questionnaire was also used as an additional instrument in the detection of differences among the three instructional strategies for formative evaluation, in terms of students' receptivity to the epistemological framework.

The Final Questionnaire had three parts. Sixty six and fifty students answered the questionnaire in the pilot and second runs, respectively.

The content and the students' answers and opinions expressed in the first part of the questionnaire are presented in Table 20. In this table, the first nine items were answered by the students of both the first and the

Table 20. Final Questionnaire - Part One. Students' opinions about the Analytic Method (Vee) used in the laboratory work. The number of answers given by 66 students of the first (pilot) research run and by 50 students of the second research run are indicated.

Instructions: Each statement expresses an opinion about the Analytic Method (Vee) used in the laboratory classes and tests. Read each statement carefully and indicate your level of agreement or disagreement with it.
Key: Strongly Agree (SA); Agree (A); Undecided (U); Disagree (D); Strongly Disagree (SD).

	SA	A	U	D	SD	RR*
1. The Analytic Method (Vee) was very useful for the comprehension of the laboratory classes.	10	48	2	6	0	F
	8	38	0	4	0	S
2. I do not recommend the continuity in the use of the Analytic Method in the Physics II laboratory classes.	1	3	7	24	31	F
	0	0	2	34	14	S
3. I recommend the use of the Analytic Method in other laboratory classes (different from Physics II).	17	39	6	3	1	F
	1	39	9	1	0	S
4. The Vee helps me very little in the comprehension, analysis, and description of the structure (parts and relations among these parts) of a laboratory experiment.	0	4	3	35	24	F
	0	1	2	35	12	S

(Continue)

* RR (Research Run) indicates the first (F) or the second (S) research run.

Table 20. (Continued)

	SA	A	U	D	SD	RR
5. There is little possibility to put into practice the Vee in other circunstances (out from the Physics II laboratory classes).	0 0	1 1	12 6	35 36	18 7	F S
6. The Analytic Method (Vee) helps me to observe the constant interaction between the theoretical (conceptual) and the practical (experimental, methodological) domains of an experiment.	25 7	35 40	1 3	5 0	0 0	F S
7. The comprehension of the Analytic Method (Vee), and its elaboration for the laboratory experiments, was difficult.	13 0	36 12	3 4	14 29	0 5	F S
8. The right (methodological, experimental) side of the Vee was easier to understand and to describe than the left (theoretical, conceptual) one.	16 12	29 23	6 5	13 8	2 2	F S
9. The three instructional units* about the Analytic Method were badly made (disorganized and not clear).	2 0	29 3	4 6	25 35	6 6	F S

(Continue)

* Only two instructional units were elaborated in the first (pilot) research run (See comments in Section III-6.1). The three instructional units about the Vee, provided to the students of the second research run, are shown in Appendix A.

Table 20. (Continued)

	SA	A	U	D	SD	RR
10. If the Vee had been given at the very beginning of the course and elaborated since the first laboratory experiment, I would have progressed more in the understanding and use of the Analytical Method.	19	28	8	7	4	F
11. It would be more fruitful if the Vee had been introduced slowly in the course and had begun to be elaborated by the students only at the third laboratory experiment and test.	5	11	5	22	7	S*
12. The Analytic Method (Vee) was taught and required (in the laboratory tests) in an appropriate level.	7	29	5	9	0	S
13. The Analytic Method did not motivate me to the laboratory classes.	0	0	1	32	17	S
14. The Vee stimulated and developed my sense of critical appraisal in the laboratory classes.	6	31	6	7	0	S

(Continue)

* Questions 11 to 21 were answered only by students of the second research run.

Table 20. (Continued)

	SA	A	U	D	SD	RR
15. The Vee is an excellent auxiliar framework in the understanding and description of the relation between physics and nature, i.e., the relation between the physicists' description of nature and nature itself.	7	30	9	4	0	S
16. The Vee helped me to understand the processes involved in a scientific investigation.	12	32	4	2	0	S
17. The learning and use of the Vee contributed to my growth in the scientific analysis of physics events (phenomena).	11	35	2	2	0	S
18. The Analytic Method contributed very little in my understanding of physics as being a body of knowledge resulting from scientific inquiry processes.	0	2	4	37	7	S
19. The use of the Analytic Method and all the emphasis given to the laboratory classes and tests prejudiced the level of my general learning in the Physics II course.	2	4	8	21	15	S

(Continue)

Table 20. (Continued)

		SA	A	U	D	SD	RR
20. The Clinical Interviews	CI(21):	5	13	3	0	0	S
The Group Discussions	GD(12):	2	5	3	1	1	S
The Written Feedback	WF(17):	1	10	3	2	1	S
(From these three activities, consider the one in which you participated) were worthwhile because they contributed to correct deficiencies in the understanding and use of the Analytic Method (Vee).							

second research runs (identified by F and S at the right of the scores, respectively). The item 10 was answered only in the pilot run, and the items 11 to 21 were answered only by the students of the second research run.

The second part (Part Two) of the questionnaire with students' opinions is presented through the Tables 21 and 22 These two tables were the second parts of the questionnaires used in the first and the second research runs, respectively.

In the third part of the questionnaire, each student had opportunity to freely to express his/her final comments, critics and suggestions concerning the study and the use of the epistemological framework in the physics laboratory context.

Table 21. Final Questionnaire of the First Research Run - Part Two. Students' opinions about the terminology used for each part of the Analytic Method (Vee) and their difficulties in the identification and understanding of the function of each part (term). The number of answers given by 66 students are indicated.

Instructions:

a) Concerning the terminology used by the Analytical Method (Vee) in the description of the structure of a laboratory experiment, indicate your opinion whether the term of the Vee was or was not appropriate to its function;

b) Concerning the identification of each term of the Vee and the understanding of its function, indicate your level of difficulty in this identification and understanding.

Term of the Vee	Appropriate							Difficult						
	not very						very	not very						very
	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Event(s) and object(s)	0	0	3	6	8	16	33	39	12	7	6	0	0	2
Basic (Telling) question(s)	0	2	1	6	2	13	42	35	12	7	5	3	1	3
Key concepts	1	3	1	10	12	19	20	12	7	15	19	8	0	5
Definitions	4	6	7	17	11	11	10	4	7	12	22	10	4	7
Principles and laws	5	3	8	12	11	13	14	9	6	7	16	10	9	9
Theory	2	8	3	17	8	13	15	9	6	10	17	8	9	7
Measurements (Records of events)	1	1	3	7	4	24	26	31	11	13	5	2	2	2
Transformations of measurements	2	7	6	8	15	15	13	13	12	5	16	8	4	8
Interpretations of data	2	3	2	8	11	19	21	8	13	9	20	8	5	3
Affirmations of knowledge (Knowledge claims)	7	2	15	11	10	11	10	6	14	10	12	8	8	8
Affirmations of value (Value claims)	7	4	14	12	13	7	9	4	8	7	14	12	9	12
Philosophy (System of values)	11	9	12	11	7	5	11	4	7	2	8	7	9	29

Table 22. Final Questionnaire of the Second Research Run - Part Two. Students' opinions about the terminology used for each part of the Analytic Method (Vee), their difficulties in the identification of each part and in the understanding of the function of each part (term). The number of answers given by 50 students are indicated.

Instructions:

a) Concerning the terminology used by the Analytical Method (Vee) in the description of the structure of a laboratory experiment, indicate your opinion whether the term of the Vee was or was not appropriate to its function;

b) Indicate your level of difficulty in the identification of each part (term) of the Vee;

c) Indicate your level of difficulty in the understanding of the function of each part (term) of the Vee.

Term of the Vee	Appropriate					Difficult to identify the term of the Vee					Difficult to understand the function of the term				
	not very				very	not very				very	not very				very
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Event(s) and object(s)	0	2	5	16	27	30	10	7	2	1	34	12	2	1	1
Basic (Telling) question(s)	0	0	6	14	30	30	11	6	2	1	32	14	4	0	0
Key concepts	2	3	13	13	19	15	15	15	4	1	23	11	13	3	0
Definitions	2	4	13	17	14	2	16	22	8	2	11	16	17	5	1
Relationships among concepts	0	4	15	15	16	3	10	22	12	3	10	18	15	6	1
Principles and laws	1	4	9	17	19	4	10	22	11	3	14	14	15	5	2
Measurements (Records of events)	1	2	3	13	31	30	14	4	1	1	31	15	3	1	0
Transformations of measurements	2	4	7	16	21	20	16	10	2	2	24	14	10	1	1
Interpretations of data	1	4	7	13	25	8	18	16	6	2	18	14	16	1	1
Affirmations of knowledge (Knowledge claims)	5	9	10	13	13	13	11	15	11	0	15	12	12	9	2
Affirmations of value (Value claims)	6	13	12	12	7	8	11	14	13	4	10	10	16	8	6
Philosophy (System of values)	10	13	13	10	4	5	6	10	19	10	4	6	17	16	7
Interaction (between the two sides of the Vee)	2	3	10	23	12	3	14	19	13	1	12	18	12	6	2

Let us now analyse the first part of the Final Questionnaire shown in Table 20.

In order to have an idea about students' answers to the questions, we used the Likert's scale[8]. That is, we assigned the value of 4 to a SA (strongly agree) and changed the value to 0 (zero) to a SD (strongly disagree) in the case of statements in favour of the Analytic Method (the epistemological Vee) and, otherwise, we assigned values varying from 0 (zero) to a SA to 4 to a SD in the case of statements non-favourable to the Vee. Of course, the Likert's scale provides us with a general an approximate idea about the students' opinions because the numbers assigned to the answers are arbitrary and it is possible that a SA answer to a favourable question, e.g., it is not very similar to a SD answer to a non-favourable question.

Only 12 items out of the 20 items shown in Table 20 are statements that actually express a favourable (or non-favourable) opinion concerning the Analytic Method; they are the items 1 to 6, and the items 13 to 18. The students of the second research run answered all these items but the students of the first research run answered only the first six items

Applying the Likert's scale on these items the students' answers indicated a total score of 1232 out of a maximum possible of 1584 [9] in the first research run, and a total

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(8) Worthwhile material concerning analysis of questionnaires may be found in "Research in Education" by Best, J.W., 1970, Englewood Cliffs, Prentice-Hall.

(9) Maximum possible: 4 points per item per student x 6 items x 66 students = 1584 points.

score of 1813 out of a maximum of 2400[10] in the second research run. These total scores, 1232 and 1813, represent 78% and 75% of the possible maximum scores in the first and second research runs,respectively. This reflects a students' good [11] receptivity to the Analytical Method (epistemological Vee). These statistics are summarized in Table 23.

Table 23. Students' receptivity to the epistemological Vee.

Research Run	Number of Students	Number of Items	Likert Scale: Maximum Total Score	Likert Scale: Total of Neutral Opinion	Students' Opinions: Total Score
First	66	6*	1584	792	1232
Second	50	12**	2400	1200	1813

*Items 1 to 6 specified in the Table 20.
**Items 1 to 6 and 13 to 18 specified in the Table 20.

Table 20 also shows the students' opinions concerning some aspects of the Vee (items 7 and 8), the instructional materials and program (items 9 to 12, and 19), and the formative evaluation strategies (item 20).

In the item 7 of the Table 20, we can observe that the students of the pilot research run had more difficulties than the students of the second research run in the understanding and elaboration of the Vees. Even considering the differences

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(10) Maximum possible: 4 points per item per student x 12 items x 50 students = 2400 points.

(11) We consider a good receptivity because 75% is at the mean position between the maximum receptivity and the neutral opinion (2/4 = 50%).

between the two samples of students, we may say that this happened mainly because the instructional materials and the program of the first run were inferior in quality to the ones of the second run when general improvements were made. The students' opinions given in the item 9, in the same Table 20, confirm this point of view: 31 out of 66 students of the first run, against only 3 out of 50 students of the second run, saw the instructional units as disorganized and non clear.

Through the item 8 of the Table 20, we can conclude that most students agreed or strongly agreed that the right (methodological) side of the Vee was easier to understand and to describe than the left (conceptual) one. This confirms the results obtained through the laboratory tests.

The items 10 and 11 of the Table 20 were already analysed in the Section III-6.1. The students' opinions, expressed through these two items, indicate that it is appropriate to introduce a general overview of the Vee at the very beginning of a course.

The item 12 shows that most students of the second research run considered the Vee as being used at an appropriate level.

The item 19 shows that 6 out of 50 students of the second run believed that the use of the Vee and the emphasis given to the laboratory classes and tests had prejudiced their general level of learning in the Physics II course. Usually, these students refer that time is taken from the theoretical classes with a consequent reduction in the amount of theoretical content and in the total amount of physics problems which are solved in these classes.

The item 20, concerning the three formative evaluation strategies, will be analysed in the next section.

Let us now analyse the students' answers to the second part of the Final Questionnaire through the data shown in Tables 21 and 22 which refer to the first and the second research runs, respectively

In Table 21 we can observe that a significant number of students of the pilot research run considered the terminology used for some terms of the Vee as not very appropriate to represent their functions; that is, a significant number of students assigned the low scores 1, 2, or 3, which correspond to the students' opinion that the terminology was not very appropriate to represent the function of the term. Such is the case of the following terms:

- Philosophy (System of values): 32 out of 66 students assigned the lower scores 1 to 3;
- Affirmation of value (Value claim): 25 out of 66 students;
- Affirmation of knowledge (Knowledge claim): 24 out of 66.

A not quite significant number of students also considered other terms as not appropriate; such is the case of the terms Definition (17 out of 66 students assigned the lower scores 1 to 3), Principles and laws (16 out of 66 students), Theory (13), and Transformations of measurements (15)

The low scores assigned by these students to the terms Definitions, Principles and laws,and Theory, probably were determined by the fact that, in the pilot research run, the students were not provided with some basic ideas concerning the nature, the structure and the functions of a theory and its component parts. Consequently, without a better idea about a theory and its parts, the students considered those terms as not very appropriate.

The introduction os these ideas was made in the second research run through the theoretical classes as we mentioned in Section IV-6. We consider that the introduction of some basic ideas about a theory was very worthwhile for the students; this is evident by observing the data shown in Table 22. In this table, through the set of data situated at the left side of the table, we can observe that most students considered as appropriate to their functions the terms Definitions, Relationships among concepts, and Principles and laws. We contend that, because the students of the second research run received some basic ideas concerning the nature and the structure of a theory and its component parts, they became more familiarized with these terms and their functions. Consequently, they considered the terminology used for those terms as being very appropriate to their functions.

However, we can observe (in Table 22) that even in the second research run there was some terms of the Vee which terminology was considered as being not very appropriate by a significant number of students; such is the case of:

- Philosophy (System of values): 23 out of 50 students assigned the lower scores 1 and 2 to the terminology of this term;

- Affirmations of value (Value claims): 19 out of 50 students.
- Affirmations of Knowledge (Knowledge claims): 14 out of 50.

The low scores assigned by 23 out of 50 students to the term "philosophy", is consequence of two facts. First, by intending to simplify (for the students) the meaning of "philosophy", we defined it as "a system of values which could be underlying the theory of an experiment as well as originating the value claims about the knowledge claims and/or about the experiment as a whole". Second, questions about the possible philosophies were not asked in the laboratory tests and they were discussed very superficially in the theoretical classes of the course. It is evident that this superficial approach was not sufficient and probably determined the students unhappiness with the use of the term "philosophy".

The term "affirmations of value (value claims)" deserves some comments which we will present later.

Concerning the term "affirmations of knowledge (knowledge claims)", most of the 14 students who considered the terminology of this term as not very appropriate prefer to use just the terms "results", or "answers", or "findings", or "conclusions".

Let us now analyse the students' opinions concerning their difficulties in the identification of each part of the Vee and in the understanding of its function.

To facilitate the observation and the analysis, let us add the number of students of the second research run (see Table 22) who assigned the scores 1 and 2, corresponding to a "not very difficult", in each term; in a similar way, let us add the number of students, in each term, who assigned the scores 4 and 5 which correspond to a "very difficult". These transformed data are shown in Table 24.

In Table 24 we may observe that a significant number of students (23 out of 50 students, that is, 46%) indicated that they had difficulties to understand the function of the term "philosophy", and they also indicated difficulties to identify (29 out of 50 students, 58%) the same term in the laboratory context. This evidences that the superficial instructional approach (mentioned earlier), which we used for the term "philosophy", probably also contributed for these students' difficulties. Remembering that a significant number of students (23 out of 50, 46%) also assigned the lowest scores to the terminology of "philosophy", we permit ourselves to infer that when the students do not understand the meaning of a term of the Vee they have more difficulties to identify the term, and they are more likely to disagree with its terminology.

The data in Table 24 also show that a significant number of students had difficulties to understand (14 out of 50 students, that is, 28%) and to identify (17 out of 50, 34%) the term "affirmations of value (value claims)". We point out that 19 out of 50 students (38%) also assigned low scores to the term "affirmations of value (value claims)". Because we consider that the meaning of "affirmations of value" was well defined and illustrated through several examples (as may be

Table 24. Students' opinions about their difficulties in the identification of each part of the Vee and in the understanding of the function of each part. The data refer to the second research run and were obtained through a transformation of some data of the Table 22. Total number of students = 50.

Term of the Vee*	Difficult to identify the term of the Vee			Difficult to understand the function of the term		
	not very		very	not very		very
	1 and 2	3	4 and 5	1 and 2	3	4 and 5
Event	40	7	3	46	2	2
Telling question	41	6	3	46	4	0
Key concepts	30	15	5	34	13	3
Definitions	18	22	10	27	17	6
Relationships	13	22	15	28	15	7
Principles & laws	14	22	14	28	15	7
Measurements	44	4	2	46	3	1
Transformations	36	10	4	38	10	2
Interpretations	26	16	8	32	16	2
Knowledge claims	24	15	11	27	12	11
Value claims	19	14	17	20	16	14
Philosophy	11	10	29	10	17	23
Interaction	17	19	14	30	12	8
Totals	333	182	135	412	152	86

* The terms are better specified in the Table 22.

observed in Appendix A), we infer that these students' difficulties and reactions were probably determined by their difficulties in stating the significance and utility of the established knowledge claims and/or of the whole experiment. Otherwise, we must emphasize that "value claims" were asked only in the first two laboratory tests; this may have been an insufficient number of opportunities for the students to think and overcome their difficulties concerning the understanding and the use of the term.

In Table 24 we may also observe that most of the students indicated that they had no difficulties in the understanding and identification of the terms located at the bottom of the Vee, that is, the "event", the "key concepts", and the "measurements". This also happened with the terms "transformations of measurements", "interpretations of data", and "telling (basic) question".

In Table 24 we may also observe that some students indicated that they had difficulties in the understanding and in the identification of some other terms of the Vee; such is the case of:

- Relationships among concepts: 14% of the students indicated that they had difficulties in the understanding, and 30% in the identification of this term;
- Interaction (between the two sides of the Vee: 16%, and 28%;
- Principles and Laws: 14%, and 28%;
- Definitions: 12%, and 20%.

These students' opinions (from 12% to 30% of the students), that they had difficulties in the understanding and identification of these four specific terms, confirm the information which we collected through the laboratory tests and the formative evaluation activities. That is, students' main difficulties in the conceptual domain of the Vee came from their (a) lack of mastery of the theoretical background of the experiment, (b) difficulties in expressing relationships among concepts, and (c) lack of knowledge about the nature, structure and functions of a theory and its component parts. Even more, these students' difficulties also represented obstacles in the description of the "interaction" (constant interplay) between the conceptual and the methodological domains of the structure of knowledge involved in a laboratory experiment.

Concerning the difficulties in the understanding of the function and in the identification of the term "affirmations of knowledge (knowledge claims)", indicated by 22% of the students in both cases (see Table 24), we infer two possible reasons for these difficulties. First, these difficulties perhaps may be related with that (mentioned earlier) students' reaction to the terminology of this term. Second, some of these 22% of students argued that they considered as unnecessary the establishment of "knowledge claims" after they had carried out the "interpretations of data"; that is, they considered that the "interpretations of data" also included the "knowledge claims".

It is also interesting to observe in Table 24 that the number of students who indicated difficulties in the identification of each term of the Vee it is higher (except the term "knowledge claims") than the number of students who indicated difficulties in the understanding of the function of the corresponding term. This may be observed by comparing the number of students who assigned the scores 4 and 5 in the two columns, or by comparing the totals at the bottom of the Table 24. This probably happened because each new laboratory experiment required a particular application of the Vee.

The third part of the Final Questionnaire, as we mentioned before, asked the students to freely express their final comments, critics and suggestions concerning the Analytic Method (epistemological Vee) with which they had just finished to work with in the Physics II laboratory context. A sample of some expressions written by the students in the third part of the Final Questionnaire is presented in the Appendix G.

As soon as we received the first answered questionnaires, we took a glance at some students' comments and we decided to formulate few additional questions to the students. Sixty four students answered these additional questions. This number of students is higher than the number of students (50) who answered the Final Questionnaire because the additional questions were attached to the last written examination (concerning the theoretical classes) of the Physics II course, and 64 students, who were involved in this research study, performed this written examination.

The additional questions of the Final Questionnaire, with the frequencies of the students' answers, are presented in Table 25.

Table 25. Additional Questions of the Final Questionnaire.

The frequencies of the answers given by 64 students are shown.

Question	Many	An acceptable number	Few	None
1. How many physics laboratory classes did you have in the secondary school or before you came into college ?	3	15	25	21
2. How many laboratory classes did you have in the Physics I course ?	0	5	11	47

3. Did you already take a course (in any discipline) through which you had the opportunity to study and analyse the structure of scientific knowledge (product of scientific inquiry) in a similar way as was done with the Analytic Method, Vee, through the laboratory classes of the Physics II course ?

Yes: 7
- Just theoretic course: 2*
- Theoretic-practical course: 5**

No: 57

* Preparatory School of the Army; Scientific Methodology.

** Chemistry (3 mentions); Biology (3); Mineralogy (1).

From the frequencies shown in Table 25 we may conclude that:

1. The physics laboratory work, in the secondary schools where most of the students who answered the questions had studied, in general, was not too much emphasized.
2. The laboratory work in the Physics I course, which comes before the Physics II course that provided the population of this study, practically did not exist. This, of course, determined a great number of students' difficulties mainly by the lack of practicing some laboratory skills such as the concerned with the graphic construction and analysis.
3. The Analytic Method involved actually a new subject matter for most the students. This supports our initial point of view, stated in the Chapter I, that the students usually are not provided with an epistemological framework to guide them to the understanding and description of a laboratory experiment. In other words, teachers in laboratory teaching assume that the students know how to learn from nature when students actually do not know it. How could they, if almost nobody teaches it ?

Let us now go into the last section of this data analysis chapter.

IV-11 Comparative Analysis of the Three Formative Evaluation Strategies

Having in mind the additional research question of this study stated in the Section III-4, let us now carry out a comparative analysis of the three experimental groups which involved the clinical interviews (CI), the group discussions (GD), and the written feedback (WF). This analysis will compare the three experimental groups in terms of:

- the means in the five laboratory tests;
- the students' receptivity to the Vee;
- the students' receptivity to the formative evaluation strategies;
- the time involved in conducting the three strategies.

Table 26 summarizes the performance of the three experimental groups of the second research run in the five laboratory tests. Applying the F-test to the data, that is, using an One-factor Analysis of Variance (ANOVA)[12], we obtained the F-ratios (SS_b/SS_w) indicated in Table 26. From these F-ratios we may conclude that, in all the five laboratory tests, even at a level of significance .1, it is not possible to reject the null hypothesis H_o of no statistical difference among the three experimental groups.

Table 27 shows the frequencies of the answers given by the students of the three experimental groups, of the second research run, to the twelve questions of the Final Questionnaire which aimed to detect the students' receptivity to the Vee.

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(12) Reference: Glass and Stanley, 1970, Chapter 15.

Table 26. Data of the Five Laboratory Tests.

The number of students (N), the means (M), and the standard deviations (SD) of the means of the three experimental groups are indicated.

Test	Group	N	M	SD	SS_b	SS_w	F*
1	CI	25	5.98	1.49			
	GD	23	5.00	1.83	7.17	3.61	1.99
	WF	26	5.10	2.18			
2	CI	24	8.19	1.03			
	GD	20	8.05	1.13	2.53	1.33	1.91
	WF	23	7.56	1.25			
3	CI	24	6.47	1.22			
	GD	19	6.47	1.52	0.01	2.11	0.01
	WF	25	6.51	1.52			
4	CI	24	7.08	1.45			
	GD	19	7.29	1.02	0.79	1.46	0.54
	WF	22	7.45	0.96			
5	CI	24	7.27	1.79			
	GD	18	7.72	1.65	1.09	2.93	0.37
	WF	21	7.38	1.52			

* F-test, One-factor Analysis of Variance (ANOVA): Glass and Stanley, 1970, Chapter 15.

These twelve questions are specified in Table 20 and they were already analysed, as a whole, through Table 23.

Using the Likert's scale (see the reference given in footnote 8) we obtained, for the three experimental groups, the total scores indicated at the bottom of the Table 27. Considering the possible maximum total scores of each group, we obtained the percent relations between the total score of

Table 27. Receptivity of the three experimental groups to the Vee.

Question*	Group	N	SA	A	U	D	SD	CI	GD	WF	Total
1	CI	21	5	14	0	2	0	64			
	GD	12	2	10	0	0	0		38		
	WF	17	1	14	0	2	0			48	150
2	CI		0	0	0	14	7	70			
	GD		0	0	0	8	4		40		
	WF		0	0	2	12	3			52	162
3	CI		0	18	3	0	0	60			
	GD		1	9	2	0	0		35		
	WF		0	12	4	1	0			45	140
4	CI		0	1	0	14	6	67			
	GD		0	0	1	5	6		41		
	WF		0	0	1	16	0			50	158
5	CI		0	0	2	15	4	65			
	GD		0	0	0	9	3		39		
	WF		0	1	4	12	0			45	149
6	CI		3	17	1	0	0	65			
	GD		2	9	1	0	0		37		
	WF		2	14	1	0	0			52	154
13	CI		0	0	0	12	9	72			
	GD		0	0	0	6	6		42		
	WF		0	0	1	14	2			52	166
14	CI		4	14	2	1	0	63			
	GD		1	9	1	1	0		34		
	WF		1	8	3	5	0			39	136
15	CI		2	12	4	3	0	55			
	GD		4	6	1	1	0		37		
	WF		1	12	4	0	0			48	140
16	CI		4	13	3	1	0	62			
	GD		4	8	0	0	0		40		
	WF		4	11	1	1	0			52	154
17	CI		6	14	1	0	0	68			
	GD		2	9	1	0	0		37		
	WF		3	12	0	2	0			50	155
18	CI		0	0	2	15	4	65			
	GD		0	0	1	9	2		37		
	WF		0	2	1	13	1			47	149
a) Total Score**								776	457	580	1813
b) Maximum Total Score								1008	576	816	2400
c) Percent Relation a/b								77%	79%	71%	75%

*The questions are specified in Table 20.
**Scoring system: Likert's scale refered in the text.

each group and its possible maximum total score; they are also shown at the bottom of the Table 27. We can observe that the percent relations are approximately the same, about 75%, for all the three groups as well as for the total of students. This suggests that practically there was not significant difference among the three experimental groups in terms of the students' receptivity to the Vee expressed through the Final Questionnaire.

Let us now compare the students' receptivity to the three formative evaluation strategies. Through the question 20 of the Final Questionnaire (see the Table 20) each student expressed his/her opinion about the strategy in which he/she had participated; that is, if the specific strategy had or had not been worthwhile in correcting deficiencies in the understanding and use of the Analytic Method (Vee).

The data obtained from the students' opinions are shown in the 3x3 contingency Table 28. In this table, the scores of each group which represented agreement were added, and the same with the scores representing disagreement, in order to increase the validity of the χ^2-test [13]. Using this test, we obtained the value of $\chi^2 = 5.102$. This value, when compared with the critical values given by tables, in our case for 4 degrees of freedom, permits us to affirm that the null hypothesis (of independence among the three modes of classification which the contingency Table 28 is based) cannot be rejected even at the .2 level. In other words, there is no statistically significant difference among the

(13) Reference: Mode, Elmer B., 1966, "Elements of Probability and Statistics", Chapter 11. New Jersey: Prentice-Hall,Inc.

Table 28. The Students' Receptivity to the Three Formative Evaluation Strategies. The data refer to the students' answers to the question 20 of the Final Questionnaire presented in the Table 20.

	SA+A	U	D+SD	
CI	18	3	0	21
GD	7	3	2	12
WF	11	3	3	17
	36	9	5	50

students of the three experimental groups in terms of their receptivity to the specific type of formative evaluation strategy in which they were involved during the course.

The Table 29 presents the time involved in conducting the three formative evaluation strategies. We can observe that the clinical interviews required about twice more time than the written feedback (involving nearly the same total number of students per activity), and that the written feedback required more time than the group discussion (about 1.5 times more, if the total number of students, or activities, are equalized).

We must state that the information collected through the clinical interviews seemed to us more worthwhile and significant for instructional and research purposes. As we mentioned earlier, this impression may be determined by the higher amount of time that we dedicated to the clinical interviews in

Table 29. Time involved in Conducting the Three Formative Evaluation Strategies. The number of students (N) and the time in hours(h) are indicated.

	First Set		Second Set		Third Set			
	N	Time(h)	N	Time(h)	N	Time(h)	N	Time(h)
CI	23	11.50	19	9.50	22	11.00	64	32.00
GD	20	3.00	17	3.00	16	3.00	53	9.00
WF	25	6.25	27	6.75	11	2.75	63	15.75
Total	68	20.75	63	19.25	49	16.75	180	56.75

comparison with the other two strategies. But, if we look at the students' performance in the laboratory tests and at the students' receptivity to the Vee and to the formative evaluation strategies, we will see no significant difference. This may be more easily understandable when we put ourselves in the place of the student. For the student, in general, there was not any significant difference in the amount of time he/she dedicated to the understanding and use of the Vee; that is, each student was involved, in general, during the same total amount of class time in the course, independently of the formative evaluation activities in which he/she took part.

Even more, in this study there was a constant interaction among the students of the three experimental groups with the consequent sharing of meanings; that is, the three treatments were not pure because they were not completely independent. The third instructional unit about the Vee (see Appendix A), for instance, had its elaboration based on information which was collected through the three formative evaluation strategies, and the same instructional unit was provided to all the students. The same happened with the basic ideas about the nature and structure of a theory and its parts, which were provided to all the students; and the same with the the discussions about the graphic construction and analysis, that we mentioned before.

In summary, only you, the teacher and/or researcher who is reading this work, can decide which instructional and research approach is more appropriate to the needs and work conditions of the educational context where you are putting your time and efforts. For us, however, as we mentioned before, the clinical interviews seemed to be more worthwhile and significant for instructional and research purposes.

Chapter V

SUMMARY AND FINAL INTERPRETATIONS

Following previous experience and research in laboratory instruction which indicated the need of providing students with a heuristic device to help them in the understanding and description of the structure of knowledge of laboratory experiments, this study was based on providing students with Gowin's epistemological Vee through an introductory laboratory physics course at Federal University of Rio Grande do Sul, in Brazil.

V-1 The Educational Context, the Problem and the Basic Assumption

Physics II is the second one of a sequence of three one-semester courses in General Physics on electromagnetism and thermodynamics to engineering students at Federal University of Rio Grande do Sul, in Brazil.

Our experience as a teacher and the research findings of a study carried out by Moreira (1977) provided evidence that, in the Physics II laboratory context, there was some students' apparent inability to learn the educative materials presented, in spite of the improvements made in the teaching methods and in the instructional materials.

What are the educational objectives of the laboratory ? What should be taught to the students ? Laboratory is defined as "a place for scientific experiments". Physics has been defined to be both a body of knowledge and a process of inquiry. "Knowledge", used in this study, refers to the "results or products of inquiry". We think that this process of inquiry ought to be taught to students in a laboratory context. That is, in addition to teaching them laboratory skills, physics concepts and relationships among concepts, and certain attitudes, students ought to be taught how to learn from nature without the assistance of either a laboratory guide or a teacher.

One of the major mistakes made by the teachers in laboratory teaching is to assume that the students know how to learn from nature when students actually do not know it.

Facing the problem that the Physics II laboratory work was not being often effective, we assumed that this was in part happening because the students were not being provided with an epistemological framework that could guide them to the understanding and description of a laboratory experiment.

In other words, we assumed that the laboratory work was not being often effective because, in part, the students did not know how to learn from nature, they did not know about processes of inquiry and, consequently, they did not understand and know how to describe the structure of knowledge of a laboratory experiment. The term structure, in this study refers to the parts of a whole, it also refers the function of each part, and the relationships among these parts.

Therefore, we decided to provide the Physics II students with an epistemological framework in order to make possible their improvement in the understanding and description of the structure of knowledge involved in a laboratory experiment.

V-2 The Main Research Objective

An evaluation of students' performance in the understanding and use of Gowin's epistemological framework (the Vee) was the main objective of this research. That is, this study intended to investigate the students' conceptions and misconceptions, main difficulties and abilities, as well as feelings and receptivity in the comprehension and use of Gowin's Vee in the Physics II laboratory context.

We selected Gowin's Vee as an appropriate epistemological framework to guide students to the understanding and description of a laboratory experiment. The Vee is a method for the analysis of knowledge claims (products of inquiry); that is, the Vee is a heuristic device for the analysis of the structure of knowledge as a product of disciplined inquiry. In Educating (D.B.Gowin, 1981) the reader can find clear operational definitions and explanations for each term (part) of the Vee, and also for the relationships among these parts which describe the structure of knowledge. In this study, the reader may find the Vee illustrated by means of the Figure 1 and described in Section II-3 and Appendix A.

The evaluation of students' performance in the understanding and use of the Vee was differentiated in three levels of students' achievement:

1. The classification of the parts of the structure of knowledge

of a laboratory experiment;

2. The description of relationships among these parts;
3. The application of the epistemological framework to new problems and situations of a laboratory experiment.

V-3 <u>The Theoretical Background of the Research Study</u>

The theoretical framework of this research study is mainly based on concepts, definitions, and relationships among concepts which are involved in Gowin's epistemological Vee, in Gowin's triadic model of teaching, in the concept of formative evaluation, and in Gowin's ideas about learning.

In the anterior section we already indicated where may be found descriptions concerning the Vee structure and all the concepts and relationships which it may involve.

Formative evaluation, for the purpose of this study, means the use of a systematic evaluation in the teaching and learning process with the objective of improving this process through feedback. It is also anticipated that an appropriate formative evaluation approach will help to make the process of teaching more effective, long before any summative (final) evaluation takes place. Formative evaluation yields feedback and facilitates assessment of students' understanding and enables the teacher to take decisions soon enough to correct deficient teaching methods and promote more meaningful learning. A conceptual analysis of formative evaluation is presented in Appendix B.

In relation to teaching, we decided to use another Gowin's model as a theoretical framework. Gowin (1981) sees teaching as a triadic (three-way relation) episodic exchange of meanings of pieces of knowledge (educative materials) between teacher and student, and the occurence of successful teaching as the achievement of shared meanings between them. Gowin's triadic model of teaching is described in the Section II-4 and illustrated by means of the Figure 2.

We see coherence between Gowin's model of teaching and an appropriate formative evaluation approach because through both feedback may be provided and sharing of meanings may be carried out among teacher(s), students, and educative material.

Concerning the concept of learning, we used Gowin's ideas as a reference. According to Gowin (1981), after the achievement of shared meanings, the student is then ready to decide to learn or not because learning is a responsibility of the individual; learning is not a responsibility that can be shared. Gowin defines learning as "an act of an individual to connect up the new pattern of meanings with the old one (that the student brings to the teaching situation), and to work voluntarily to fit them together". And he clarifies that: "The re-organization of meaning is under the voluntary control of the learner ... according to his or her own interest".

V-4 The Experimental Procedure

This study was carried out through two research runs: a pilot run and a second research run. The pilot run was carried out during the first semester of 1980 (from March to June). After that, the instructional, evaluative and research materials, as well as the design of the experiment, were improved for the second research run from August to November of 1980.

Each run lasted about 15 weeks and dealt specifically with the laboratory activities related to five laboratory experiments on electricity and magnetism performed in five 2-hour classes by roughly 80 students (two course sections) of the Physics II course at UFRGS, in Brazil. During the first and second research runs, nearly 270 and 370 students were respectively enrolled in 6 and 9 sections of the Physics II course.

Students of the two course sections used in the experiment were not randomly selected because students are free to enroll in any of the sections of Physics II, but once they are enrolled no changes can be made. At registration they are not aware of which teacher will be in charge of a certain course section.

The nearly 80 students received the following research written materials: instructions about the epistemological Vee (Appendix A), laboratory guides (Appendix C), and laboratory tests (presented and analysed in the Chapter IV).

Students' performance in the achievement of the epistemological Vee (understanding and use in the three levels mentioned earlier) was evaluated through five written tests concerning the five laboratory experiments of the Physics II course. In the second research run, the first three tests were individually answered by the students during a period of 45 minutes for each test, and this time was taken from the theoretical classes (a kind of lecture combined with recitation) which came one or two days after the laboratory work. The fourth and fifth tests, in the second run, lasted respectively 45 and 30 minutes and were individually answered in the 2-hour classes when the last two experiments were performed.

The five written laboratory tests were individually answered and supposed to provide evidence about the students' level of achievement of the epistemological Vee applied to the description of the structure of knowledge of each experiment The criteria used in assessing the student understanding and use of the Vee through the laboratory tests were based upon previously prepared possible answers by the author and upon a Vee of each experiment. In addition, a concept map (see example in the Appendix D) illustrating the conceptual structure of each laboratory experiment was drawn in order to assist the researcher in carrying out the evaluation of the tests. These maps had also been used as reference in the preparation of the laboratory guides. A zero to a maximum of 10 points scale was used to score each laboratory test, which was separated into its several component parts in order to increase the range of the evaluative discrimination.

For each one of the five tests, were calculated the following statistics: the mean of each test item and its standard deviation; the total mean of the test and its standard deviation; the reliability coefficient of the test; the standard error of the measurements.

In addition to the five laboratory tests, three different formative evaluation strategies were used in order to evaluate the students and to provide them feedback in the achievement and use of the epistemological framework. These three strategies also served as three different channels of information for research purposes.

The three formative evaluation strategies were named: Clinical Interviews (C.I.), Group Discussions (G.D.), and Written Feedback (W.F.). The three strategies are described in the Section III-3 and the rationales for the development of the clinical interviews and the group discussions are presented in the Appendixes E and F, respectively.

The main differences among these three experimental treatments, used to stimulate feedback and sharing of meanings as well as to increase the amount of research information, are concerned with the kind of feedback that each group received after performing the laboratory experiments and tests:

- The G.D. experimental group, in the second research run, was divided in two sub-groups, each one with about 5 students, for the purpose of group discussions lasting about 45 minutes per sub-group, three times along the semester;
- The C.I. students were excused from the class planned for group discussions, but they were required to participate in individualized clinical interviews, lasting half an hour per student, during the same week of the group discussions (three times along the semester);

- The W.F. group was also excused from the class planned for the group discussions, but W.F. students received back their laboratory tests with comments and individualized remedial written work requirements; this was done with emphasis on written communication, so that no more than fifteen minutes per student per test were taken from the teacher (reasercher)

In the second research run, when the research design of the experiment was improved, three experimental groups were randomly selected from each one of the two course sections used in the experiment. The three experimental groups refer to the three different formative evaluation strategies which were used in order to provide feedback to the students in the understanding and use of the epistemological Vee Just one of these three strategies was used with each student.i.e., each student received just one of the three possible treatments for feedback.

The use of the three formative evaluation strategies generated an additional research question of this study:

- Given three different formative evaluation strategies, the C.I., G.D., and W.F., to support and assess the students in the mastery and use of the epistemological Vee, what differences would arise among them in terms of.

a) Students' performance in the laboratory tests ?

b) Students' receptivity to the epistemological Vee as expressed both during the course and in a final questionnaire ?

In both research runs, one week after the fifth (last) laboratory test, students answered a Final Questionnaire. The aim of this questionnaire was to collect students' opinions and final critical comments relative to their participation, difficulties, and learning insights in the understanding and use of the epistemological framework (Vee) that they had just finished to work with in the Physics II laboratory context.

The questionnaire of the first research run, in particular, provided information which was used as a reference when modifications were made for improvement in the research and instructional programs for use in the second research run.

The questionnaire of the second research run also helped in the answering of the additional research question. That is, the questionnaire was also used as an additional instrument in the detection of differences among the three instructional strategies with formative evaluation in terms of students' receptivity to the epistemological framework.

V-5 The Research Findings

Taking into account that several shortcomings happened in the pilot research run which were eliminated in the second run (as explained in the Chapter III) we will present mainly the findings established through the second research run.

Before presenting a summary of the research findings, let us review the main research objective of this study. The main research objective (see pages 4 and 21) was:

To evaluate the students' performance in the achievement and use of an epistemological framework for:

(a) the understanding and the description of the relation between physics and nature, and (b) the recognition of physics as being both a body of knowledge and a process of inquiry.

As we mentioned earlier, in this study the term "knowledge" refers to "products of inquiry", and the term "structure" refers to "the parts of a whole, the function of each part, and the relationships among these parts". Then, the main objective of this research study may be stated through other words appropriate for the laboratory context. That is, the main research objective was:

To evaluate the students' performance in the achievement and use of an epistemological framework as a heuristic device for the understanding and description of the structure of knowledge involved in a laboratory experiment.

Concerning the main research objective, let us now present the major findings of this research study. They were established through the data analysis of the students' performance in the five laboratory tests, through the three sets of formative evaluation activities, and through the data analysis of the students' opinions in the final questionnaire.

V-5.1 Students' Performance in Using the Vee

From the first to the fifth laboratory experiment and test, there was a progressive improvement in the students' understanding and use of the epistemological framework (the Vee) for the analysis of the structure of knowledge involved in each one of the five laboratory experiments.

This improvement includes the proposed three levels of students' achievement mentioned earlier, even the highest one, that is, the "application of the epistemological framework to new problems and situations of a laboratory experiment in order to establish knowledge claims". The students' performance in this highest level of achievement was also satisfactory but the findings are preliminary and deserve additional research studies to increase their validity.

The mentioned students' improvement is evident through the data analysis presented in the Chapter IV of this study, and it may be claimed even considering the interference of two factors: the differences among the five laboratory experiments, and the increase (with the time) of the students' familiarity with the terminology of the epistemological Vee. We contend that, in addition to the learning of the "Vee language", the students also improved their ability in using the Vee for a better understanding and description of the structure of knowledge of the laboratory experiments. Even more, coherent with the moral justification of this research study (Section II-5), we contend that the teaching and learning process is likely to become more efficient when both the subject matter and its epistemology keep going together.

We also contend that the information obtained by the three different formative evaluation strategies permitted us to comprehend some of the students' basic difficulties (which we will summarize later) in the understanding and use of the Vee in time for remedial feedback.

In terms of Gowin's triadic model for teaching (Section II-4), we think that by giving our meanings through instructional materials about the Analytical Method (the Vee) to the students, and receiving their meanings through the laboratory work, the tests, and the formative evaluation activities, an exchange of meanings occurred. This sharing of meanings probably contributed to the increase in the students' understanding of the Vee and in their ability to use it in the Physics II laboratory context.

V-5.2 Students' Performance in the Highest Level of Achievement and Use of the Vee

The fifth (last) laboratory experiment and test was used to evaluate each student in the proposed third (highest) level of achievement of the epistemological framework (Vee): application to a new situation in the laboratory context in order to obtain knowledge claims.

To permit this kind of evaluation, the fifth laboratory content was divided into three different parts (relative to three different events or phenomena) and each student worked alone without a laboratory guide but with a laboratory test concerning one specific event which he/she received at random. To make possible the students' individual work, special arrangements were made in the laboratory class; these arrangements are described in the Section IV-9.

The following findings and inferences may be stated through the analysis of the students' performance and receptivity in the fifth (last) laboratory experiment and test:

When the students were required to learn from nature on their own, in the fifth (last) laboratory experiment and test, they had some difficulties. These difficulties were mainly concerned with aspects of practical nature, with the theoretical background of the experiment, and with skills on graphic representation and analysis of data. In addition, of course, some difficulties arose because the students were being required to perform at the highest proposed level of achievement of the Vee for the first time in the course. That is, for the first time in the course they had to plan and develop an experimental procedure, by using the epistemological Vee as a reference, in order to analyse a physics phenomenon and to establish knowledge claim (s).

However, in spite of these difficulties, the students' performance in this highest level of use of the Vee was satisfactory, as can be observed through the data analysis of the fifth laboratory experiment and test presented in the Section IV-9. Our point of view is that this satisfactory performance was made possible, in great part, because the students used the Vee as a reference. That is, the students had clear ideas about the structure of knowledge of a laboratory experiment and, consequently, they were capable of projecting and executing an experiment (without a laboratory guide) in order to obtain knowledge claim (s).

The students liked the kind of work carried out in the fifth laboratory class because of the challenging situation that required individual thought and application of the Vee.

We were positively surprised with the students' enthusiasm with this fifth laboratory approach. This students' receptivity was reflected through their opinions in the third part of the Final Questionnaire which is presented in the Appendix G.

Concerning the students' satisfactory performance and receptivity in the highest level of achievement of the Vee, the findings suggest further research because they were established just through one laboratory experiment and test and, consequently, as mentioned before, they are preliminary.

V-5.3 Students' Main Difficulties in Using the Vee

Let us now present the major research findings concerned with the students' main difficulties in the understanding and use of the Vee.

The methodological domain of the Vee (experiment) was more easily understood and described by the students than the conceptual one.

Students' main difficulties in the conceptual domain came from their (a) lack of mastery of the theoretical background of the experiment, (b) difficulties in expressing relationships among concepts, and (c) lack of knowledge about the nature, structure and functions of a theory and its component parts.

These students' difficulties also represented obstacles in the description of the constant interplay between the conceptual and the methodological domains.

Some students' difficulties in the expression of relationships among concepts was evident because it happened in all the five laboratory tests.

Concerning the students' insufficient understanding of the theoretical background (left side of the Vee) when performing an experiment, although they had received the laboratory guide in advance and also the theoretical classes concerning the same theory, we suggest a possible solution: the use of a pretest preliminary to the laboratory work. Through this pretest, a minimum performance level concerning the theoretical background of the experiment would be required from each student as a condition to perform the laboratory work. We did not put this remedial solution into practice in this study but it could be tried out in other research run.

With reference to the students lack of knowledge about the nature, structure and functions of a theory and its component parts (that is, the concepts, definitions, concept definitions, assumptions, relationships among concepts, laws, and principles), this students' deficiency was observed by the time of the third laboratory and test. By that time, most students did not know the main functions and purposes of a theoretical model which are: to describe and explain phenomena, to predict natural outcomes, and both to make happen and control events. By that time, most students did not know, e.g., that a law (or a principle) fulfills two main functions: first, it summarizes many regularities in events and so makes for the economy of thought, because if one knows the law (or principle) one does not need all events; second, it enables one to predict further events, because it tells one that if a phenomenon is an instance of a law, it will behave as the law (or the principle) states.

In order to minimize this students' deficiency, we used every opportunity from the Physics II theoretical classes to introduce some key ideas concerning the nature, structure and functions of a theory and its parts.

Let us return to the major research findings concerning the students' main difficulties in their understanding and use of the Vee.

Students' main difficulties in the methodological domain (right side of the Vee) came from their lack of skills in (a) the graphic representation of data, (b) the drawing of a "best-fit" curve through the data points, and (c) interpreting the curve as satisfying or not satisfying an equation.

These students' difficulties were also detected by the time of the third laboratory experiment and test and, after that, we used every opportunity from the Physics II classes to illustrate some basic techniques about graphic representation and analysis of data.

V-5.4 Students' Receptivity to the Vee

The students' answers to a final questionnaire permitted us, in part, to confirm some of the research findings already stated. In addition, the following main findings are established through the data analysis of the final questionnaire.

In both the research runs, the students' opinions reflected a good (about 75% of the possible maximum by using the Likert's scale) receptivity to the use of the epistemological framework (Vee).

In the second research run, the students' receptivity to the Vee was evidenced by their answers to 12 items of the final questionnaire. These 12 items (see Tables 20 and 27) involved statements concerning the validity and usefulness of the Vee for:

- the laboratory classes in general (items 1 to 3 in Tables 20 and 27);
- the comprehension, analysis, and description of the structure of knowledge involved in a laboratory experiment (item 4);
- other circunstances out from the Physics II laboratory classes (item 5);
- observing the constant interaction between the theoretical (conceptual) and the practical (experimental, methodological) domains of an experiment (item 6);
- motivating the students to the laboratory classes (item 13);
- stimulating and developing the students' sense of critical

appraisal in the laboratory classes (item 14);

- the understanding and description of the relation between physics and nature, i.e., the relation between the physicists' description of nature and nature itself (item 15);
- understanding the processes involved in a scientific investigation (item 16);
- the students' growth in the scientific analysis of physics events (phenomena)(item 17);
- the understanding of physics as being a body of knowledge resulting from scientific inquiry processes (item 18).

Even in the second research run, there was some terminology of the Vee which was considered as being not very appropriate to its functions by a significant number of students. Such is the case of: "philosophy" (system of values), 23 out of 50 students assigned the lowest scores to the terminology of this term; "value claims" (affirmations of value, in equivalent Portuguese words), 19 out of 50 students; and "knowledge claims" (affirmations of knowledge, in equivalent Portuguese words), 14 out of 50 students.

The low scores assigned to term "philosophy", as we already commented in Section IV-10, is consequence of two facts. First, by intending to simplify the meaning of "philosophy", we defined it as "a system of values which could be underlying the theory of an experiment as well as originating the value claims about the knowledge claims and/or about the whole experiment". Second, questions about the possible philosophies were not asked in the laboratory tests and they were discussed very superficially in the theoretical classes of the course. It is evident that this superficial approach was not sufficient and probably determined the students unhappiness with the use of the term "philosophy".

Concerning the term "value claims", its meaning was well defined and illustrated through several examples (see Appendix A) and we infer that the students' difficulties and reactions were probably determined by their difficulties in stating the significance and utility of the established knowledge claims and/or of the whole experiment. In addition, "value claims" were asked only in the first two laboratory tests and, consequently, the students had not a sufficient number of opportunities to overcome their difficulties with the understanding, use and the terminology of the term. We permit ourselves to make this inference because we think that when the students do not understand the meaning of a term of the Vee they have more difficulties to identify the term, and they are more likely to disagree with its terminology.

Concerning the term "affirmations of knowledge (knowledge claims)", most of the 14 students who considered the terminology of this term as not very appropriate prefer to use just the terms "results", or "answers", or "findings", or "conclusions".

The Final Questionnaire also showed that:

In the secondary schools, where most of the students who answered the Final Questionnaire had studied, the physics laboratory work, in general, was not emphasized.

The laboratory work in the Physics I course, which comes before the Physics II course that provided the population of this study, practically did not exist. This lack determined an increase in the students' difficulties in the laboratory work mainly by the lack of practicing some skills such as those concerned with the graphic construction and analysis of data.

The epistemological Vee (named Analytic Method, or just Vee, in the Physics II course context) involved a new content for most of the students. This fact supports our initial assumption that students usually are not provided with an epistemological framework to guide them to the understanding and description of the structure of knowledge involved in a laboratory experiment.

V-5.5 The Three Formative Evaluation Strategies

Concerning the additional research question of this study, by comparing the three experimental groups (C.I., G.D., and W.F.) in terms of students' performance in the five laboratory tests, the students' opinions through the Final Questionnaire, and the class time involved, the following knowledge claims are established.

In all the five laboratory tests, it was not possible to reject the null hypothesis H_0 of no statistical difference in performance among the three experimental groups, even at the level .1 of significance.

There was practically no significant difference among the three experimental groups in terms of students' receptivity to the Vee as expressed through the Final Questionnaire.

There was no statistically significant difference among the three experimental groups in terms of receptivity to the specific type of formative evaluation strategy in which the students of the three groups were involved, even at a level .2 of significance.

The clinical interview required about twice time to carry out than the written feedback (involving nearly the same total number of students per activity).
The written feedback required more time than the group discussions (about 1.5 times more, if the total number of students in both activities are equalized).

The clinical interviews seemed to this author more worthwhile and significant for instructional and research purposes because they provided the more valuable information. It is true that this impression may have been caused by the large amount of time that the author dedicated to the clinical interviews.

During the Physics II classes, there was no correlation between the particular formative evaluation strategy in which a student participated and the amount of class time he/she dedicated to the understanding and use of the Vee.

We must emphasize that the findings concerning the comparative analysis of the three experimental groups were established and are valid for the particular instructional approach (or a similar one) carried out in this study; that is, in this study there was a constant interaction among the students of the three experimental groups with the consequent opportunities for sharing of meanings. Consequently, the three treatments were not pure because they were not completely independent. The instructional feedback about the Vee was based on the information which was collected through all the three formative evaluation strategies, and the same instructional feedback was provided to all the students.

V-6 Author's Reflections

Our study is a first attempt, in a Brazilian educational context, in providing college students with an epistemological framework to help them in the understanding and description of the structure of knowledge involved in physics laboratory experiments.

We claim that our findings indicate that this attempt was successful and worthwhile, and that most students appreciate it.

At first, this study was not intended to be a check of the validity and usefulness of Gowin's epistemological framework (Vee). However, the experience that we attained through our research study (based on formative evaluation, sharing of meaning, and feedback) permits us to claim that the Vee is actually an excellent epistemological framework.

The Vee is likely to help the students in their comprehension of physics and its structure. The Vee is likely to help the students in getting a view of the relation between practice and theory, in achieving understanding of scientific processes, in developing critical appraisal and inquiry, and in providing the students with a way for action, on their own, when facing a phenomenon of scientific interest.

The Vee has a strong communication power. If the reader had asked which aspect of this study was the most stimulating to this author, he would answer it was the deep and clear communication which happened between this author (teacher) and the students by using the "Vee language" as a reference (epistemological framework). This kind of easy and strong communication happened not only in the laboratory classes but also during the other course activities. A sample of the students' ability in carrying out this kind of communication is shown in Appendix G.

The evidence that the Vee has an excellent structure, a strong communication power, and it is likely to improve abilities on scientific inquiry, are the most important findings of this research study. This statement is based on our belief that the invention of "organization" was human being's first most important achievement; the second was "communication", and the third is the "development of scientific inquiry".

We contend that the ability to analyse phenomenon(a) and to establish knowledge claims, which are products of inquiry, may be improved by providing students with some kind of organized and communicable epistemological framework in addition to the subject matter content. We claim that Gowin's epistemological Vee showed to be this kind of framework.

APPENDIX A

INSTRUCTIONAL UNITS ABOUT THE EPISTEMOLOGICAL VEE

INSTRUCTIONAL UNITS ABOUT THE EPISTEMOLOGICAL VEE

Institute of Physics, UFRGS
Physics II - 1980

Analytic Method for the Laboratory Experiments

First Instructional Unit

Introduction

We are introducing a method for the analysis of the structure of the laboratory experiments.

The term "structure" refers to the parts of a whole, it also refers the function of each part, and the relationships among these parts. For instance, when we talk of a soccer team with someone we identify each player and his field position, we describe his function in the team and we discuss how the players (in their functions) relate among themselves, i.e., how they interact. Other examples might be: the structure of a building or an engine, the structure of the human body, and the structure of a society.

When we speak of the structure of a laboratory experiment we refer to the identification of the several parts of the experiment, such as the event, the method, and the knowledge claims. We also describe the function of each part and the functional relations among these parts.

We are introducing the analytic method in order to help you in the understanding of the laboratory experiment structure. The laboratory tests will indicate your level of knowledge in understanding and describing the structure of each laboratory experiment with the help of the analytic method.

In addition, the analytic method may also be used for the critical analysis of lectures, books, articles, and research works based on experimental procedures in general.

Description of the Analytic Method

The analytic method, which will be used in the laboratory classes and tests, consists basically of answering the following six questions to make clear the structure of knowledge of the laboratory experiments:

1) What is (are) the observed event(s), i.e., the phenomenon(a) which is (are) being studied?
2) What is (are) the telling question(s)[*] of the experiment?
3) What are the key concepts?
4) What method(s)[**] is (are) used to answer the telling question(s)?
5) What are the knowledge claims[***] in the experiment?
6) What value claims[***] can be made in the experiment?

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[*] Portuguese term which corresponds to the English word "basic" was used instead of "telling";

[**] the expression "experimental procedure(s)" was also used instead of "method(s)";

[***] Portuguese terms which correspond to the English words "assertions" and "affirmations" were used because they provide the best translation to the Portuguese of the term "claims" originally introduced by Gowin (1970).

For instance, let us consider the analysis of a laboratory experiment:

1. <u>Events</u>

<u>Events</u> are phenomena which happen naturally or which one make happen in nature. The experimental inquiry process is basically a process by which one goes from events to answers of questions about these events.

A first difference among events was mentioned above:

a) Events which happen or one can make happen or reproduce and manipulate in laboratory activities such as the fall of bodies, and the scattering of particles by atoms;
b) Events which happen in nature but which one cannot make happen, i.e., one cannot reproduce or manipulate them in experimental situations. This events can only be observed and studied as they happen such as eclipses and supernovae.

Another important difference that can be made is among events that can or cannot be recorded. It is difficult to imagine events which cannot be recorded, but, we can mention, for example, mental processes such as the learning of a physics concept, and the "insight" in the solution of a problem.

Recordable events can be differentiated as follows:

a) Events directly recordable, i.e., events that can be seen, photographed, or measured directly, such as the falling bodies;
b) Events not directly recordable, i.e., events that cannot be seen, photographed, or measured directly, such as

movement of atomic particles, and stars which are going into gravitational collapse (black holes).

Facts are records of events. According to the dictionary definition, a fact is that which actually exists, which is real.

In short, an event is what happens. The events are the source(s) of experimental evidence in the process of scientific inquiry.

2. The Telling (Basic) Question(s)

The telling question is the question which identifies the phenomenon to be studied in a way that something will probably be measured, discovered, or determined by answering this question. The telling question informs about the central point of the experiment; that is, the reason of being of the experiment. Essentially, it tells what is being inquired.

3. The Key Concepts

The key concepts are the fundamental concepts of the field of study of the experiment. These key concepts are involved in the different parts of the structure of knowledge of the experiment and, in general, most of them appear in the telling question.

We define a concept as a linguistic symbol (sign) which points to regularities in events. In other words, a concept is a logical and abstract entity of the human mind; it represents a set of objects or events with some common characteristics which may be refered and identified by a particular name or symbol.

For instance, the concept of liquid points to qualities which are common to the milk, oil, and water, but it does not refer the several differences (which exist) among them.

In summary, a concept is a mental and symbolic representation of a general characteristic of objects and events; it permits a generalization.

A generalization is the full meaning of a concept to all cases to which the concept may be applied; the generalization is the process by which one recognizes the characteristics which are common to several objects and/or events. Therefore, a concept has to a small(er) extent the "power" of generalization which a principle or a law have to a great extent. This should not be a surprise because both principles and laws contain concepts and relationships among concepts.

The development of new concepts and the evolution of old ones lead to new kinds of observing ancient objects and events, i.e., they lead to new forms of selecting new objects and events which deserve to be recorded and analysed. New concepts originate new kinds of observations, of measurements (records), and of transformations of these measurements. The inverse process also happens, i.e., new kinds of observations, etc., originate new concepts.

However, the question "What are the key concepts" proposed in our analytic method requires not only the identification and description of the key concepts, but also the explanations of how they are logically related among themselves. These concepts and relationships among them form a <u>conceptual</u>

structure. This conceptual structure, which can be illustrated on a concept map, establishes a pattern of reasoning to relate a concept with another. This conceptual structure also serves to guide a researcher in the development of experimental procedures (methods) of research studies.

4. The Method

The research method is a particular experimental procedure. In an experiment, the scientist is investigating an event and looking for answers to the questions about the event, i.e., a phenomenon which happens or which the scientist makes happen in the laboratory and that is manipulated in order to be studied in its several aspects.

In order to record the events and perform an experimental procedure, the scientist uses the equipment. This equipment can be simple and common like a meter and/or sophisticated like an electronic computer. The records of events provide data to the scientist. In general, the scientist presents the data in the form of graphs, tables, and equations, in order to interpret them and to get conclusions (results), i.e., in order to get answers to the questions under investigation. The results are then compared with tables, graphs, equations, laws already known from other investigations or anticipated (expected) from a theory. The theory is the structured set of concepts, definitions, principles and laws that constitute the conceptual basis of the experiment.

In summary, the method (experimental procedure) is the sequence of the following steps:

a) Records of events, i.e., measurements;

b) Transformations of measurements, i.e., data organization;

c) Interpretations of data;

where:

a) Records of events are the measurements which permit the study of the events. Records of events constitute an essential part of the research. Indeed, very much time is generally used in the invention of techniques and devices with the purpose of making records which can serve as an index of the phenomenon being studied.

b) Transformations of measurements are the acts of processing the records of events. They are the calculations, the plotting of records in a graph, the processing by a computer, etc.. Sometimes the records are so much transformed that the results remain so far away from the events that the connection among the experimental data and the events is lost.

c) Interpretations of data are the processes of analysis and synthesis of the experimental data such as the analysis of a graph and the synthesis represented by an average value computed from several numerical records. In short, interpretations are the final steps which enable to establish the knowledge claims (affirmations of knowledge)

5. The Knowledge Claims

Knowledge claims (affirmations of knowledge) are the answers to the telling (basic) questions; they are the conclusions.

A knowledge claim is a product of inquiry. An inquiring process includes events, telling questions, concepts, methods, and techniques which are all involved in the process of establishing knowledge claims.

Usually, an investigation originates additional questions together with the answers to the initial questions. This is a characteristic of the scientific investigation; that is, the characteristic that permits an evolution starting from the formulation of new problems.

6. The Value Claims

The value claims (affirmations of value) refer to the significance, utility, importance of the following:

a) The knowledge claims obtained at the end of the scientific investigation such as "the results of this research will help the economy of oil";
b) The scientific investigation by itself. Some examples are the affirmations about the utility of a certain method, the precision of a new technique of measurement, the clarification of a concept, and/or the didatic value of an investigation as well as of an experiment.

The scientific inquiry and the consequent knowledge claims involve several possible value claims. When analysing and choosing these values, one may consider several patterns such as economic, political, educational, didactic, social, moral, aesthetic, technical, instrumental (for technological or scientific use), ethical, and humanistic.

The following are examples of value claims:

Social value: "All the persons should know the results of this research: that smoking causes lung cancer". Aesthetic value: "A nice demonstration... A coherent and elegant mathematical proof". Didactic value: "This experiment helped me to understand the electromagnetic theory". Instrumental scientific value: "If is useful to develop the knowledge level of this specific field of study".

After all, one always can ask about any scientific investigation, experiment, and knowledge claim, questions such as "What is the value of the investigation? Of the experiment? Of the results? What is the instrumental value? What is the significance? What is the utility? Significance and utility to whom? What for?...

In summary, so far our analytic method consists of asking:

1) What is the event (phenomenon)?
2) What is the telling (basic) question?
3) What are the key concepts? How are they structured in terms of definitions, logical relationships, equations, principles and laws in order to form a theory?
4) What is the method (experimental procedure) used with the purpose of answering the telling question, i.e., what are the records of the events, the transformations of the records and the interpretations of the data?
5) What is the answer to the telling question about the event?

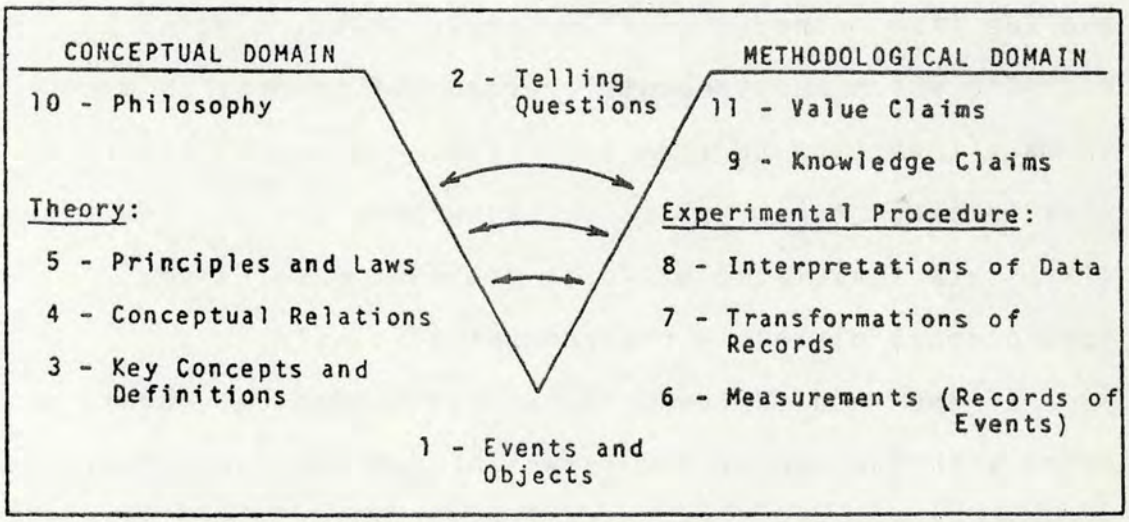
6) What is the value of the answer and of the investigation?

The answers to the six questions mentioned above will give you an initial idea of the structure of each laboratory experiment which you will perform and analyse during the course.

Similarly to a laboratory experiment, the analytic method also has its own structure which we will describe next.

Description of the Structure of the Analytic Method

We will describe the structure of the analytic method with the help of the letter V (Vee). The following figure shows the structure of the analytic method represented by the letter Vee.



The events and objects which are being observed are placed at the point of the Vee. Symbolically, the Vee points to the events and objects to indicate the sources of evidence of an investigation (experiment).

The left side of the Vee is the conceptual (theoretical) one composed of concepts, definitions, relationships among concepts, principles, and laws, which altogether form the theory. Still in this same left side there is the philosophy which, to simplify, one will just consider as being the system of values which originate the value claims.

The left side determines which events, among the involved in the phenomena, will be investigated; the conceptual side also guides the formulation of the telling (basic) questions.

As soon as the events and the telling questions are determined, the conceptual domain guides the right side of the Vee (the methodological or experimental domain) in deciding which measurements (records of events) to make, how to make them, how to transform them, and how to interpret them in order to establish the knowledge claims. The value claims are formulated based on the system of values (philosophy) placed in the conceptual domain.

If the results found in the methodological domain do not agree with the content and foresights of the conceptual domain, if necessary, the conceptual side will be always modified according to the new findings of the scientific investigation. Therefore, there is a constant interaction between the two sides of the Vee. Thus, the scientific knowledge is in constant revision: the theory is always orienting the experimental procedure and, by retribution, the experimental observations, procedures, and results are reinforcing, revising and still also changing deeply the conceptual system. This is the meaning of the crossover lines which link the conceptual and methodological sides of the Vee.

Conclusion

In order to illustrate the analytic method introduced in this instructional unit we will present an example of application of the analytic method in the next unit.

We conclude emphasizing that:

1) The answers to the "six questions" provide information about what was investigated, about the conceptual structure of the study, about the research methods and about the knowledge and value claims;
2) The "Vee", in addition, provides a map (overview) showing how all these aspects of an investigation are related with basic events that happened naturally or that were made happen during the experiment. The Vee help us to visualyze the conceptual domain, the events, the telling (basic) questions, and the methodological domain. All these parts interact and form a whole: the structure of both the scientific investigation and knowledge.

The "six questions" and the "Vee" together will constitute the instruments for the critical analysis of the work which you will develop by performing the laboratory experiments and tests of this course.

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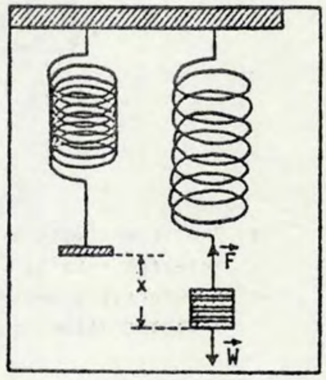
Institute of Physics, UFRGS
Physics II - 1980

Analytic Method for the Laboratory Experiments
Second Instructional Unit

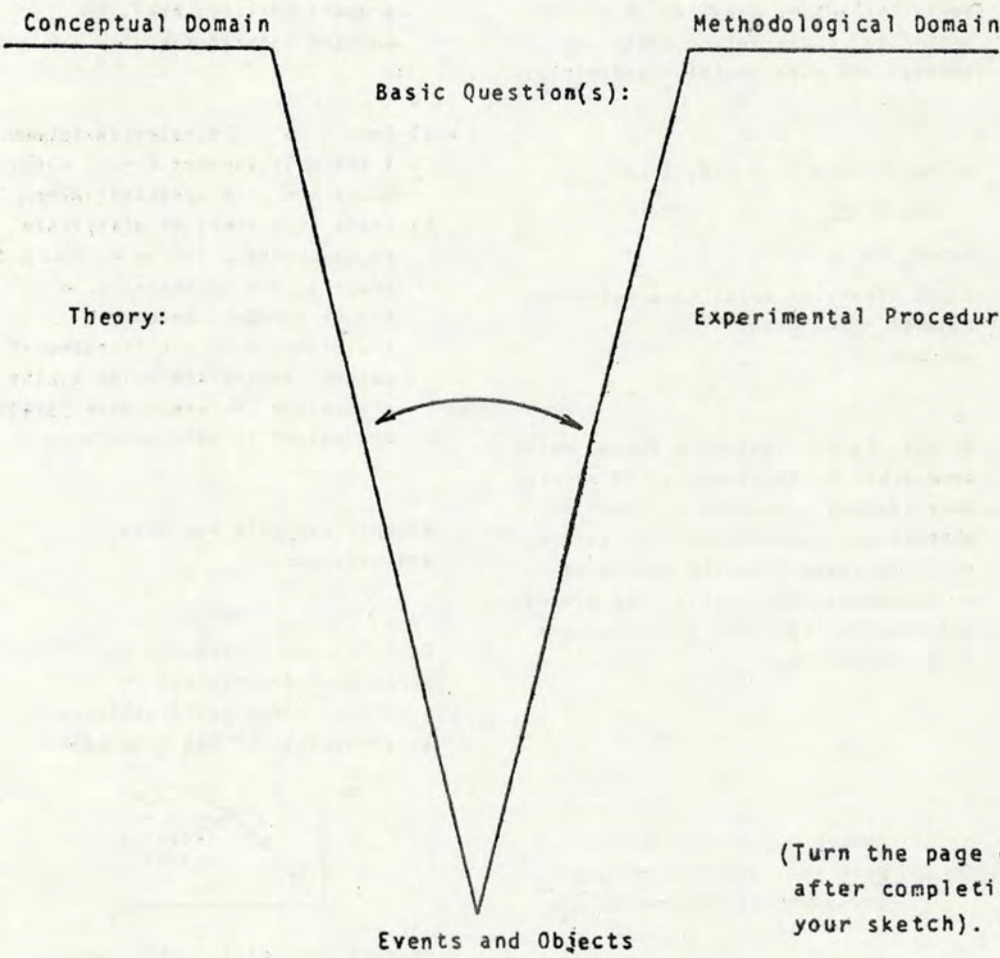
Example of Application of the Analytic Method

To illustrate, we will apply the analytic method to a simple and known experiment: "Determination of the elastic characteristics of a spring".

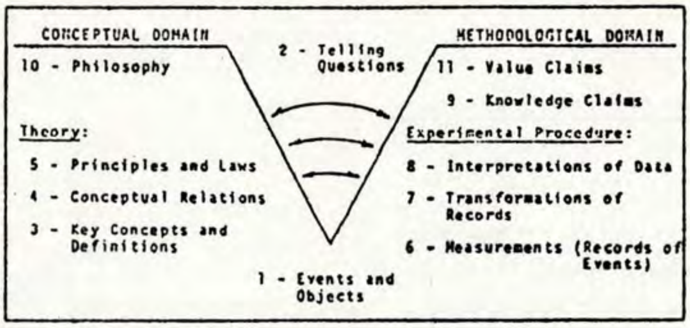
In this experiment (see Figure at the right) a spiral spring is hung by one extremity and the other is dislocated by the addition of known m_i masses, where $i = 1,2,3,\ldots$ To each weight $W_i = m_i g$ which is added, the spring is stretched of x_i from the undeformed position.



In the space below, sketch the structure (the Vee) of this experiment.



(Turn the page only after completing your sketch).



2 a) What is the relation between <u>x</u> and <u>m</u>?
b) Is there an elastic limit? What is its value?

10
a) The technologic application of the research results it is useful.
b) A laboratory experiment has a didactic value.

5
Newton's laws of gravitation and of mechanics. Conservation (mass and energy) and superposition principles.

4
$m = \Sigma m_i$; $\vec{W} = \Sigma m_i \vec{g}$; $\vec{F} = -\vec{W}$; $\vec{x} = \Sigma \vec{x}_i$;
$i = 1, 2, 3, \ldots$;
$m_1 \cong m_2 \cong m_3 \cong \ldots$;
It is likely to exist some relation between <u>x</u> and <u>m</u> but it is still unknown.

3
Weight, force, restoring force, mass, acceleration, acceleration of gravity, displacement, elasticity, limit of elasticity, proportionality, vector, etc.. Concepts from the theory of measurements and errors; from graphic construction and interpretation and from statistics.

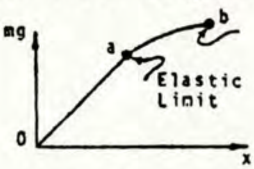
1
Masses m_i ($i = 1, 2, 3, \ldots$) hung in a spiral spring and producing displacements $\vec{x}_i$.

11
a) Useful for the construction of dynamometers and shock absorbers.
b) Very good experiment to introduce the first ideas from the theory of measurements and errors, proportionality, etc., in physics laboratories.

9
a) From <u>0</u> to <u>a</u> the relation between <u>x</u> and <u>m</u> is linear: $\vec{F} = -k\vec{x} = -m\vec{g}$, where $k = \ldots$(a constant) N/m$\pm\ldots$%.
b) There is a limit of elasticity at the point <u>a</u> for $mg = \ldots$ N $\pm \ldots$%; after <u>a</u>, the relation is no longer constant because <u>k</u> diminishes with the increase of weight. Beyond the point <u>b</u>, the elongation increases even though the weight is held constant.

8
Graphic analysis and data interpretations.

7
Calculations of average x_i, of percentual errors, and of $W_i = m_i g$; graph construction and determination of the <u>k</u> constant.



6
Measurements of $\vec{x}_i$ after hanging and after removing the m_i.

Institute of Physics, UFRGS
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<u>Analytic Method for the Laboratory Experiments</u>
Third Instructional Unit

I - The results of the first laboratory test, concerning the first experiment (Simulated Electrostatic Field), were:

Question		% of the scores of 74 students			Mean Score	Standard Deviation
		0 Wrong	0.5 (±)	1.0 Correct	Difficulty and Discrimination Levels	
Item	Content					
1.a	Event	45	24	31	0.43 difficult	0.42 good
1.b	The term "simulated"	63	14	23	0.30 very difficult	0.41 good
2	Basic (Telling) question	19	15	66	0.74 very easy	0.40 good
3.a	Key concepts	9	65	26	0.58 easy	0.28 intermediate
3.b	Relationships among concepts	37	59	4	0.34 very difficult	0.28 interme.
4.a	Measurements (Records of events)	8	30	62	0.77 very easy	0.33 good
4.b	Transformations of measurements	15	35	50	0.68 easy	0.36 good
4.c	Interpretations of data	39	18	43	0.52 intermediate	0.46 good
5	Knowledge claims	39	22	39	0.50 intermediate	0.45 good
6	Value claims	31	35	34	0.51 intermediate	0.41 good

Total Mean: 5.4.

Standard Deviation of the Total Mean: 1.9.

Reliability Coefficient of the Test: 0.67.

Standard Error of the Measurement: 1.1.

II - Orientations for the next laboratory tests:

a) To identify the event (occurrence which serves as source of evidence) it is useful to verify <u>what</u> is being measured because the measurements are "the records of the events". This leads us to consider frequently how the measurements are made, and how is the working system of the measurement instrument(s) and its (their) influence on the event(s).

b) "Are the lines of force perpendicular to the equipotential lines?" cannot be a basic (telling) question of the first lab because we deliberately drew the lines of force perpendicular to the equipotential ones based on information already known from the theory. To test this perpendicularism we would need another experiment to obtain separately the two families of lines for posterior confrontation.

c) The relations among the key concepts are expressed by means of:

- mathematical equations, for example:

  $\Delta V = -\int \vec{E}.d\vec{l}$; or $E_l = -dV/dl$;

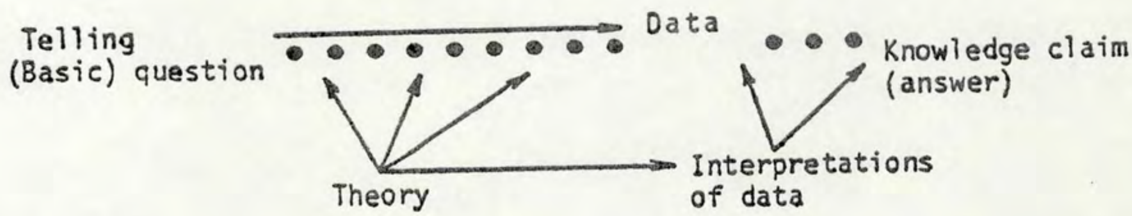
- definitions, for instance:

  $R = V/i$ (electric resistor); or $i = dq/dt$ (electric current);

- logical relations given by practical rules, for example: "The tangent to a line of force at any point gives the direction of $\vec{E}$ at that point"; or "The magnitude of $\vec{E}$ is proportional to the number of lines of force per unit cross-sectional area"; or "A line of force is perpendicular to the equipotential surfaces (lines)".

All these formulas, expressions, and statements, are relating key concepts (most fundamental concepts).

d) Data are the "transformed records of events". Interpretation of data is the final analysis (helped by components of the theory) that permits to get and formulate an affirmation of knowledge (answer to a basic question); see the following illustration.



e) A knowledge claim (affirmation of knowledge) is a specific answer to a telling (basic) question formulated at the beginning of the experiment. During the inquiry process, additional questions may come about with (or without) their corresponding answers.

f) A value claim (affirmation of value) involves an evaluation, it requires a judgement about the utility, the importance, the quality, and/or the validity of a knowledge claim or of the experiment as a whole. The value claim is not a simple repetition of a knowledge claim already expressed by other words.

APPENDIX B

CONCEPTUAL ANALYSIS OF FORMATIVE EVALUATION

CONCEPTUAL ANALYSIS OF "FORMATIVE EVALUATION"

1. Identifying the Concept

The concept: "Formative Evaluation".

The context: Introductory Physics Laboratory Course (at College).

Our motivation in doing this analysis: to clarify the concept meaning of "Formative Evaluation", to deal with the following telling question:

> "To what extent can a formative evaluation, discovering deficiencies and successes in the intermediate stages of an instructional approach to introductory physics laboratory at college, provide opportunity of feedback for teachers and students and a consequent better achievement?" (Adapted from Michael Scriven, 1967).

2. Clear (Model) Cases

Example 1: Teacher self-rating (about his laboratory teaching) used in conjunction with students ratings (feedback) as a mean of highlighting discrepancies for the individual instructor and as an aid to instructional improvement. (Adapted from Centra, 1972, and from Tom & Cushman, 1975).

Example 2: The instructor and a group of about 8 students around a table with all the materials of a physics experiment (already done by everybody): the instructor selects one (or more) specific instructional objective(s) of the experiment and designates a student to practically illustrate that objective(s); then each other student gives a grade (score) for the presentation and an average score is computed, informed and, finally, a critical appraisal is developed. (Adapted from Postlethwait, et al., 1972).

Example 3: A two students/group laboratory work is interrupted at the middle of a 3-hour class period, during 15 or 20 minutes, to develop some general discussion with (and among) all the about 30 students; Gowin's "unpacking" system (or five telling questions, or epistemological "V") is applied on the experiment to give the opportunity to everybody see "what it is really going on". (Taken from Professor Gowin's classes and adapted from M.A. Moreira's thesis - 1977).

Example 4: Several and frequent questions are included in a lab-guide (or in a separate sheet); the students give written answers that then are checked against a key (model) for self--correction and revise (reformulate) the incorrect ones. (This ideia came from Millman's Educ-352 course at Cornell and from one of the programmed instruction characteristics: active answers with imediate self-correction).

3. The Used Language

Focusing on language we investigate attributes (characteristics explained by indicating the causes) of the "Formative Evaluation" concept. We got a characterization of what "should be" a formative evaluation (FE) from Cronbach (1963) and Scriven (1967)'s articles:

a) FE identifies aspects of the course where revision is desirable.
b) FE is used to improve the course while it is still fluid.
c) FE contributes more to improvement of education than evaluation used to appraise a product already placed on the market. (Adapted from Cronbach's "intrinsic evaluation").
d) FE has the role of discover deficiencies and successes in the intermediate stage of a process.
e) FE tests the work while it is being developed, produces revision, and provides feedback.
f) FE is outcome evaluation of an intermediate stage in the development of the teaching instrument.
g) ..., a major difficulty with evaluation involving intermediate goals, ..., lies in the formulation of the goals. ... How do we decide which should receive precedence? (From Michael Scriven, 1967).
h) ..., there are several opportunities of sequential learning evaluation that can be explored, i.e., situations where ability to learn new material presupposes the availability of the old one. (Adapted from Ausubel 1966's article).

We selected some key words to help us to indicate something caused by formative evaluation (to see its attributes).

From the four given concrete examples:

give and receive answers
give and receive grade (or score, or rating)

compare	self-correct
use in conjunction	revise
discuss	feedback
observe discrepancies (differences)	reformulate
examine	improve
criticize	

From the experts' language:

identify
discover
test
evaluate
appraise

intermediate	contribute
interact	develop
revise	improve
process	
feedback	
sequence	

4. The Activities

Concerned with the "know-how" (activities) we focus on what is really being done in our four model cases:

- active interaction (participation) with materials and people;
- people evaluating and self-evaluating;
- comparing (discussing, appraising) different evaluations (answers);
- revising (redoing) after feedback.

5. Contrary Cases

In order to clarify (refine) the concept meaning, we present two situations (in our laboratory physics context) that are not examples of formative evaluations.

Contrary Example 1: A student receive back his final report on an experiment; corrected by the teacher, it has some checks in red ink, there is no critics, or praise, or comments, or suggestions, but only a final grade (score). Nobody (instructor and students) have time because it is time to do the next scheduled experiment. (Taken from the most real laboratory evaluation situations).

Contrary Example 2: A teacher receives bad results in the students' rating on a questionnaire (organized by the college administration) evaluating his laboratory course just finished. The instructor does not care because he did not a self-rating on the same questions, he thinks the students do not have capacity to evaluate his course, and, anyway, he will teach another course at the next term. (This idea came through when doing a paper on the Cornell student rating form, to Millman's Educ 519 course).

From these counter-examples, we can see that formative evaluation is not present when there is not:

- discussion, communication, share of meanings;
- conversation ("give reasons, weigh evidence, justify, explain, conclude, and so forth", adapted from Green 1971);
- time to review (redo);
- care (interest, motivation, positive attitude to improve);
- contrast with a self-rating (self-evaluation) producing some sort of impact;
- mutual trust between the people involved;
- purpose (goal) to be achieved;
- responsability.

6. The Reasons for Doing

Trying to infer the "know-why", that means to search the reasons why people act in a way that contributes to formative evaluation, we did the following list:

Action

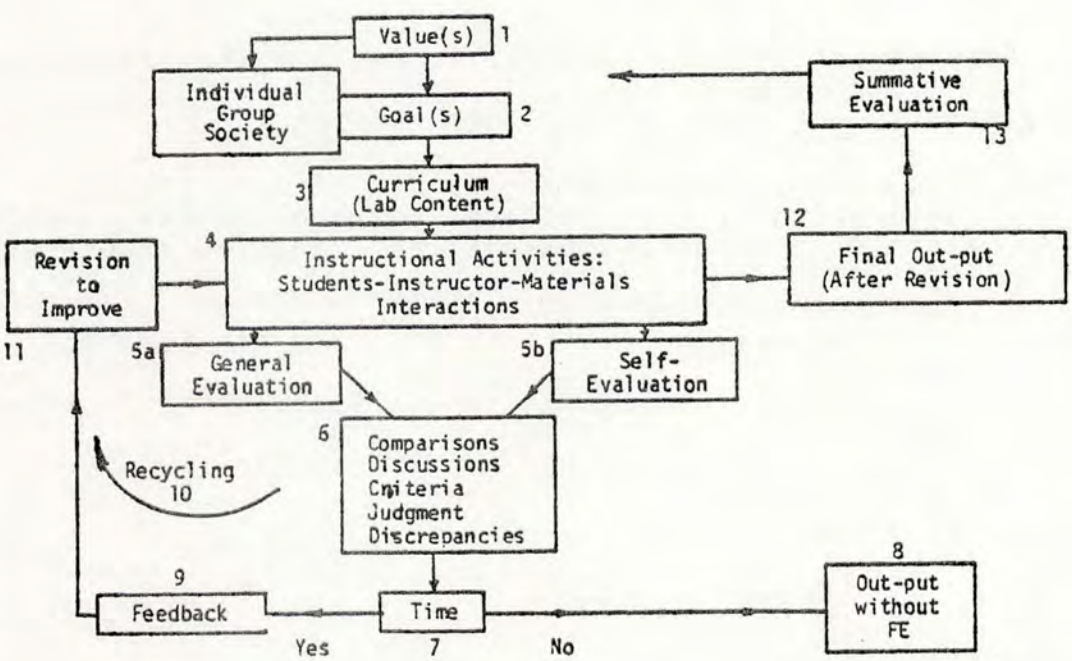
a) Active interaction (participation).
b) Evaluating and self-evaluating.
c) Comparing different evaluation results.
d) Revising (redoing).

Reason

a) Interest on some value and, as a consequence, positive attitude that results in the activity.
b) To collect evaluative criteria (standards) for congruent judgment*.
c) To decide what modification are needed*.
d) To implement (improve, develop) in order to achieve the goal(s) determined by the value(s).

* Stated in idealistic terms.

7. Concept Map of Formative Evaluation



FORMATIVE EVALUATION (a cycle)

Observing the conceptual map we can see some essential parts:

a) the values and consequent goals that supply the individual, or the group, or the society, with motivation to a positive attitude reflected in cooperative activity;

b) the curriculum content and the instructional approach that must be offered according with (a) above;

c) the confrontation between the general evaluation and the self-evaluation, with its results;

d) the time as a terrible constraint diminishing the possibility of recycling;

e) the opportunity to do again only specific activities with the purpose of improvement.

8. Conclusion

To reduce vagueness we could remove each key word from our concept map, having in mind the counter-examples and the characteristics that are not present when we do not have a formative evaluation (see section 5, please). For instance, without time to review, or without interest and purpose to be achieved, there is not formative evaluation, and so on.

The use of inventive cases, by removing key words, could criate in our imagination an anxious world without place to mistakes - and we also learn through mistakes...

Our analysis and the consequent meaning of formative evaluation seem passive of use in other contexts (different from an introductory physics laboratory course).

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APPENDIX C

THE LABORATORY GUIDES

THE LABORATORY GUIDES

Institute of Physics, UFRGS
Physics II - 1980

Laboratory Experiment I

EXPERIMENTAL STUDY OF A SIMULATED ELECTROSTATIC FIELD

I. Introduction

In this first experiment you will have opportunity to study, in practice, electric fields, electric potential differences, lines of force, and equipotential lines.

II. Theoretical Background

The electrostatic field, as we have seen before, may be described not only by a vector, the electric field intensity vector $\vec{E}$, but also by a scalar function, the scalar electric potential V. In addition, this field may be also described graphically or visualized through lines of force. These are three different ways of describing the same thing and, as such, one can expect that they are related. Indeed, this relationship exists and can be summarized as follows:

The tangent to a line of force at any point gives the direction of the electric field vector $\vec{E}$ at that point. The lines of force are drawn so that the number of lines per unit cross-sectional area is proportional to the magnitude of $\vec{E}$.

If $\vec{E}$ is known in every point of the field, the potential difference between any two points, or the potential at an arbitrary point, may be calculated through the equation

$$V_B - V_A = -\int_A^B \vec{E} \cdot d\vec{l}$$

Reciprocally, if V is known throughout a certain region, $\vec{E}$ may be calculated through the equation $\vec{E} = -\text{grad } V$. From this equation we infer that if we travel through an electric field along a straight line and measure V as we go, the rate of change of V with distance that we observe, when changed in sign, is the component of $\vec{E}$ in that direction. The minus sign implies that $\vec{E}$ points in the direction of decreasing V.

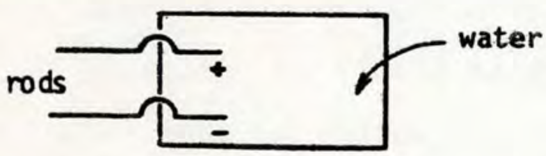
The lines of force and, consequently, the electric field vector $\vec{E}$, are perpendicular to the equipotential surfaces of the electric field.

These relationships provide the theoretical background necessary to the kind of experimental study of an electrostatic field to be done in this experiment: if the potential could be measured in a large number of points of an electric field, we could connect the points of same potential to obtain equipotential surfaces. Having these equipotential surfaces it would be possible to draw lines of force (perpendicular to the surfaces) and obtain the direction of the electric field. $\vec{E}$ would point in the direction of decreasing V and the density of lines of force would give information about the magnitude of this vector. Thus, we could, in principle, study in detail electrostatic fields due to arbitrary distributions of charge, e.g., the field of a dipole, the field of a capacitor, or the field of a charged body of arbitrary shape.

III. Considerations of Practical Nature

In order to carry out the above outlined experiment, we immediately face a practical problem: the instruments of measurement (the voltmeter in this case) measure potential differences and not the potential at a certain point. In addition, these instruments work only when connected to an electric circuit through which an electric current passes. They measure the potential difference through the equation $V = IR$. However, if the field is static there is no motion of charges in such a field and, consequently, there is no electric current.

A way of overcoming this difficulty is to simulate an electrostatic field. This simulation can be achieved by placing the extremities of two charged rods in a fine layer



of chemically treated water (water from the faucet). An electric field will be established in the region surrounding the rods, however as the water layer will contain ions that will move under the action of this field, an electric current will be originated in the water. This current will be extremely weak but large enough to allow the use of a sensitive voltmeter to measure potential difference in the established field (which will be only slightly affected by the current). With these measures, equipotential lines, which will allow the drawing of lines of force and provide information about the field vector, might be determined. Attaching conductors of certain size and shape to the extremities of the rod that are inside the water, different field configurations can be simulated and experimentally studied.

IV. Procedure

1. The following equipment is available to you: a small electrolytic tank, a multimeter, electrodes, a DC power

supply, connecting wires, and conductors of various shapes and sizes. Draw a scheme showing how you will use this equipment to measure potential differences inside the liquid layer.
Drawing:

2. Connect the equipment according to the above scheme and ask the teacher or a proctor to check the connections before turning the power on.

3. Determine several different points with the same potential and draw on graph paper the corresponding equipotential line. Using this method draw several equipotential lines and some lines of force. If you did not attach any conductor to the extremities of the electrodes, they played the role of point charges and what you have represented graphically is the field of an electric dipole. For a dipole, determine several points with a same potential and drawn the corresponding equipotential lines on a milimetrical paper. Using this method, draw several equipotential lines and some lines of force to obtain an electric field configuration of a dipole. The lines of force do not cross. Why?
Answer:

4. To represent graphically a uniform field, repeat the previous procedure attaching two parallel metallic plane plates to the extremities of the electrodes. What to you observe concerning the equipotential lines and the lines of force in the region between the plates?
Answer:

5. Place a metallic cylindrical tube between the parallel plates. Repeat the previous procedure. What do you observe concerning the potential inside the cylinder? Why?
Answer:

6. Draw the lines of force due other conductors with different shape.

V. Report

As final report of this laboratory experiment,

a) you must show your answers to the questions of the items IV.3 to IV.5;

b) the group must show the electric field graphic representations (on milimetrical paper) required in the items IV.3 to IV.6.

Laboratory Experiment II

LINEAR AND NONLINEAR RESISTORS (OHM'S LAW)

I. Introduction

In this experiment you will be verifying experimentally if a conductor follows or not the Ohm's Law; you will be measuring resistances, currents, potential differences and not only making calculations involving these physics entities. You will also have an additional opportunity of getting acquainted with measurement instruments, electric circuits, electric components, and experimental procedures, which will help you in the future (in practice) and which surely will be worthwhile to you in the comprehension of concepts.

II. Theoretical Background

You already saw that when an isolated conductor is placed in an external electric field, an electric polarization occurs (accumulation of positive electric charges at one side and negative ones at the other) in a way that the external field is cancelled completely by the field induced in the internal region of the conductor. This means that inside a conductor in equilibrium the resulting electric field is null. It follows that the electric field on the surface of a conductor in equilibrium is always normal (perpendicular) to the surface and that all excess of charges is located on the surface (not necessarily in an uniform way).

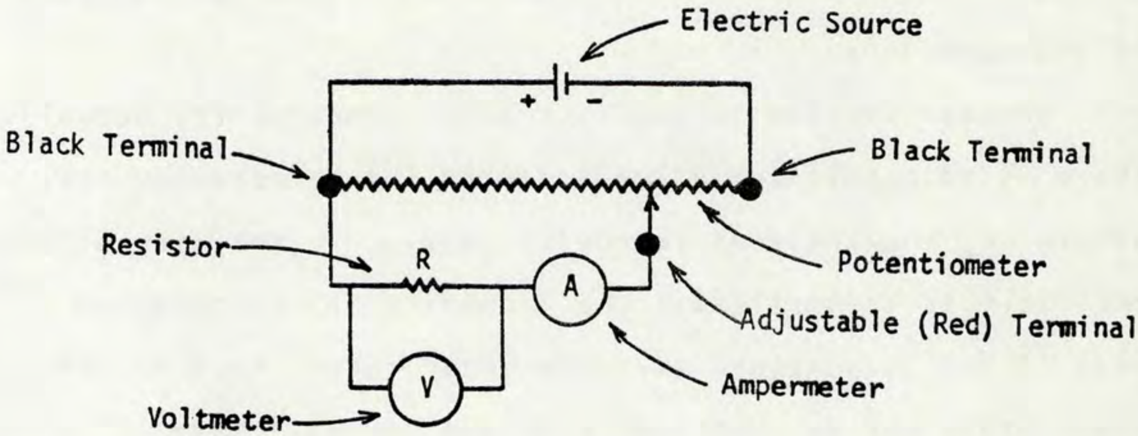
Otherwise, when the conductor is under the action of an electric field and, at the same time, it also belongs to a closed circuit, the establishment of an electric current (instead of polarization) is the resulting effect. In this case, there is not electrostatic equilibrium and the field inside the conductor is not null, no more worthing the anterior affirmations concerning an isolated conductor. In the case of a metallic conductor, the free (conduction) electrons are accelerated by the field but, due to the successive collisions with the ions of the crystalline structure of the metal, they adquire a nearly constant speed named drift speed. This flux of electrons dislocating through the conductor (with the drift speed) it is the electric current.

If the conductor is subject to an electric field $\vec{E}$, this means that there is an electric potential difference V between any two points of the conductor. The relation between the potential difference V and the electric current I established in the conductor is $V = RI$, where $R = V/I$ is named (defined) as electric resistance of a conductor. To some conductors, when the temperature is mantained constant, the relation V/I is also constant; in this case, one says that these conductors follow the Ohm's Law. Resistors constructed with materials which obey the Ohm's Law are named linear resistors.

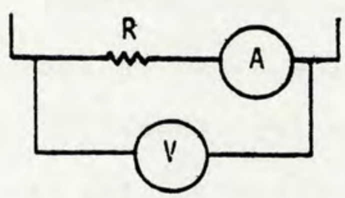
If the relation V/I = R is constant, the V vs. I graph will show a straight line with angular coefficient that it is equal to R. Then, one can determine if a given resistor is or is not linear by taking several measurements of V and the corresponding I (at constant temperature) and sketching a V vs. I graph. This will be done through this experiment, i.e., the linearity (or not) of several resistors will be analysed through V vs. I graphs under the condition of conductors at constant temperature.

III. Considerations of Practical Nature

In order to take several measurements of V and I for a given resistor, one needs a dispositive capable of furnishing an adjustable electric potential difference and one also needs instruments to measure V and I, i.e., a voltmeter and an ampermeter. It would be possible to connect the following circuit:



In this circuit, by varying the position of the adjustable terminal of the potentiometer one can vary the electric potential difference applied on the resistor R which can be measured by the voltmeter. With the ampermeter one can measure the corresponding electric current. However, in this circuit the ampermeter is actually indicating the current that flows through the resistor R plus the current that flows through the voltmeter. Another possibility would be to make the following connection:



In this case, the ampermeter will only indicate the current through the resistor but the voltmeter will indicate the electric tension applied on both the resistor and the ampermeter. You must choose the best one from the two possible circuit connections; in any case, however, never connect the ampermeter in parallel with the electric source.

The use of the potentiometer permits measurements of V and I that <u>are not</u> directly affected by the internal resistance of the electric source, which, as a consequence, is not considered.

Another problem is the control of temperature. Actually, there is no conditions of controlling the temperature but, otherwise, the temperature coefficient of resistivity of some resistors is so small that the linearity may be observed even if the temperature vary. In other cases, however, the temperature has an important role and you will have opportunity to observe it.

You will receive the necessary equipment to study the linearity, or nonlinearity, of several resistors. You will receive four resistors: a common resistor, a light bulb, a LDR (light dependent resistor) and a NTC (negative temperature coefficient).

IV. Procedure

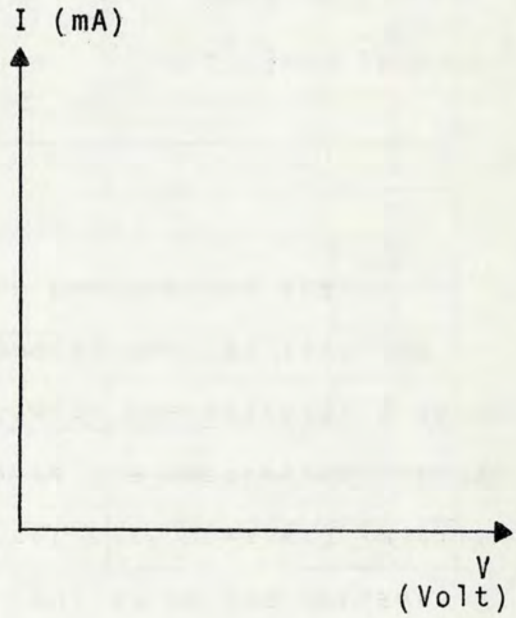
1. You must connect the appropriate circuit, perform the measurements, register them in tables, and sketck I in function of V graphs. From the graphs you must conclude about the linearity or nonlinearity of the given resistors and calculate the resistance R when they are linear. Try to understand what you are doing, the phenomena, the key concepts involved, and the questions being investigated. If necessary, get help from your teacher or instructor.
2. Using the connected circuit, perform 10 pairs of measurements for the common resistor. Complete the table

and sketch a I vs. V graph. Does the common resistor follow the Ohm's Law? Why?

Common Resistor
Scales: Voltmeter, 25 V;
Ampermeter, 2.5 mA.

N	I 10^{-3} A	V Volt	R = V/I KΩ
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

$R_{average}$ =



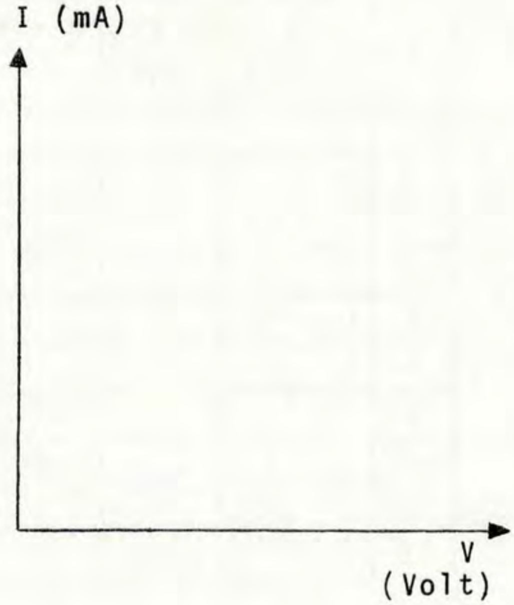
3. Compare the numerical value obtained for $R_{average}$ with the value measured directly in the ohmmeter. You will probably find two different values and, even more, if you read the value written on the resistor you may find a third one. Analyse the differences among the resistance values with your colleagues. In which value do you trust more? Why?

4. Put the voltage down to zero and replace the common resistor by the light bulb. Change the voltmeter scale to 5 V and the ampermeter scale to 250 mA. Perform 10 pairs of measurements for the light bulb, complete the table,

and sketch the graph. Does the light bulb follow the Ohm's Law? Why?

Light Bulb
Scales: Voltmeter, 5 V;
Ampermeter, 250 mA.
Maximum Voltage: 6.3 Volts.

N	I 10^{-3} A	V Volt
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		



5. Replace the light bulb, first by a NTC resistor, and later by a LDR resistor. Report your observations and conclusions concerning the possible practical uses of these two resistors. (You must have special care when using the NTC resistor to evitate damage of the ampermeter because, above a certain temperature, the electric current increases very quickly).

V. Report

As final report of this laboratory experiment, the group of students must show the tables, the graphs, and the answers asked in the items 2 to 5 of the experimental procedure.

Laboratory Experiment III

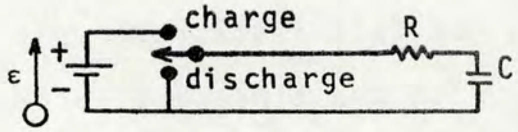
RESISTOR AND CAPACITOR IN SERIES CIRCUIT

I. Introduction

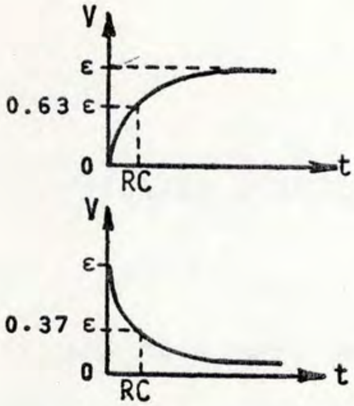
In this experiment you will work with a RC circuit of direct electric current through which you will analyse experimentally the processes of charge and discharge with time of the electric potential differences across the capacitor; you will also determinate the capacitative time constant RC of the circuit.

II. Theoretical Background

1. The RC circuits are the ones which in addition to electric sources and resistors also have capacitors. The theoretical analysis of the series RC circuit is made in the textbook (Physics, Halliday & Resnick). In summary, both the charge and the discharge processes of a capacitor with the time are exponential processes obeying the following equations:



Charge: $q = C\varepsilon(1 - e^{-t/RC})$, or $V = \frac{q}{C} = \varepsilon(1 - e^{-t/RC})$.



Discharge: $q = C\varepsilon(e^{-t/RC})$, or $V = \frac{q}{C} = \varepsilon(e^{-t/RC})$.

This means that, if ε is the maximum tension (the electromotive force of the source) to which the capacitor will be subjected, the electric potential difference across the capacitor does not achieve instantaneously the value ε; this electric potential difference increases exponentially and it only achieves the maximum value ε after a certain time (infinite, according to theory). Otherwise, if there is an initial tension ε between the plates of the capacitor which then initiates a discharging process through an electric resistance R, this tension does not fall instantaneously to zero but it falls exponentially with the time. Only after a certain time (infinite, according to theory) the electric potential difference across the capacitor will achieve a zero volts value.

2. The capacitative time constant RC has the dimensions of time since the exponent of $e^{-t/RC}$ must be dimensionless. Concerning RC, note the following:

$$\text{Ohm} \times \text{Farad} = \frac{\text{Volt}}{\text{Amper}} \times \frac{\text{Coulomb}}{\text{Volt}} = \frac{\text{Coulomb}}{\text{Coulomb/sec}} = \text{second.}$$

In the charging process, the RC constant is the time that the capacitor needs to achieve 63% of its maximum charge (or voltage). See the anterior figures and the following:

$$V = \varepsilon(1 - e^{-t/RC}); \quad \text{when} \quad t = RC:$$

$$V = \varepsilon(1 - e^{-1}) = \varepsilon(1 - 0.37) = 0.63\ \varepsilon \quad .$$

In the discharging process, RC is the time that the capacitor needs to achieve 37% of its initial charge (or voltage). See the anterior figures and the following:

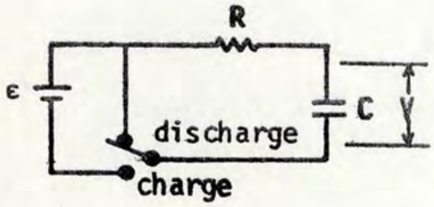
$$V = \varepsilon(e^{-t/RC}); \quad \text{when} \quad t = RC; \qquad V = \varepsilon\ e^{-1} = 0{,}37\ \varepsilon \ .$$

This permits to understand why a capacitor discharges almost instantaneously when its terminals are put in direct contact, i.e., in "short circuit": the resistance R of the product RC is very small and the capacitative time constant of the circuit is approximatelly zero.

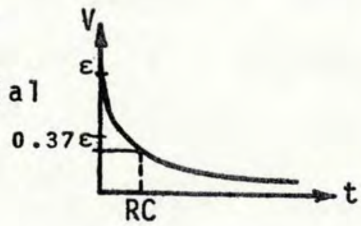
3. These theoretical considerations suggest that if one makes a "q vs. t" or a "V vs. t" graph, one may to determine experimentally the time constant RC of a circuit by interpolating in the graph the value corresponding to 63% of maximum charge (or voltage) in the charging process or,

by another way, the value corresponding to 37% of the initial charge (or voltage) in the discharging process. Exactly this will be done in this experiment.

4. The equation of the discharging process is $V = \varepsilon\, e^{-t/RC}$.



The V vs. t graph shows an exponential curve



However, if one sketches a mono-logarithmic graph the result will be a straight line because:

$$V/\varepsilon = e^{-t/RC}; \qquad \log_{10}(V/\varepsilon) = \log_{10} e^{-t/RC};$$

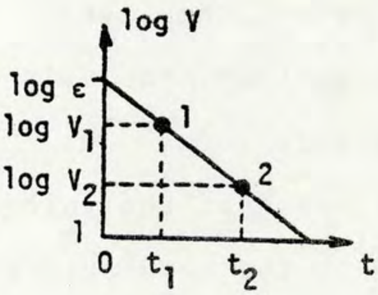
$$\log_{10} V - \log_{10}\varepsilon = -t/RC \times \log_{10} e; \qquad (\log_{10} e = 0.434);$$

$$\text{then,}\quad \log_{10} V = \log_{10}\varepsilon - \frac{0.434}{RC}\, t \quad .$$

This is an equation of a straight line $y = a + bx$ where: $\underline{a}$ is the value of $\underline{y}$ for $x = 0$, and $b = \frac{dy}{dx}$ is the angular coefficient, with $\frac{dy}{dx}$ being the declivity of the line. In the case,

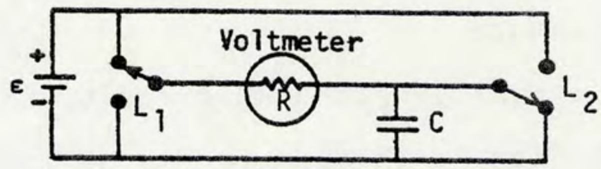
$$a = \log_{10}\varepsilon \quad \text{e} \quad b = \frac{\log_{10}V_2 - \log_{10}V_1}{t_2 - t_1} < 0 \quad ,$$

where 1 and 2 are two convenient points of the straight line which permit to determine easily and precisely the declivity of the line and the time constant RC because $\frac{dy}{dx} = -\frac{0.434}{RC}$



III. Considerations of Practical Nature

A convenient circuit to study the charge and discharge processes of a capacitor is the following:



In this circuit, when the switches L_1 and L_2 are closed as in the figure, the voltmeter indicates the source tension ε.

When the L_2 switch is opened, the capacitor begins to discharge through the internal resistance R of the voltmeter. Then, at each instant, the voltmeter indicates the tension ε - V, where ε is the source electromotive force and V is the tension across the capacitor plates.

Inverting the positions of the two switches indicated in the figure, the capacitor charges itself almost instantaneously because its terminals are directly connected to the source.

Opening the L_2 switch, the capacitor discharges through the internal resistance R of the voltmeter; then, the voltmeter indicates directly, at each instant, the value of V (the tension across the capacitor plates).

To determine the internal resistance R of the voltmeter, you must multiply the value specified by the manufacturer on the voltmeter dial (50 KΩ/V D.C.) by the value indicated by the selector, such as 25 V D.C.. In this case,

$$R = \frac{50\ K\Omega}{V\ D.C.} \times 25\ V\ D.C. = 1250\ K\Omega \quad .$$

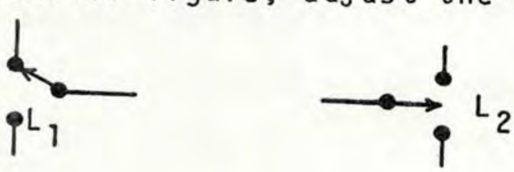
IV. Experimental Procedure

1. You will receive a pre-connected RC circuit, an electric DC-source, a voltmeter, a chronometer, a milimetric paper, and a mono-logarithmic paper.

   You will make 10 measurements of V and t (the electric potential difference across the capacitor and the corresponding time), both for the charge and the discharge processes.

2. Charge:

   With the voltmeter selector in the 25 V D.C. position, and the L_1 and L_2 switches in the positions indicated in the anterior figure, adjust the source tension to $\varepsilon = 15$ V D.C..

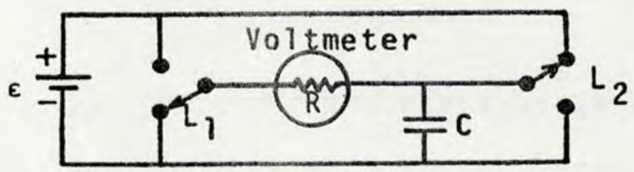


Open the L_2 switch and make 10 measurements of $\varepsilon - V$ and of the corresponding times. Complete the table and sketch a V vs. t graph in a milimetric paper.

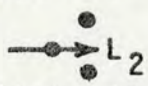
N	V(volts)	t(sec)	N	V(volts)	t(sec)
1			6		
2			7		
3			8		
4			9		
5			10		

3. **Discharge:**

Invert the positions of the two switches (to the positions indicated in the figure below).



In this position, the capacitor charges itself almost instantaneously because its terminals are directly connected to the source.



Opening the L_2 switch, the capacitor discharges through the voltmeter which indicates directly the tension V across the capacitor. In the discharge process, <u>invert</u> the wired connectors of the voltmeter because the current flows in an opposite direction.

Perform 10 measurements of V at different moments, complete the table, and sketch a V vs. t graph of the discharge process on a milimetric paper.

N	V(volts)	t(sec)	N	V(volts)	t(sec)
1			6		
2			7		
3			8		
4			9		
5			10		

4. From the two graphs, determine the values of the capacitative time constant RC of the circuit.

   Answers:

   RC = _______________ in the charge;

   RC = _______________ in the discharge.

5. Multiply the internal resistance R of the voltmeter by the capacitance C indicated on the capacitor by the manufacturer.

   Answer:

   RC = _______________

   Compare the obtained product with the values which you got in the item 4.

6. a) With the measurements of V and t for the discharge process which you already made in the item 3, sketch a graph of

$$\log_{10} V = \log_{10}\varepsilon - \frac{0.434}{RC}\, t$$

on a mono-logarithmic paper.

b) Determine the declivity of the straight line and obtain the time constant RC of the discharge; compare the result with anterior values which you already got.

V. Report

As a final report, the group must show the tables, graphs, and answers asked in the items 2 to 6.

Laboratory Experiment IV

EXPERIMENTS OF MAGNETISM (PROJECTION OF EALING FILM-LOOPS)

Having the Epistemological Vee as a framework, the following Ealing** film-loops (silent 8 mm films with notes by Dr. R.B.Adler, MIT) were projected and analysed:

Film	Ealing Tittle	Time Duration	Ealing No.	Library of Congress Card No.
I	"The Magnetic Field". Electromagnetism 1.	3 min.	80-4062	71 - 703703
II	"The Field from a Steady Current". Electromagnetism 3.	3 min. 20 sec.	80-4088	75 - 703562
III	"Field: The Force on a Current". Electromagnetism 8.	3 min. 40 sec.	80-4138	70 - 703566
IV	"Field vs. Current". Electromagnetism 6.	3 min. 35 sec.	80-4112	79 - 703563
V	"Field vs. Distance". Electromagnetism 7.	3 min. 40 sec.	80-4120	76 - 703565
VI*	"The Field as a Vector". Electromagnetism 5.	2 min. 35 sec.	80-4104	75 - 703564

* The projection of the film VI was necessary for the understanding of some laboratory techniques used in the films IV and V.

** The Ealing Corporation
Ealing Film-loops
Massachusetts Institute of Technology
Cambridge, Massashusetts, 02140

Laboratory Experiment V

ELECTROMAGNETIC INDUCTION

I. Introduction

This laboratory experiment will illustrate experimentally the theoretical classes about electromagnetic induction that you have received.

In this experiment you will work with a galvanometer which is a very sensible electric instrument. For this reason, you must take care: do not produce induced currents that may damage the galvanometer; mainly when iron cores are present, do not produce great changes of magnetic flux. Never connect the galvanometer directly to the electric source.

In the next pages you will find the theoretical background of the experiment, some considerations of practical nature, and a suggested experimental procedure.

II. Theoretical Background

The theoretical ground of this experiment is basically contained in two of the Maxwell's Equations:

$$\varepsilon = \oint \vec{E}.d\vec{l} = -\frac{d\phi_B}{dt} = -\frac{d}{dt}\left[N\int \vec{B}.d\vec{S}\right] \qquad \text{Faraday-Lenz's Law}$$

$$\oint \vec{B}.d\vec{l} = \mu_o\left(i + \varepsilon_o \frac{d\phi_E}{dt}\right) \qquad \text{Ampère-Maxwell's Law}$$

The Faraday-Lenz's Law is particularly important for this experiment. This law says that the induced electromotive force ε (emf ε) in a circuit is equal to the negative rate at which the magnetic flux through the circuit is changing. The induced current $I_i = \varepsilon/R$ (where R is the electric resistance of the circuit) appears in such a direction that it opposes the change that produced it; the minus sign in the Faraday-Lenz's Law suggests this opposition.

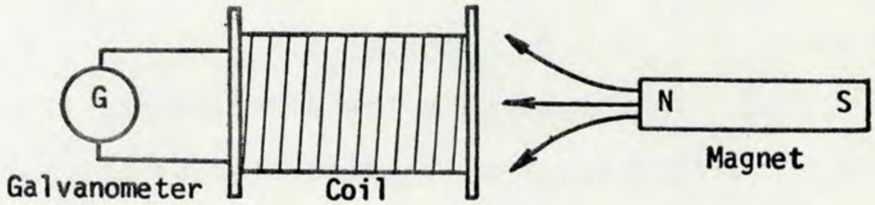
This means that, for instance, if one connects a coil to a galvanometer and one changes the magnetic flux which crosses the coil, the galvanometer will indicate an electric current induced in the coil. This induced electric current results from the emf ε (in other words, from the electric field) that is induced in the coil. In addition, the direction of this induced current will be such that it will produce a magnetic field that opposes the change of flux that produced it.

There are several possible ways of producing a change in the total magnetic flux which crosses a certain coil with N turns. The magnetic flux in each turn is defined as $\Phi_B = \int \vec{B}.d\vec{S}$; then, if one changes the inductive magnetic field $\vec{B}$, or the angular position of the coil relative to $\vec{B}$, or the total area of the coil imersed in a certain $\vec{B}$, or the number of turns of the coil, one will produce a change in the total inductive magnetic flux that will originate an induced current in the coil.

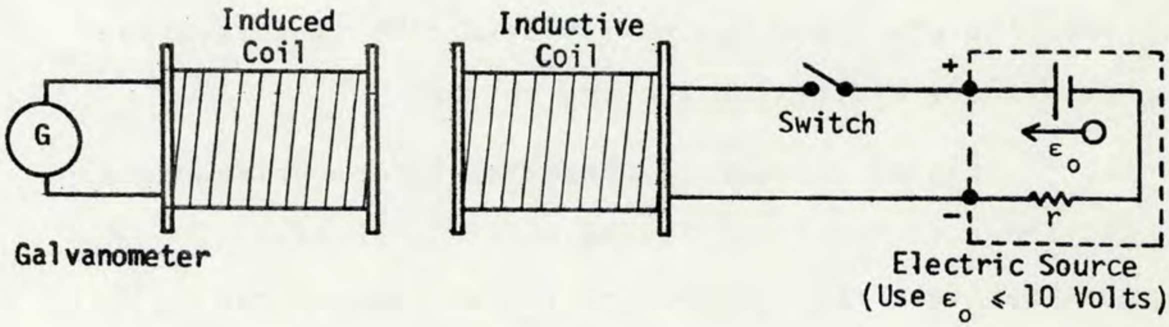
The introduction of iron cores in the coils increases the intensity of the magnetic fields and, consequently, also increases the intensity of the induced currents.

III. Considerations of Practical Nature

At first, to study experimentally the electric current induced in a coil, it is sufficient to have a magnet and a coil connected to a galvanometer.



The inductive magnetic field may also be produced by another coil carrying an electric current; this is illustrated in the next figure.



With this experimental device you can study the induced electric current in function of the relative motion between the coils, the velocity of this motion, the relative positions between the coils by putting them in several positions when closing and opening the switch; in function of the intensity of the inductive magnetic field, the distance between the coils, the relative angular position of the coils, the number of turns (each coil has a center tape which divides the number of turns to N/2); you also can study the effect of the introduction of iron core in one or in both coils (taking care with the very sensible galvanometer).

IV. Procedure

1. Determine the relation between the direction of the galvanometer deflection and the direction of the current which it indicates; for this, connect the galvanometer in series with the electric source and with a resistance of high value (20 KΩ) to protect the galvanometer. Do not connect the galvanometer directly to the source without the protective resistance.
   The direction of the current provided by the source is know, therefore you may easily determine that relation between the deflection and the current.
2. Using a magnet and a coil connected to the galvanometer (as shown in the first figure before), analyse qualitatively the several pointed aspects of the electromagnetic induction. Check if your observations and analyses agree with the theory given by the Faraday-Lenz's Law.
3. Replace the magnet by the inductive coil connected to the electric source (as shown in the second figure before) and repeat the analyses asked in the item 2.
4. Measure the induced current I_i and the corresponding distance d between the coils. Sketch a I_i vs. d graph.

5. Introduce iron core(s) in the coil(s) and repeat the procedure asked in the item 4. Take care with the sensible galvanometer.
6. Compare the two graphs and infer the mathematical relation between I_i and d in both cases (with or without iron core).

V. Report

At the end of this experiment, the students must show to and discuss with the teacher their observations, notes, analyses, graphs, and conclusions asked in the items 2 to 6 of the experimental procedure.

APPENDIX D

EXAMPLE OF A VEE AND CONCEPT MAP

A VEE FOR THE EXPERIMENT L_1
EXPERIMENTAL STUDY OF A SIMULATED ELECTROSTATIC FIELD

TELLING (BASIC) QUESTION:
How are some electrostatic field configurations due to arbitrary distributions of charges?
What are some of the knowledge claims that may be established by analysing these configurations?

PHILOSOPHY:
Scientific knowledge about nature lies in observation and experiment based on theories that organize our facts, reasoning, deepening our understanding.

THEORY:
Theory of the electrostatic field.

PRINCIPLES & CONCEPTUAL SYSTEMS:
1. Relations among intensity and direction of the electrostatic field vector, the equipotential lines, and the lines of force.
2. Mathematical relations and operations (gradient, integral, tangent, etc.)

KEY CONCEPTS:
Electric field; electric potential difference; electric (ionic) current; electric resistance; equipotential lines; lines of force; vector (intensity and direction).

INTERPLAY

VALUE CLAIMS:
1. In physics there is an interdependence between theory and experimentation, so that we can:
2. Identify the points of large and small intensity of an electrostatic field from its lines of force.
3. Determine the direction of an electric field from its equipotential lines.

KNOWLEDGE CLAIMS:
Several different electrostatic field configurations were obtained.
By using the theoretical background and analysing these configurations, some conclusions may be established:
1. The lines of force do not cross.
2. The electric potential inside a metallic cylinder is constant and, consequently, the electrostatic field is zero.
3. The electric field vector is perpendicular to metallic (equipotential) surfaces.
4. The magnitude of an electrostatic field is constant between two parallel metallic plane plates.

INTERPRETATIONS OF DATA:
1. Obtaining the direction of the electric field vector (from the transformations 1 & 2).
2. Obtaining the intensity of the electric field vector (through the lines of force).

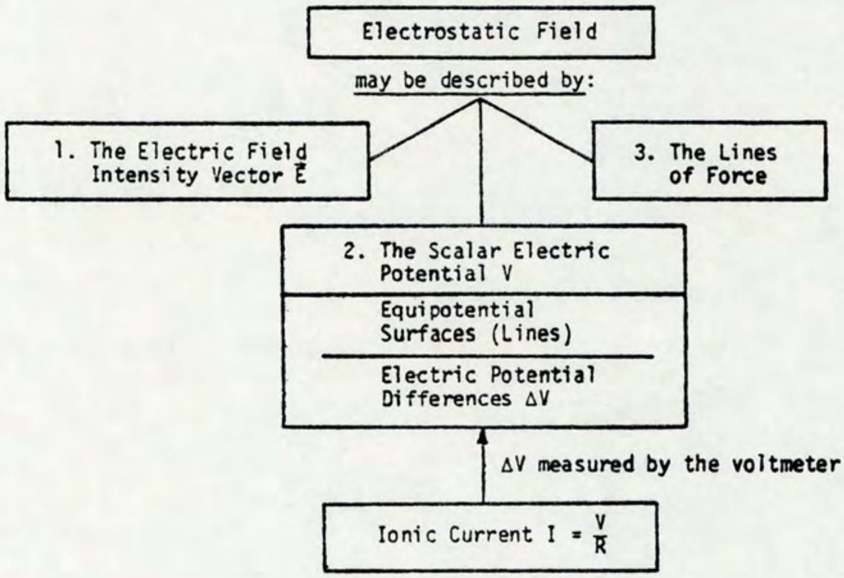
TRANSFORMATIONS:
1. Drawing equipotential lines.
2. Drawing lines of force (perpendicular to the equipotential lines).

MEASUREMENTS:
Measurements of electric potential differences in the fine layer of water.

EVENTS:
Electric power supply producing weak ionic currents in a tank with a fine layer of water.

A CONCEPTUAL MAP FOR THE EXPERIMENT L_1

EXPERIMENTAL STUDY OF A SIMULATED ELECTROSTATIC FIELD



RELATIONSHIPS:

R_{13}: The tangent to a line of force at any point gives the direction of the electric field vector $\vec{E}$ at that point. The lines of force are drawn so that the number of lines per unit cross-sectional area is proportional to the magnitude of $\vec{E}$.

R_{14}: If $\vec{E}$ is known in every point of the field, the potential difference between any two points, or the potential at an arbitrary point, may be calculated through the equation

$$V_B - V_A = -\int_A^B \vec{E}.d\vec{l}$$

Reciprocally, if V is known throughout a certain region, $\vec{E}$ may be calculated through the equation $\vec{E} = -\text{grad } V$. From this equation we infer that if we travel through an electric field along a straight line and measure V as we go, the rate of change of V with distance that we observe, when changed in sign, is the component of $\vec{E}$ in that direction. The minus sign implies that $\vec{E}$ points in the direction of decreasing V.

R_{123}: The lines of force and, consequently, the electric field vector E, are perpendicular to the equipotential surfaces (lines, in two-dimensional fields) of the electric field.

APPENDIX E

RATIONALE FOR THE CLINICAL INTERVIEWS

RATIONALE FOR THE CLINICAL INTERVIEWS

Goal and Roles of the Interviews

With the interviews, our goal was to get additional information to answer the research questions I and II (specified in Section III-1) through a formative evaluation process that we assume the interview it is.

In other words, through the interviews we aimed:

1. To detect the student's individual level and growth in the achievement and use of the Vee (Gowin, 1981) as a framework for the laboratory work;
2. To get information about students' feelings related with their laboratory activities;
3. To search for students' reasons (explanations) for their conceptions as well as misconceptions;
4. To observe when and how shifts occur in students' patterns of thinking;
5. To look for regularities of events pointed in 2, 3 and 4 above.

The interview had an important role: to make possible sharing meanings through feedback between teacher and student (following Dr. Gowin's (1981) model of teaching). This role of an interview was also pointed in some recent findings:

> "... the interview itself should be considered an instructional element." (Rowell, 1978, p. 166).

And:

> "This form of assessing cognitive structure (the interviews) may indeed have more potential as a teaching method than as a research technique." (West, 1979, p. 8).

We intentionally used the interview also as a process of instruction but, of course, we took care: this Socratic teaching (Pines, 1978, p. 30) should not inhibit the student's manifestation of reasons (explanations) for his/her conceptions and misconceptions.

The Interview Method

We used a more flexible format of interview to secure as much information as possible concerning individual student's conceptions, misconceptions, feelings, and explanations (reasons why).

The student's performance in the laboratory test(s) provided an initial reference to detect student's level of achievement and main difficulties; this determined the initial stimulus (or task) and question to initiate the interview.

The use of a lab test for preliminary assessment, and then completing this paper and pencil stage by an interview based directly upon information generated by the preliminary instrument, restricts the area of a clinical interview to those aspects already indicated by another format; "the interview retains its idiosyncratic applicability and becomes more streamlined and efficient." (Rowell, 1978, p. 214).

A summary of the interview format is presented in Figure 8.

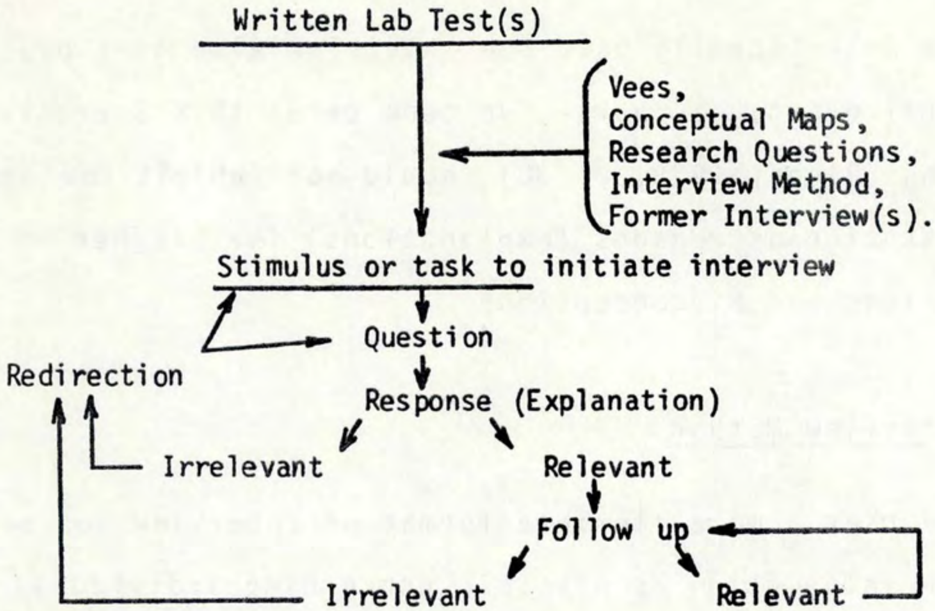


Figure 8. Summary of the Interview Format. (Adapted from Pines, 1978, p. 16a)

Requiring and analysing the student's explanations (reasons) for "why", both for conceptions and misconceptions, we used Dr. Gowin's (1981) Vee as a framework and also his point of view about "understanding" as a reference. This is shown in Figure 9.

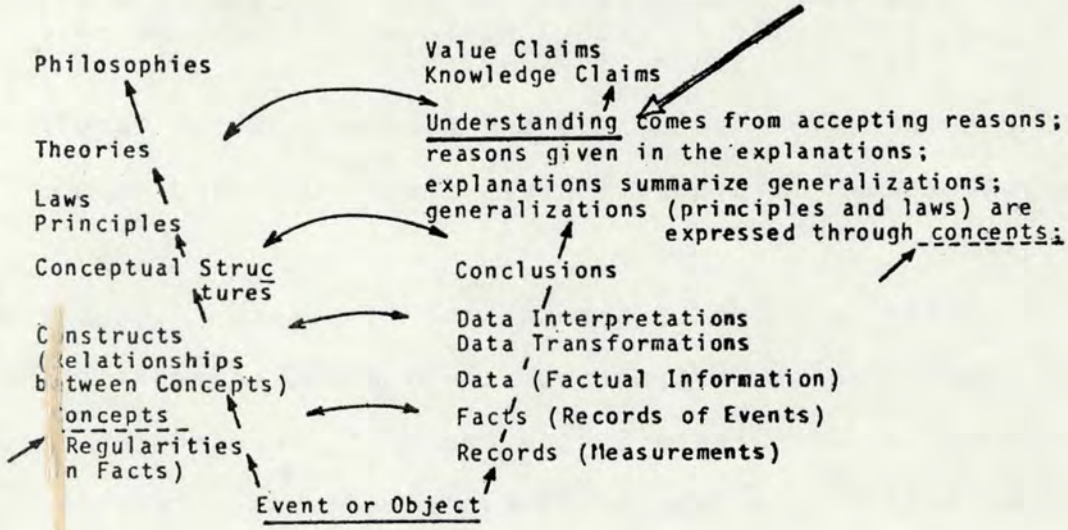


Figure 9. The Vee as a Framework for the Analysis of Student's Explanations.

In asking the student's reasons "why", the word "why" was employed in the search for information, for the purpose of inquiry. It signified the investigation of cause or reason. We did not use the word "why" connoting disapproval, displeasure, or communicating that the interviewee has done "wrong" or has behaved "badly". This was important because we were searching reasons (explanations) both for conceptions and misconceptions, as well as student's feelings.

We also provided a student with his/her own answering time because when we ask "Why?", the student may be puzzled by his/her conduct without knowing the cause, the reason, the need, the motivation, the explanation; for one thing, he/she may not really know why. Or he/she

"... may be groping for the answer and finding

> several possibilities. Different, even contradictory, forces may be impeling him/her or holding him/her back. He/she may even know or, at least, think he/she knows but not wish to reveal it." (Benjamin, 1974, p. 83).

These considerations about the use of the question "Why?" are relevant because this question was frequently used in our interviews.

In order to guide us through the interview discussions and to decide which information was relevant, in addition to the student's performance in the lab test, we used conceptual maps and Vees of the laboratory experiments as a reference to determine the bounderies of the content.

Conducting the Interview

There are several factors that must be considered before, during and after the inverview. The best summarized description of these factors were found in Pines (1978, pp. 14-44); we used it as a guide.

Just to give the reader a general idea, we will point some of these factors: the administrative details; the interview context; the equipment (tape-recorder, task materials, etc.); the tasks; the information for the interviewee; the "warm up" period; the presentation of tasks; the formulation of questions; the "follow up"; the use of a pilot study for interview development and improvement; the interviewer/ee behavior; the subject matter expertise; the interviewing experience; the types and levels of questions; the use of interviewee's terminology; the types of probes;

listening the responses; the "follow up" vs. the "cue"; the interview bias; conceptual vs. verbal understanding (or misunderstanding); types of responses; the "I don't know (IDK) students; the non-responders; the response time; the relevance of responses; leaving the interview; and other factors...

Analyzing the Interview Records

The conceptual maps and Vees served the purpose of interview planning and evaluation.

Pines (1977), Rowell (1978), and others, already used conceptual maps for that purpose. Our additional use of the Vee as a reference and framework for interview development and evaluation is a quite new fruitful approach*.

A conceptual map must represent the subject matter content with flexibility and emphasis on the variety of relations among concepts; this will reflect on the Vee that strongly deals with concepts. This flexibility will respect the idiosyncratic and evolutionary characteristics of the student's cognitive structure that, in some way, will be reflected on the lab tests and, consequently, on the interviews.

Now, it is time to talk about the "transformation of data from interviews" for the purpose of data reduction and evaluation (analysis). We were always concerned with these

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* NIE-NSF Project directed by Dr. Joseph D.Novak (1978-81); Hai Hsia Chen's master thesis (Cornell, January-80); and Charles R.Ault, Jr.'s Ph.D. thesis (Cornell, May-80).

"transformations" and, in doing the literature review on interviews, we found the same preoccupation being manifested by other researchers.

An Australian research group (West, 1979) faced the following problem:

> "There are now, both at Monash (Monash University, Australia) and elsewhere, a range of methods for eliciting information from students about their cognitive structure. The difficult task that we all face is to find a method of data reduction, of summarizing the mass of information in a manner that does not distort it, and in combining information from more than one student in a manner that is meaningful and useful." (West, 1979, p.9).

Pines (1977 and 1978), after an extensive work with interviews, already exposed his concern on data transformation:

> "If we want to find out what a person knows and ultimately how s/he comes to know, then we must ask her/him. There is no doubt that one of the most meaningful representations of cognitive structure possible can come from the data obtained from a clinical interview. The future problem is to reduce and possibly to quantify this data without losing its meaning." (Pines, 1978, p. 45).

Next, we describe the approach we used to analyze the interviews. Like Pines (1977 and 1978) and Rowell (1978), we transformed the interview events through a semantic network representation that is schematized in Figure 10.

Our model for interview analysis was adapted from Rowell (1978, p. 111); among other differences, our model differs in two main aspects:

(1) We did not draw a conceptual map (from the statements about the records) trying to represent the interviewee's cognitive structure like Rowell did it; we hoped to

avoid this additional higher level of inference;

(2) We used the Vee as an incremental reference and device for the interview planning, development and evaluation.

We anticipated this second factor as relevant for the interview improvement; the use of a Vee, in addition to a conceptual map, provided an objective framework to search and to follow the interviewee's explanations (reasons "why").

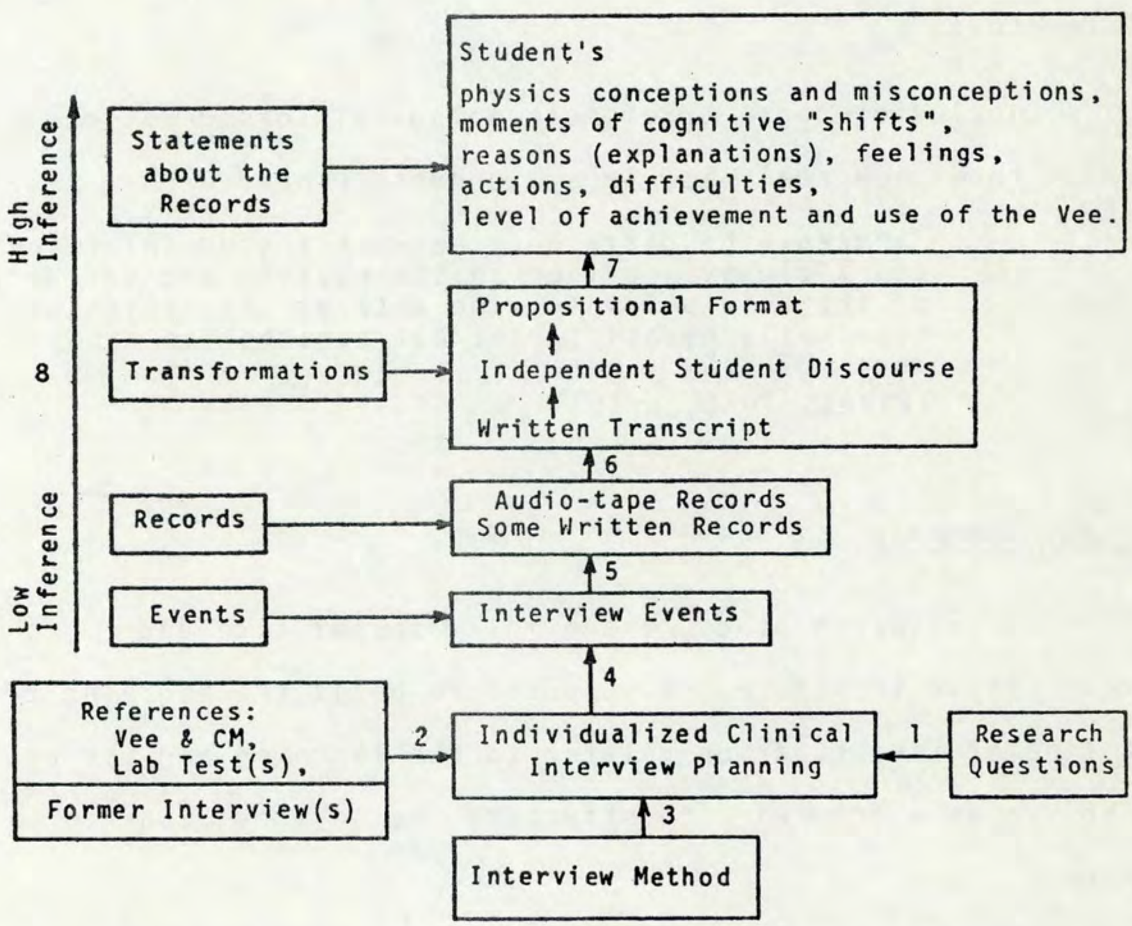

Figure 10. The Model for the Interview Analysis. (Adapted from Rowell, 1978, p. 111).

Performing the indicated transformations, for each interview, we got some "statements about the records" concerned with the student's conceptions, misconceptions, cognitive shifts, reasons, actions, feelings, difficulties, and use of the Vee.

Then we looked for some "key regularities" of those "statements about the records" that were centered in some reasons students gave for doing, thinking and feeling.

Our principal research goal was to detect some of those key regularities that appeared most frequently along the interviews.

Concluding these brief methodological considerations about interview analysis, we again quote Pines:

> "Indeed, the difference between a good interview and a clumsy one lies in the quality and validity of the data obtained. The data at this point are not easily quantifiable, but nonetheless are meaningful."
> (Pines, 1978, p.45).

Final Comments

Our research study, essentially speculative and descriptive in nature, is supposed to be at the begining of a line of investigation related to the learning and use of the Vee as a framework to structure the physics laboratory work.

The more flexible technique that we used for the interviews allows future improvement. Perhaps, in other research studies, it will be possible to develop a more standardized and comparative basis for the interviews, of course, if this could be done without losing information and without transforming the clinical interview in another single categorization device as pencil/paper tests.

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APPENDIX F

RATIONALE FOR THE GROUP DISCUSSIONS

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Objectives of the Group Discussions

With the group discussions (G.D.), our main objective was to get information through an additional channel to answer the research questions (see Section III-1).

Another purpose of the G.D. was to help the students in their understanding of the epistemological framework (the Vee) for use in the laboratory context because an important function of the G.D. was to share meanings through feedback among teacher and students.

The G.D. is a formative evaluation process and through feedback it provides information about the success and/or weakness of the individual program. The group discussion patterns can be analysed and valuables clues can be obtained for the alteration of the program of study activities.

Through the G.D., when we discussed a topic, the depth (level) and nature of the content appeared to be significantly different from those appearing when we just read or responded to written content or questions. Each student had the opportunity to compare his understanding and use of the Vee under consideration with those of the other colleagues. The G.D. became one of review, reinforcement, and correction.

Group Organization

The group must:

1. Be small enough so that each individual can be heard, can

have a contributing role, and can become well acquainted with the others;

2. Be able to find common cause fairly readily, with the individuals speaking the same language.

Also, if grouping is for purpose of urging students to learn more, then the factor by which they are grouped ought to be one which is very influential on learning. The students' achievement and/or non-achievement of some specific items of the laboratory test(s) (some specific aspects of the Vee) was such a factor.

We must diagnose the needs of each group in order to discover what factors are relevant to help a particular group proceed most effectively. This diagnosis should take place before the meeting begins, constantly throughout the discussion, and even after the meeting is over.

Satisfying the above conditions, each student was scheduled for a particular G.D. session, after considering the student performance on the anterior lab test(s). The lab test result (s) will provide an initial reference for the placement of a student in a certain specific group. During the discussion of an item by one student, the other students will be involved because they have answered the same (or similar) lab test (s) themselves and they know they will have opportunity to make additions or corrections.

Group Discussion Development

We present a summary of factors that lead to good group discussions:

1. Good group discussion is a common experience shared by everyone;
2. It is primarily a problem-solving experience;
3. It requires that every member be informed;
4. It requires that we share our information with the others;
5. It requires an objective attitude by each member toward the problem, the information, his/her colleagues, and him/ /herself;
6. It requires reflective thinking;
7. It requires good leadership;
8. It requires good listening;
9. It requires good speaking;
10. It depends upon individual contributions.

Group interactions can be described in terms of two aspects: work and emotionality. Changes in work and emotionality occur during group growth. Four developmental phases can be identified for a group:

1. Attempting to define a direction for themselves so that work may be done. Individuals are concerned with expressing personal needs and exploring the kinds of gratifications they may expect in the group.
2. Addressing itself to specific problems.
3. The group operates in a wide range of work and emotional situations.
4. The group characteristically engages in high-level work but introduces less affect into its discussions.

Two important assumptions for group operations:

First: all statements in the group are to some extent speaking for the group as a whole; from a social standpoint, the particular voice giving expression to the need is unimportant. Second: successful participation in a group is best characterized as an experience of <u>inquiry together</u>, in which problem solving is a process of successive clarification of vague and ambiguous conditions, and in which the "solution" is a confident clarification of what action the group will next engage in.

The epistemological Vee was used in the group discussions as a framework to make possible a more effective participation of everybody in that process of <u>inquiry together</u>.

<u>Relating Ourselves to the Group</u>

Our personal attitude toward the group and its function is of extreme importance to the success of the discussion. We must have a sense of belonging, willingness to change; an understanding of, and personal association with, the goals of the group; a feeling of responsability to the group; confidence in the group and in ourselves; a sensitivity to the wishes and feelings of others in the group; emotional control; a sense of achievement; an enjoyment of the discussion experience; humility; and an attitude of search and inquiry. These are all personal matters. They are essential factors in the nature of the people who are to make up the discussion group. Not all of us have these attitudes and points of view. As we strive to develop them, we shall discover that our effectiveness in discussion will increase.

The teacher's attitude during the G.D. session can exert considerable influence on a student. Students who need encouragement can be given recognition for that which they do well and made to feel pleased with their success. Students who are making poor progress can be taken to adjust for their problems.

Thelen (1961, pp. 11-14; 1967, pp. 65-68) describes 26 types of students as perceived by teachers through group activities. From those descriptions, the students could be classified under four major types: the good (those with whom teachers can work), the "bad" (the ones who anger the teacher), the indifferent (they do not care about work and education), and the lost students.

Analysing the Group Discussion Records

We taped and analysed the G.D. sound records in the same way as we did with the records from the interviews (See Appendix E with Figure 10).

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APPENDIX G

SAMPLE OF STUDENTS' EXPRESSIONS WRITTEN IN THE FINAL QUESTIONNAIRE

SAMPLE OF STUDENTS' EXPRESSIONS WRITTEN IN THE FINAL QUESTIONNAIRE

The following statements, taken in the second research run, represent a sample of students' expressions written in the third part of the Final Questionnaire through which they were asked to express their final comments, criticism, and suggestions for improvement, concerning the study and use of the Analytic Method (the epistemological Vee) in the physics laboratory context.

"I think that the Analytic Method (Vee), and its use through the labs, was very well structured both in the Method (very objective and coherent) and in the activities (interviews, etc.). I think that this Method could be already carried out earlier in the secondary schools. Without the knowledge of this method, or another framework, the student just describe the events without any deep analysis. ... I used to write too much extensive lab reports but, some of them, without organization, just describing the events and the measurements and without a deep sense of analysis. I feel sorrowful that I did not know this Method earlier; in that case I could have done best works and reports in former courses."

"The Analytic Method (Vee) and the laboratory classes were very important mainly to see the differences between the physics of the papers and the reality. I think the Vee helps very much the student in the development of a 'scientific analysis of the physics events'. I suggest that the approach used in the last experiment (with no lab guide) should already be used in the third experiment; this would earlier improve that ability in analysis. I don't know if it is just my case but, in the fifth (last) lab, without a lab guide, I carried out more things, I research, I did more graphs than, perhaps, was being expected by the teacher. Critics: more time for the lab, and improve the quality of the lab equipment; it is very poor."

"At first I had some difficulties in the understanding of some parts of the Vee, mainly the definitions, laws and principles, but this was solved through the explanations during the interviews."

"In general, the Analytic Method is efficient but, for best results, it would be necessary more course time, perhaps 8 hours/week instead of just 6 as we have now."

"The Analytic Method is a good teaching system in providing the student with a real view of the relation between practice and theory, a point that is ignored in most courses at this moment. By separating the parts of an experiment and with the study of each part, through the Vee, we have conditions 'to open' an experiment in order to analyse it through several possible angles. If there is a good theoretical basis, the Analytic Method would be an ideal supplement for the disciplines which require an overview of the subject matter. But, I think that, due to the necessity of a progressive comprehension of the Vee and its parts, it should not be taught in just one course term. It should be introduced slowly and earlier through other courses."

"The teacher used too much time with the Analytic Method and this prejudiced the learning of the course content. I think that you should not work so much on the Method because it is easy to understand it."

"I liked very much the lab classes and the Analytic Method. They helped me in the understanding of the scientific processes used in physics and in other scientific disciplines. I suggest to improve the theoretical background of the students in order to strengthen the left side of the Vee; if the student understands the theoretical aspects of the experiment, he may conclude by himself what is going on."

"The Analytic Method carried out in the lab classes provided me with a new view concerning the scientific reality and the problems of proposing a theory that may actually be checked through practice. In brief, the Vee made me clear a new way of scientific reasoning concerning concrete facts.

It is fundamental, to any profession of the scientific-technical area, to develop a unit of scientific reasoning because an architect, engineer, needs create, needs make up, and this is not possible if one doesn't know at least some basic scientific investigation techniques. Specifically in the Physics II course, the Method helped in providing the students with that unit of scientific reasoning as well as in the understanding of the course content because, in my case, that theory involved in the lab experiment became actually understood by me."

"Until today, I had not been introduced to a model (for the analysis of the scientific investigation methods) as well organized as the Vee it is I have no doubt about its validity and utility in a teaching up-to-date. The excess of information, which we are receiving at the present times, it is difficultating the process of critical reasoning of the individuals. ... there is a danger: we are going to enter into an era of ignorance due to a blind faith in 'science', if human being doesn't begin to develop one's critical appraisal and inquiry. I think that this role of studying the science critically must be assumed by epistemology (Obs: the term epistemology was actually used by the student). Consequently, the enterprise of introducing the Vee in the Physics II course was valid. By the way, the Vee is of fundamental importance in any science course and mainly in the theoretical-practical courses in order to evitate the 'cook-book' approach."

"In general, the Analytic Method is useful in the comprehension of the physics and its structure. However, I think that in order to improve still more this notion of structure, it should be more emphasized the aspect of the interaction between theory and practice. ... In my point of view, the function of the event should also become more clear. As a whole the Method is good and may also be used in other situations out from physics."

"Even considering that the teacher put much emphasis on the Vee, I think that it should continue in use in the Physiscs II lab classes and it could be introduced, inclusively, in other disciplines which also have laboratory work."

"Suppress some parts of the Vee such as philosophy (system of values) and value claims which have not very much to do with the experiment and just complicate the student's life."

"An experiment without a lab guide is more appropriate for the comprehension of the use of the Vee because it requires the use of the Vee at the same time that we are carrying out the experiment; then, it permits to visualize the use of the Vee. In other experiments (with a lab guide) we just follow the written instructions and only at the end of the experiment that we use the Vee by identifying the parts of the experiment. The experiments without a guide, by surprise, should be repeated several times through the lab course."

"I understood the Analytic Method (Vee) as a way for action when facing a phenomenon of scientific interest. That is, I have a method for action when facing an event. However, this way for action can more easily be assimilated by doing many labs, and labs in the same way of that one of the fifth lab (with no lab guide). ... Finally, the learning and practice of the scientific investigation processes through the Analytic Method should already begin in the Physics I course and continue in Physics II, in order to facilitate the students' assimilation of those ideas."

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