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ABSTRACT

This study explored the possibility of developing classroom strategies that would encourage physics teachers to put greater focus on a more qualitative, metacognitive approach to problem solving. The empirical part of this research was carried out with students approximately 16 years of age in physics (i.e., introductory Newtorian mechanics) classes at two Portuguese high schools with both qualitative and quantitative procedures being used. Interviews were used as well as a five-month quasiexperimental versus control design. Data analysis indicates significantly higher progress for the experimental students as contrasted with their control peers in metacognitive problem solving abilities, and less significant differences regarding qualitative conceptual and attitudinal change. The results suggest that a metacognitively-oriented problem solving approach might be a suitable means to assure a synergetic interaction between the scientific concepts and the thinking skills. Contains 25 references. (DDR)

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Problem Solving In Physics:
Towards A Metacognitively Developed Approach

Paper Presented by:

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Oak Brook, IL — March 21-24, 1997

Problem Solving in Physics:
Towards a Synergetic Metacognitively Developed Approach[1]

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ABSTRACT

Based on writers like Vygotsky or Kelly, there are some theoretical reasons to believe that instead of predominantly concerned with their students' quite problematic change of conceptual ideas (with content), physics teachers should put a greater concern on the thinking process, that is, on problem solving ability, moving from the typical formulaic, quantitative orientation to a more qualitative, metacognitive approach. This study refers to an investigation designed precisely to examine whether it might be possible to derive such classroom approaches. The empirical part of the research was carried out in the field of physics, at two Portuguese high schools. Both qualitative (interviews) and quantitative research procedures were used. The quantitative dimension took the form of a five-month quasi-experimental *versus* control design, involving tenth grade students. The analysis of data seems to indicate significantly higher progress for the experimental pupils as contrasted with their control peers, in what some metacognitive problem solving abilities are concerned; less significant differences regarding qualitative conceptual and attitudinal change were displayed. Our claim that a metacognitively oriented problem solving approach might be a suitable mean to assure a synergetic interaction between the scientific concepts and the thinking skills seems to have acquired considerable support.

INTRODUCTION

Education is the acquisition of the art of the utilisation of knowledge.

\- Whitehead.

As Whitehead (1970) used to say, if we intend to develop in our students the important "cultural" dimension of the act of thinking, it becomes an imperative to achieve that knowledge, which is fostered by school, does not store in their minds as mere "inert ideas":

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[1] The study referred in this paper is only part of a broad theoretical and empirical study, and related to the first author's doctoral thesis work (Neto, 1995); in the paper, emphasis is mainly put on a significant part of the quantitative dimension.

> That is to say, ideas that are merely received into the mind without being utilised, or tested or thrown into fresh combination. (pp. 1-2).

Since education is, in the author's words, "the acquisition of the art of the utilisation of knowledge", any education which doesn't prepare students for problem solving ("for keeping knowledge alive") will never be a true education.

Problem solving gains, in this way, a primordial educational role. This is evident in the writings of John Dewey, when he considers that the problems are indispensable to the act of thinking itself: they end up by being the stimulus or the driving force of the thinking process, once, metaphorically speaking, thinking is not a case of "spontaneous combustion":

> The origin of thinking is some perplexity, confusion, or doubt. Thinking is not a case of spontaneous combustion; it does not occur just on "general principles". There is something that occasions and evokes it... The nature of the problem fixes the end of thought, and the end controls the process of thinking. (Dewey, 1933, p. 15)

This close association between problem solving and thinking have been later retaken by other authors. Duncker (1972), for example, conceived a "problem" as any situation in which an individual formulates an *objective* - as a sequence of perplexity, confusion or any doubt that he wants to be solved - but he does not know, at the start, how to attain it. Finding himself unable to progress from the given situation to the desired one, through the simple use of immediate, routine operations, he will have to engage in and to develop thinking. It is the nature of the problem that, as Dewey used to stress (1933), determines the objective of thinking, that is to say, guides and regulates it.

This explains why the identification of the *very nature of the problem* becomes, to most writers, the decisive step in problem solving and, after all, in the quality of thinking. It is, that way, a decisive event of what we call today *metacognition* - a cognitive process that has, at last, strong affinities with the kind of thinking that Dewey used to prize and whose development he used to recommend above all: *the reflective thinking.* Loosely referring to one's knowledge and control of one's own cognitive system (Brown, 1987), metacognition is seemingly ubiquitous in recent theorising and researching on learning, remembering and problem solving.

Following that stream, Sternberg (1985) conceives and describes intelligence as a mental function that involves problem solving, and is supported by fundamental processes like planning, revising, monitoring and evaluating the ongoing solving strategy and the solution founded. This important component of intelligence corresponds to the most dynamic dimension of metacognition, which is the crucial intellectual process in problem solving and, for that reason, in any intelligent activity (Valente, Gaspar, Salema, Morais and Cruz, 1987). On this account, choosing it as a source of central inspiration of this study is not a matter of chance. That is to say: although this study, upon problem solving in physics, is not a study concerning metacognition in just a strict, academic sense, it is, however, a study of metacognitive orientation, whether in the teaching facet or in the learning one.

Being the importance of problems and problem solving - as a motor for the act of thinking - , already asserted, it derives that school should give it a significant part of its time. Unfortunately, as signed by Popper (in Popper and Lorenz, 1990), "the fact is that our pedagogy supercharges children with answers, instead of letting them ask any questions, and when they ask them they happen to be ignored" (p. 49).

THE PROBLEM IN STUDY

We mean that between what we claim to school, in the sense of bringing up to date and developing the students' cognitive potential, and what school is supposed to accomplish, it seems to exist a reasonable dissonance. This situation should be outdone by assuring new ways of pedagogical actuation that, instead of contributing to "fill the student's heads with inert ideas", can provide them with a living knowledge, capable of forming a "path", a "way to the future", an assertion that is clearly expressed in the following Vygotsky's words:

> For a time our schools favoured the "complex" system of instruction, which was believed to be adapted to the child's ways of thinking. In offering the child problems he was able to handle without help, this method failed to utilise the zone of proximal development and to lead the child to what he could not yet do. Instruction was oriented to the child's weakness rather than is strength ... Instruction must be oriented toward the future not the past. (Vygotsky, 1986, p. 189)

Thus, in Vygotsky's opinion (1978; Van der Veer and Valsiner, 1991), education should devise situations in students' zone of proximal or potential development; situations which are not exclusively turned to the already attained cognitive levels, but preferably to what students can achieve in co-operation and dialogue with more competent people, that is, to the future.

It is to school, that is, to a systematic and organised education, that Vygotsky ascribes this fundamental role. He sends to school the obligation to create situations of systematic learning, which are consonant with the students' (each student) zone of proximal development. And one of the most powerful tools that school may use to accomplish this purpose will be, precisely, the one that, better than any other institution, school can help students develop: the *scientific concepts*.

Indeed, Vygotsky made a distinction between two basic forms of reality construction, that give place to two distinct, even though synergetic, categories of concepts: the *scientific concepts* and the *spontaneous concepts*. Scientific concepts develop in the highly structured and systematic environment of the classroom; the spontaneous ones, on the contrary, emerge from the spontaneous reflection (social and culturally stimulated, yet more assistematic) from the child upon his surrounding reality.

Due to the richness of its concepts and to the cognitive challenge they may implicate, school physics is a subject especially suited to create classroom situations (that is to say, problems) which fit in the students' zone of proximal development. The fact is that, and quite unfortunately, physics has not, in general, succeeded in updating that virtual vocation.

The traditional classroom approaches usually lead students to think that solving problems in physics is equivalent to doing exercises of mathematical calculus. Consequently, students unduly conclude that conceptual (qualitative) knowledge is nothing else but a set of superfluous abstractions that are useless in problem solving (Mestre et al., 1993). That way, students develop what we designate as a "formula obsession"; That way physics will hardly get rid of its reputation of being, as said by Hewitt (1983), a "miscellany of mathematical equations of the worst kind: literal equations". The study of physics is, in this way, reserved to those (a few ones) who have a bent for mathematics; something that is, naturally, lively deplored by Hewitt:

> I have for a long time felt that the study of physics is too important, too fascinating, too beautiful to be restricted to the few who possess a knack for mathematical analysis. (p. 305) ... Let me put it in very strong terms to make my point: A physics student who lacks a conceptual understanding of physics and who is working physics problems is akin to a deaf person writing music or a blind person painting. (p. 309)

A *new pedagogy* is, indeed, necessary; one that might contribute to solve the "problem of problem solving in school physics". The approach to the teaching of physics, and to the development of the students' competence in problem solving, that we proposed to delineate and test, intends to attain that goal. Its validation on the field imposed the necessity of finding some answers to multiple questions. From the most important ones we elect:

- Will such approach favour the development of the thinking ability, particularly the "thinking of physics and with physics"?

- Is it likely to enhance the students' competence in physics problem solving, whether its nature is qualitative or quantitative?

- Will it be able to promote the development of important metacognitive strategies for problem solving?

- Will such an approach favour the development of metacognitive experiences (habits and attitudes) that might favour students' problem solving performance?

- Will it be able to contribute to a positive change of attitudes - in general, of unfavourable tendency - viewing the subject in question?

- A collateral question seemed to be still important for us: being a fact that diverse factors may constrain the changes, and that sometimes the ways in which they do it are unsuspected, will factors such as the students' level of logical thinking, their individuality, operationalized under the epistemic styles, could be assumed as conditioning factors and, according to it, as good predictors of problem solving competence in school physics?

THEORETICAL FRAMEWORK

Adopting a position that, in a certain way, may be consensual, we assume that a *problem* is a situation that imposes difficulties for which we don't know the solution or even if it exists. Distinguishing, particularly, between real life problems and academic ones, we assume, equally, that the problems in analysis are essentially *academic problems*, though they are not really traditional.

Under these conditions, the fundamental vectors of this study upon problem solving are the principles that can be framed by the following assertions:

1. Problem solving implies the commitment with the task of the psychological subject, looked upon his globality. Under this compromising, a strong relevance is acquired by *affective-motivational resources*, *individuality factors*, such as *cognitive styles,* or the *cognitive development* (enhancing the influence of the *piagetian logical thinking* level) and, last but not the least, *metacognitive resources*.

2. Supported by authors like Kelly (1963) or Vygotsky, it is possible for us to develop an argumentation that calls in question the so-called *conceptual change paradigm*, if envisaged as the chief goal for science education; the teaching-to-think goal is contraposed, an aim that became imperious in view of the needs and challenges of our present society - and, after all, of any time, once, as said by Patrício (1983) "thinking is, in fact, an *essential quality* of man while human being" (p. 58).

3. In this sense, it is not possible to disregard some detours that the orientation nowadays dominant in science education, the constructivism, has taken - namely, the almost exclusive emphasis on declarative knowledge. Contraposing this, we support a *total constructivism*, made of *declarative* but also *procedural* knowledge, which prefers to seek for synergies instead of establishing artificial rupture between scientific knowledge and spontaneous knowledge.

4. As a reaction to some noxiousness of the traditional didactic orientations, in terms of problem solving in physics, namely its exaggerated emphasis on the quantitative aspect, we follow the opinion of those who claim in favour of a more "qualitative physics", without, in any case, signifying the total abandon of the quantitative. It just means that this dimension has to be adequately moderated, managed with parsimony. According to this, we claim for the necessity of achieving a methodological effective transposition, where the automation and mechanisation are replaced by the metacognitive awareness and reflective, productive thinking.

The Experimental Approach: Fundamental Cornerstones

Constructivist perspective. As stated before, in the pupil's knowledge construction process, problem solving can play a fundamental driving role. The static and the dynamic dimensions of knowledge are both equally important there. In the present research, attention was therefore paid not only to declarative knowledge but to procedural knowledge as well. A constructivist perspective for knowledge and learning, was then adopted, in which knowledge is thought not only according to its "static" aspect but also to the "dynamic" one (not only as content but also as a process).

Knowledge organisation. The solver's structure of knowledge (be it declarative or procedural) is crucial for his progress towards the solution. In what school Newtonian introductory mechanics (the subject under study) is concerned, this implies that the fragmented approach usually followed ought to be replaced by a more holistic one. In accordance with this, a great deal of appropriate organizative pedagogical tools like conceptual maps were provided to our experimental subjects. Coherently, all the experimental strategy has been thought to approach kinematics and dynamics in a more integrated way (Appendix 1), raising connections, parallelisms and analogies, instead of treating them in a fragmented way, as it is usual to do (Neto and Almeida, 1990).

Metacognitive training. Students should be helped to make explicit their own thinking processes while problem solving; this is essential if they are to be successful in dealing with the serious demands of the physics problem solving activity. Instead of having students solve only routine tasks, teachers should put them face to real problem solving ones. In line with this, some relevant supports of our approach may be outlined as follows:

- A qualitative analysis of the problems, as a decisive means to a good problem representation, was frequently stimulated. The utilisation of external representations (diagrams) was also repeatedly fostered.

- Explicit training on several metacognitive strategies (planning the solution, monitoring the progress or evaluating, for instance) was also provided. It was supported by *systematic metacognitive worksheets.*

- Instead of the commonly used short problem statements we used longer (more extensive) ones. For the reasons that are full explained below, the latter are, in our opinion, specially suited to have students develop problem solving metacognitive skills.

Traditional approach. It's substantive support is the utilisation of *"problematic" routine tasks*, conducive to mechanical, automatic and acritical behaviour. Such tasks are essentially exercises of numerical computation or "closed problems", which are always settled upon the utilisation of rules and algorithms previously learnt and automatically applied (Garrett, 1987; Gil Pérez and Martinez Torregrosa, 1983).

They appear associated with *short and condensed verbal statements*, where numbers predominate upon words (at least in terms of emphasis); where the physical situation is presented in a lean way (out of context); where, in short, all attention converge to the primacy of the formula and the automatic computation of which the formula is the landmark. Because of such characteristics, the identification of the problem is practically accomplished, at start, and the student is not stimulated to mobilise and to practice that kind of strategy. The same thing happens to the distinction between the essential and the accessory, the identification of the key-information and the previous devising of a solving plan. It is likely that, for most students, such activities are located below their respective zone of potential development.

On the other hand, the dominance conferred to the quantitative dimension of knowledge, minimises the student's awareness about the decisive role of qualitative knowledge in problem solving. It only contributes to accentuate the student's obsession by formulas, which will take him, although unconsciously, to disregard the necessary reflection upon that qualitative knowledge background.

Experimental approach: Without denying the importance of exercises, rules and algorithms, as necessary (although non-sufficient) pre-requisites to the resolution of quantitative physics problems, the experimental approach we designed and implemented, tried to pass on beyond such pre-requisites. For that reason, it appeared supported by problematic tasks of a more demanding level, in closer accordance with the "real" meaning of the word "problem". Seeking for higher levels of cognitive functioning and monitoring than those of the previous approach, the tasks we are using now, despite being intellectually more demanding, try not to push students beyond their potential cognitive level. In other words, they are striving for potential development of each student.

The novelty of the situation is now sufficiently moderate to assure, on one hand, that a student might not experience insuperable cognitive and affective hindrances; and, on the other hand, to assure that edge of minimum cognitive conflict that is supposed to be necessary to the activation of his motivational mechanisms (Flavell, 1987). As material support for that being accomplished, students used *systematic metacognitive worksheets* (Appendix 2) for problem solving in physics, which were conceived to provide systematic training, adequate guidance on cognitive and metacognitive strategies for problem solving and to stimulate students to verbalise, as much as possible, the thinking processes that embody such strategies.

And it was this way that, instead of condensed problem statements, we decided to create our own statements, to be used within the experimental groups. Differently from the first ones, these are *problems of long enunciations*, in which words predominate upon numbers (see Appendix 3).

Their descriptive nature may elicit a much better contextualization of the problematic situation. This situation can therefore be more easily visualised and internally represented by the pupil. Besides that, the same descriptive nature causes the pupil to have to mobilise important metacognitive strategies in order to identify and define the very problem, before embarking on the quantitative routine procedure. The pupil is forced to make conscientious efforts so that he can distinguish between relevant and irrelevant information, trying to locate the key-words or phrases which are supposed to act as fundamental stimulus for adequate information to be retrieved from long-term memory. Once the pupil has engaged himself on such previous qualitative solving stages, his customary obsession by the traditional formulaic approach might be at least unfostered. On the other hand, this type of problem statement causes the student to eventually pose a greater concern on trying to use certain metacognitive strategies, like planning, controlling or evaluating his progress.

The Design

The empirical part of the research was carried out in the field of physics (more precisely in introductory Newtonian mechanics), at two Portuguese high schools. Both qualitative (semistructured interviews and content analysis of the students' written material) and quantitative research procedures were used. The quantitative dimension took the form of a quasi-experimental (three classes) *versus* control (one class) design (Cook and Campbell, 1979). The pupils, aged about sixteen, were studying the part of physics of their Physics and Chemistry same discipline.

The researcher himself taught one experimental class (E1) and the control class (C) at one school; two other experienced physics teachers were put in charge of the other experimental classes (E2A and E2B) at the other school. Those teachers had been provided adequate theoretical and practical training on the field of problem solving, metacognitive pedagogical aids and conceptual physics. Due to some insurmountable local constraints, it turned out to be not possible to collect data for all the pupils that formed classes E2A and E2B and for all the instruments used. Because of that, and for the sake of statistical convenience, a mixed treatment group (E2) was created. The statistical design can then be sketched as follows:

E1	**O1**	**X**	**O2**
C	**O1**		**O2**
E2	**O1**	**X**	**O2**

A five-month classroom-based action research field study was then carried out. The subject of introductory (Newtonian) mechanics was taught to the participants as part of the regular course. This consisted of four lessons a week, which, depending on the circumstances, could take the form of lectures, instruction on problem solving strategies, and individual and group problem solving work based on adequate worksheets. These were conceived to provide systematic and explicit guidance on problem solving and metacognitive behaviour. The control group followed a traditional lecture/routine puzzle solving approach, in close relation to the strategy proposed on the textbook adopted.

The Instruments

Nine tests (sub-tests or questionnaires) were administered to the pupils, six relating to the dependent variables, and three having to do with the moderator ones (Table 1). All the instruments were developed, adapted or compiled by the researcher himself. In order to test and, eventually, bring some adjustments to the instruments so prepared, pilot tests and expert judgements were previously conducted. An analysis content of the students' written work and a number of exhaustive semistructured interviews involving both experimental and control pupils were also used.

Table 1

The Instruments Used in the Study

	INSTRUMENTS	*pre*	*post*
NUCLEAR FIELD	• **Test of Physics Quantitative Problem Solving (TPQTPS)**	✓	✓
	• **Test of Physics Qualitative Problem Solving (TPQLPS)**	✓	✓
	• **Test of Problem Solving Metacognitive Strategies (TPSMS)**	✓	✓
	• ***Test of Comprehension of 9th Grade School Physics*** **(TC9SP)**	✓	
	• ***Test of Piagetian Logical Thinking*** **(TPLT)**	✓	
	• ***Epistemic Styles Inventory*** **(ESI)**	✓	
METACOGNITIVE EXPERIENCE FIELD	• **Problem Solving Metacognitive Experience Questionnaire (PSMEQ)**	✓	✓
AFFECTIVE FIELD	• **Test of Attitude Towards Physics and Chemistry (TATPC)**	✓	✓
	• **Test of Attitude Towards Physics Problem Solving (TATPPS)**	✓	✓

For the sake of data analysis convenience, we decided to consider the three broad categorising fields of quantitative variables, illustrated in Table 1 and described below.

Nuclear field (cognitive-metacognitive). Being the very core of the research, it embodies a number of relevant cognitive and metacognitive type processes and strategies (both quantitative and qualitative), closely related to the students' ability for problem solving in physics. This field was operationalized by means of the instruments also indicated. For methodological and practical reasons, the first three instruments — whose post-versions are the dependent variables in this field (and the main dependent variables in the study, actually) — correspond to three autonomous parts of the same evaluation document called the *Physics Metacognitive Problem Solving Assessment Sheet* (Appendix 3). As they constitute the main part of the study, and because of space reasons, only for them a brief description will be provided in this paper:

- **TPQTPS.** Both the pre and the post versions of this instrument were based upon the solution of two long statement quantitative problems appearing in each of the two parts of the above mentioned Assessment Sheet. The students' problem solving performance were evaluated against a set of adequate pre-defined key scoring criteria.

- **TPQLPS.** Both the pre and the post versions of this instrument include a set of qualitative problematic situations in which it was required from the students to elaborate complete sentences trying to full explain their points of view, whether scientific or alternative.

- **TPSMS.** This test was shaped by a composite of six questions (repeated twice), relative to important metacognitive processes and strategies and associated to the items 1, 2.1, 2.2, 2.4, 2.5 and 2.8 of the Assessment Sheet. The questions asked the students to verbalise, by writing, diverse important metacognition-related personal strategies and events. The answers were scored on the grounds of the quality, adequability and exhaustiveness of the students' verbal argumentative statements.

Metacognitive experience field. This field is not so much associated with cognitive/metacognitive processes, as it happened with the previous one, but rather with important attitudinal indicators which are supposed to have great impact on the students' metacognitive behaviour when trying to cope with complex tasks. In other words: while the previous instruments were in close relation to what Flavell (1987) calls "cognitive knowledge", especially to its procedural dimension, this field variables are better framed by what the same author calls "metacognitive experience". Composing the *Problem Solving Metacognitive Experience Questionnaire,* those indicators were operationalized by the remaining Likert-type scales of the Assessment Sheet and had to do with the following behaviours, feelings or attitudes; levels of compression before and after the solution ($COMP_{b,a}$), facility ($FAC_{b,a}$), confidence

(CONF$_{b,a}$), content knowledge competence (KNOWL), attention (ATTEN), revision concern (REV), commitment to the task (COMMIT) and evaluation of the ongoing process (EVAL).

Affective field. In obvious close relation to the preceding one, this field was operationalized by the following instruments: a Likert-type instrument called *Test of Attitude Towards Physics Problem Solving*; and an instrument based on the semantic differential technique and labelled *Test of Attitude Towards Physics and Chemistry.*

THE RESULTS

As explained before, information presented in this paper is only part of an huge amount of theoretical and empirical data related to a doctoral thesis on the field of problem solving in physics. So, at this point, we will try to present a significant part of the empirical results, putting the emphasis on its quantitative dimension. At the start, a global view of the changes shown by the two experimental groups as compared to the control one will be presented in Table 2.

A Global Field View

Table2

The Initial Versus the Final Relative Global Positions

MANOVA	**Nuclear Field**		**Metacognitive Experience Field**		**Affective Field**	
	Initial	Final	Initial	Final	Initial	Final
E1 $\propto$ C	=	>	=	>	>	>
E2 $\propto$ C	>	>			>	>

- "=" denotes that no statistical global difference existed between the groups
- ">" denotes that the first group scored higher than the second group in the field as a whole

At first glance, it appears that, in what the two first fields of intervention are concerned, group E1 did clearly better than its control counterpart. In fact, if at the initial state the two groups were statistically equivalent in those two fields, at the final state the experimental group clearly surpassed the control one. No conclusions can be derived for now with respect to other aspects. Further refinements on the analysis are therefore required. A multivariate analysis of covariance was then performed (Table 3), whose goal was to compare relative global changes instead of relative global states

Table 3

Relative Changes: An Overall Field Comparison

MANCOVA	FIELD	*lambda*	d.f.	level p	DECISION
E1 ∝ C	**Nuclear** Covariables: TPQTPSpre, TPSMSpre, TPQLPSpre, TC9SP, TPLT	0,41	(4;25)	0,00 ***	E1>C
	Metacognitive Experience Covariables: all the respective scales	0,42	(11;21)	0,03 **	E1>C
	Affective Covariables: TATPCpre, TATPPSpre	0,88	(2;36)	0,09 *	E1>C
E2 ∝ C	**Nuclear** Covariables: TPQTPSpre, TPSMSpre, TQLPSpre	0,70	(3;30)	0,01 ***	E2>C
	Affective Covariables: TATPCpre, TATPPSpre	0,75	(2;46)	0,00 ***	E2>C

* *Weakly Significant* ** *Significant* *** *Highly Significant*

Significant positive relative changes for both pairs of groups and for all three fields appear to be revealed. Only for the affective domain and group E1 that significance proved to be somewhat weak.

A Relative Variable Intra-Field View

A few important aspects were not illuminated yet. For instance, nothing in the foregoing discussion indicates which (if any) of the two experimental groups took more advantage of the experience. The next stage of the analysis (Table 4) may eventually contribute to disclose some of those unrevealed aspects. This time, the analysis is focused not on the totality of every field but to the specificity of each of its composing variables. Three graphs, one for each field, will help illuminate the changes as for this step of the analysis.

Table 4

Relative Changes: A Variable Comparison

ANCOVA	**VARIABLE**	**F**	**d.f.**	**p level**	**DECISION ***
E1 ∝ C	***TPQTPS***	44,87	(1;44)	0,00	**E1>C**
	TPSMS	22,14	(1;44)	0,00	**E1>C**
	TPQLPS	12,12	(1;39)	0,00	**E1>C**
	COMPb	0,14	(1;42)	0,71	E1=C
	COMPa	4,19	(1;41)	0,00	**E1>C**
	FACb	9,03	(1;42)	0,00	**E1>C**
	FACa	17,01	(1;41)	0,00	**E1>C**
	CONFb	2,41	(1;42)	0,13	E1=C
	CONFa	8,87	(1;41)	0,00	**E1>C**
	KNOWL	4,18	(1;44)	0,00	**E1>C**
	ATTEN	0,85	(1;44)	0,36	E1=C
	REV	0,42	(1;44)	0,52	E1=C
	COMMIT	1,44	(1;44)	0, 23	E1=C
	EVAL	16,71	(1;44)	0,00	**E1>C**
	TATPC	5,40	(1;40)	0,00	**E1>C**
	TATPPS	9,34	(1;42)	0,00	**E1>C**
E2 ∝ C	***TPQTPS***	34,54	(1;39)	0,00	**E2>C**
	TPSMS	0,66	(1;39)	0,42	E2=C
	TPQLPS	2,77	(1;49)	0,12	E2=C
	TATPC	7,74	(1;56)	0,00	**E2>C**
	TATPPS	12,87	(1;48)	0,00	**E2>C**

** All the inequalities are highly significant.*

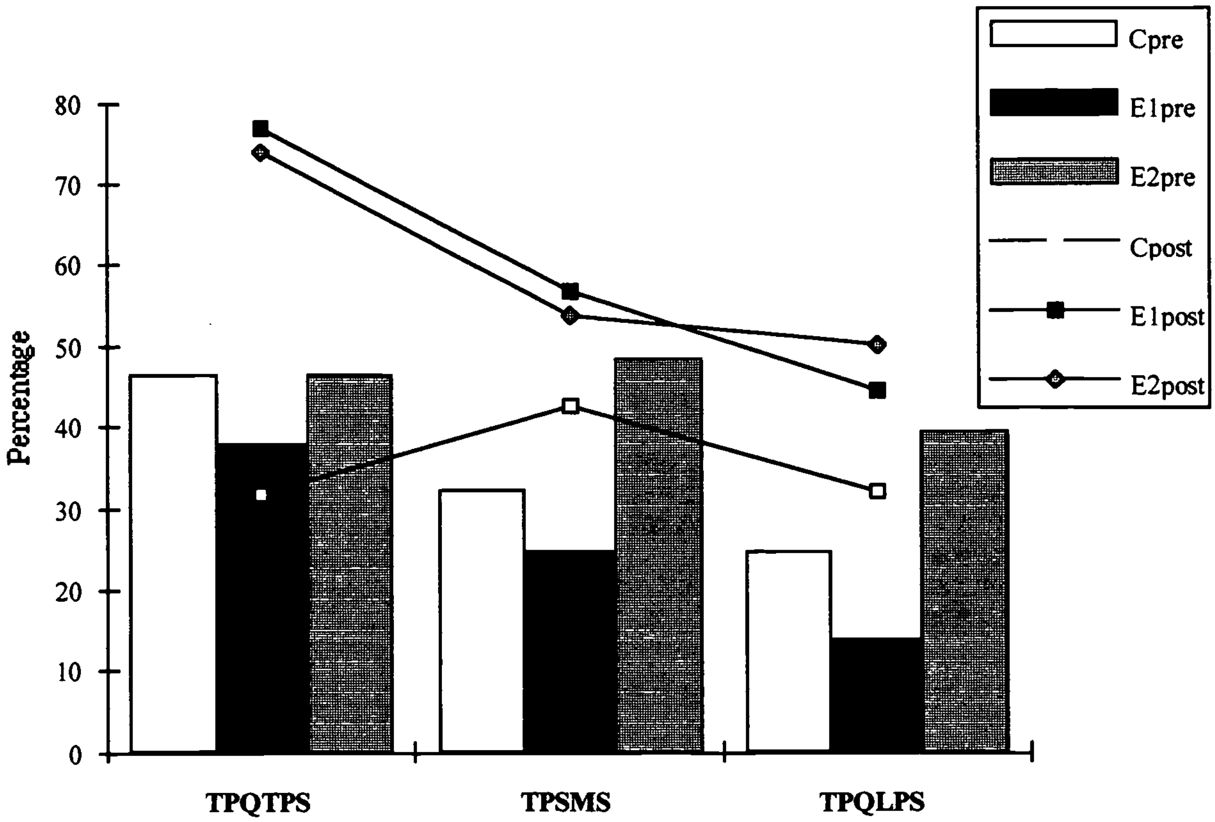

Fig. 1 — *Relative Variable Changes Regarding the Nuclear Field*

As it happened with the field as a whole, both of the two experimental groups, as contrasted with the control group, did clearly better in all the three variables in question (Table 4, Fig. 1). While positive gains were displayed by the control group only for two variables (TPQLPS and TPSMS), the other groups got higher final marks in all the variables. But, whereas the relative changes are all significantly positive for group E1, for E2 they are only significant in the case of TPQTPS.

Besides other reasons that might explain this relatively less impact of the experience on E2 and in what this field is concerned, two facts deserve in our opinion special consideration:

- Firstly, the shorter training time this group has been provided. Time is obviously a crucial factor for any type of change to happen and to be detected.
- Secondly, the type of teacher guidance provided. While this group was taught by their own teachers, the group E1 was taught by the researcher himself. There are always unavoidable distortions and inexorable idiossincratic reinterpretations when any researcher has to communicate his models to his co-operators.

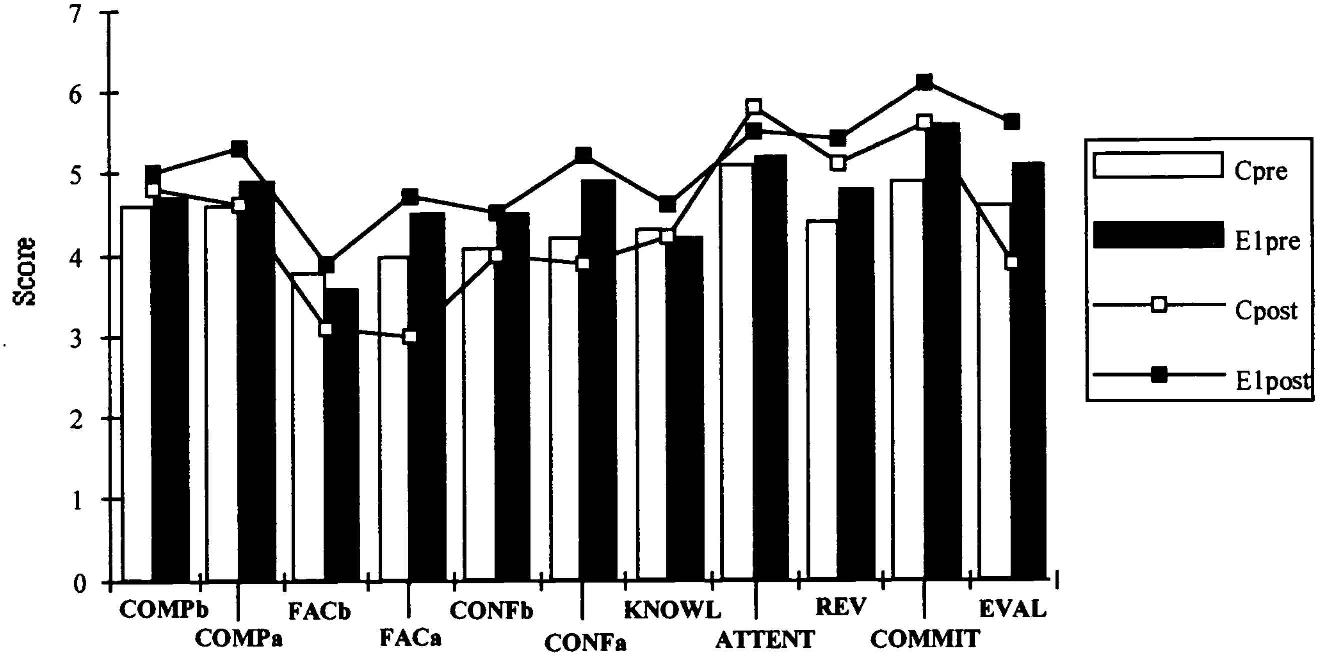

Fig. 2 — *Relative Variable Changes Regarding the Metacognitive Experience Field*

As for this field of analysis, there seems to exist a sharp distinction between the two group's behaviour: a great irregularity for group C as opposed to an almost complete regularity for E1. This group's gains are nearly all positive (Fig. 2). Furthermore, more than 50% of those gains reflect a significant relative improvement. On the whole, while group E1 seems to have much benefit with the intervention in what some favourable metacognitive experiences are concerned, the control group appears to have hardly experienced any significant global change.

Affective Field

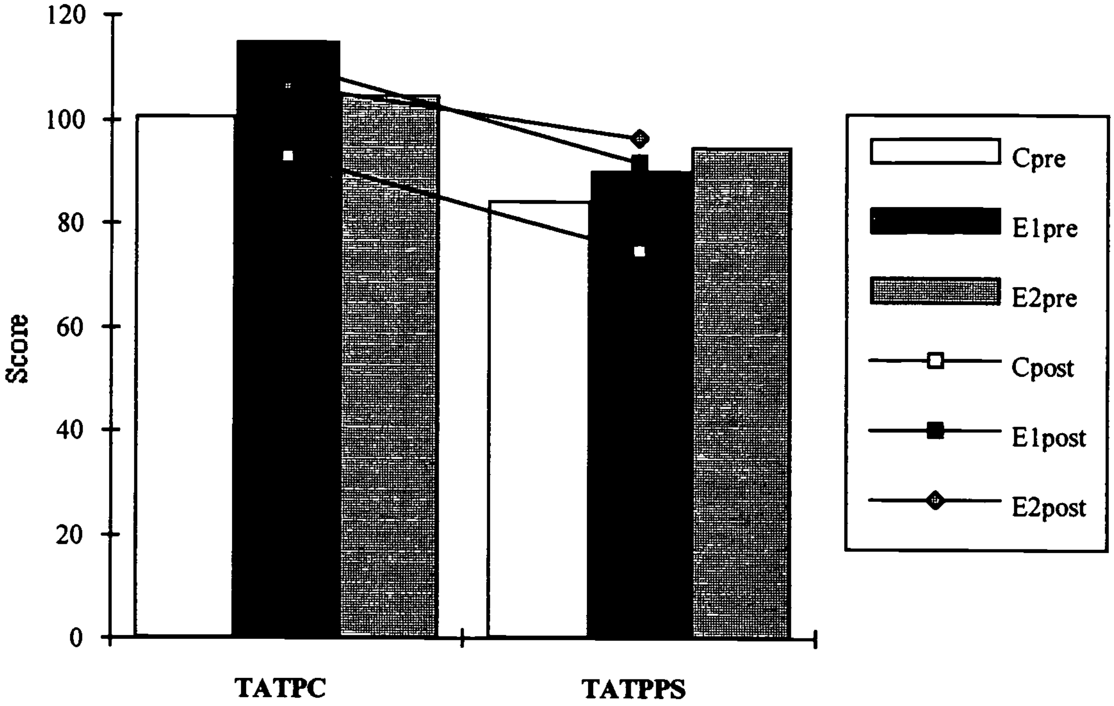

Fig. 3 — *Relative Variable Changes Regarding the Affective Field*

The initially identified positive differences between both groups E1 and E2 and group C, were also present at the final state (Fig. 3). But, whereas for the previous fields the experimental groups tended to score higher at the final state, here the situation proved to be somewhat different. No important pre-post differences were displayed by these groups, except for a slight decrease for group E1 in what attitude towards Physics and Chemistry is concerned (Table 4). But, as a significant decrease was revealed by the control group for both variables, the experimental groups' comparative changes turned out to be positive.

Overall, it appears that an unfavourable affective impact on the learning and problem solving process in physics might be ascribed to the traditional approach. As for the experimental approach the situation is quite different: students seem not have been much affectively affected by the intervention; it looks as if their attitude towards the learning and problem solving in physics has remained practically unchanged.

Some Interview Results

In order to reinforce some of the previously derived conclusions, some students' interview-derived information will be presented now in Table 5.

Table 5

The Traditional vs. The Experimental Approach: The Students' Final Opinions

		Frequency			***Statistical Difference***	
CATEGORY	**GROUP**	**Fav**	**Hesit**	**Unfav**	**U Test**	
STATEMENTS	E1	**10**	**-**	**-**	U=20,0**	$p \leq 0,050$
	C	**4**	**5**	**-**		
[redacted].	E1	**10**	**-**	**-**	U=15,0**	$p \leq 0,020$
APPROACH	C	**3**	**5**	**1**		

* *Weakly Significant* ** *Significant* *** *Highly Significant*

The two samples' opinions about the general features of the respectively followed approaches are clearly different (Table 5). All of the experimental subjects interviewed seem quite have appreciated both the long statement problems and the overall approach. A few of them even expressed great enthusiasm with regard to this type of academic physics problems. Most of the common psychological constraints encountered in the realm of problem solving in physics appear to have been overcome by the experience. As for the control sample, the hesitant category was predominant. There are, however, some reasons to believe that the general tendency might point to its unfavourable pole. Curiously enough, in spite of the fact that they were not provided so much training on long statement problems, almost all of the control students interviewed denoted greater preference for them, in contrast with the traditional short ones.

DISCUSSION AND PEDAGOGICAL IMPLICATIONS

The analysis of data seems to indicate significantly higher progress for the experimental pupils, as contrasted with their control peers, in what some cognitive and metacognitive problem solving abilities are concerned; less significant differences regarding qualitative conceptual change were still displayed. Our claim that a metacognitively oriented problem solving approach might be an adequate alternative to the conceptual change paradigm (Posner et al., 1982), and a suitable means to assure a synergetic interaction between the scientific concepts (content) and the thinking skills (process) seems to have acquired considerable support.

When supporting the substitution of the spontaneous knowledge by the scientific knowledge, as the major finality for science teaching, the conceptual change paradigm ends up by aiming at unreal and reducing educational goals:

- Unreal, provided that the endogenous, structural and idiosyncratic character of the personal and spontaneous constructs, turns the "abandonment" of those constructs, by the students, quite improbable.
- Reducing, provided that those orientations end up by over-emphasising one of the components of the scientific knowledge (the conceptual one) to de detriment of the other (the procedural one), which cannot help being considered less important.

On the other hand, when admitting that the spontaneous knowledge lacks of educational value, having to be "combated" whenever it collides with the scientific knowledge, that paradigm ends up by establishing antagonisms and noxiousness that are not free of partiality: it only takes in regard any negative influence that the spontaneous knowledge may have on the learning of the scientific knowledge, ignoring the role that, like any mother tongue in the learning of a foreign language, the spontaneous knowledge may play. Ignoring, yet, that the personal constructs, even being dissonant with the formal criterion, have an adaptive function, provided that they raise the integration of the individuals in various contexts, without being necessary that they enter in rupture with their own systems of constructs, which are, at a large scale, the reflex of the implicit beliefs and theories of the societies and cultures where they are inserted (Kelly, 1963; Rodrigo, Rodríguez and Marrero, 1993; Solomon, 1983).

When we criticise the validity of the conceptual change paradigm as the prime finality for the teaching of science, our intention is not, in any way, to devaluate the educational importance of the scientific concepts. If it is true that the spontaneous knowledge comes from Vygotsky's conceptualisation deservedly rehabilitated, it also happens that this rehabilitation is not done at the expense of the scientific knowledge.

The learning of the scientific concepts will always be a primordial goal for school education towards a crescently reclaimed scientific literacy, no matter from which prism this problematic of education in science is analysed. And it will happen for these very reasons:

- by the role that they play in the cultural and psychological development of the students, namely in their metacognitive development;
- by their importance in the awareness of the spontaneous knowledge, guaranteeing a greater systematisation and critical evaluation of that knowledge, with a relatively superior autonomy from students towards their immediate sensorial perception.

But, although important scientific concepts might be, they should not constitute, by no means, an end in themselves. The learning of the scientific concepts, according to the Vygotskian perspective, raises out other concerns: those that are related with the cognitive development of students, a development that the scientific concepts cannot assure by themselves. It is necessary that, through them, some problematic situations are created which, being adequate to the zone of the potential development of each student, lead students to think, that is, to acquire the mental tools that permit them to build their intellectual edifice, with the help of the "cognitive bricks" that, metaphorically, the scientific concepts may constitute.

It does not mean that we must disregard the students' learning of concepts, that is to say, their need to develop the qualitative dimension of knowledge and thinking. We ought to have in mind that physics is, simultaneously, qualitative and quantitative. Both dimensions, in convergence, are necessary to build the scientific edifice. And, if managed with parsimony, both are equally important and indispensable to the cultural and intellectual development of the students.

Our approach has, precisely, by lemma this presupposition and that need of convergence. Through the analysis of its *impact*, we have reasons to claim, generically, the appropriateness of our positions, especially if some hindrances we have met are taken into account: real lessons, which are submitted to a set of inherently complex and systemic constraints. After doing the global checking of our study and confronting the results with the starting hypotheses, we believe that now we have enough reasons to affirm that some of those hypotheses have gathered unequivocal evidence, in spite of the fact that, for others, only some signs of their plausibility have emerged. And this is what is happening, particularly, to one of our fundamental heuristic questions: *has the experimental approach really favoured the reinforcement of our students' thinking skills?*

According to Vygotsky (1978, 1986), the development of higher-order thinking skills is, at a large scale, a development that comes "from the outside in": all the superior cognitive functions depart from a social and cultural context (inter-personal) to an individual one (intra-personal). It is through the progressive internalisation of the tools (linguistic and conceptual, for example) that are provided by the society, that we construct the conscious act of thinking, which activates and "regulates" the other psychological functions and allows the child's access to the highest forms of thinking, that is, to metacognition.

Accepting the premise that the development of cognitive control is, considerably, a social and cultural process, it is right to conclude that it is up to parents, teachers and other competent subjects to handle the mission of providing students with the strategies which will help them to learn and solve problems in future, autonomously. In consonance with such premise, Brown (1987) denotes that the social environments (including school) where the individuals co-operate with others who are more competent, in problem solving activities, are particularly favourable to learning.

In any attempt to develop children's cognitive skills, the linguistic interaction, the dialogue with more competent people (particularly, with the teacher), plays a role that cannot be substituted. Without this external dialogue (which becomes internal), that development will hardly happen on its plenitude.

And it was there where we can locate the main weak facet of our study. The interaction the students were provided was not as intense and diversified as it should be to respond to their needs in what their thinking skills training is concerned. For that very reason, one of the hypothesis that we initially admitted didn't achieve, surely, the validation that we were waiting for. Perhaps we were waiting for it imbued with a certain ideal: the ideal that guides the action of someone (the researcher) who necessarily has to rely upon ideal models. The classroom reality is something much more complex, principally if we are thinking of the school physics scenario. But that does not mean that we would give up trying to strive in order to have things changed. Taking all in all, and quoting Larkin and Rainard (1984), "a primary need from research in science teaching is knowledge that would guide us in better educating students to think" (p. 235).

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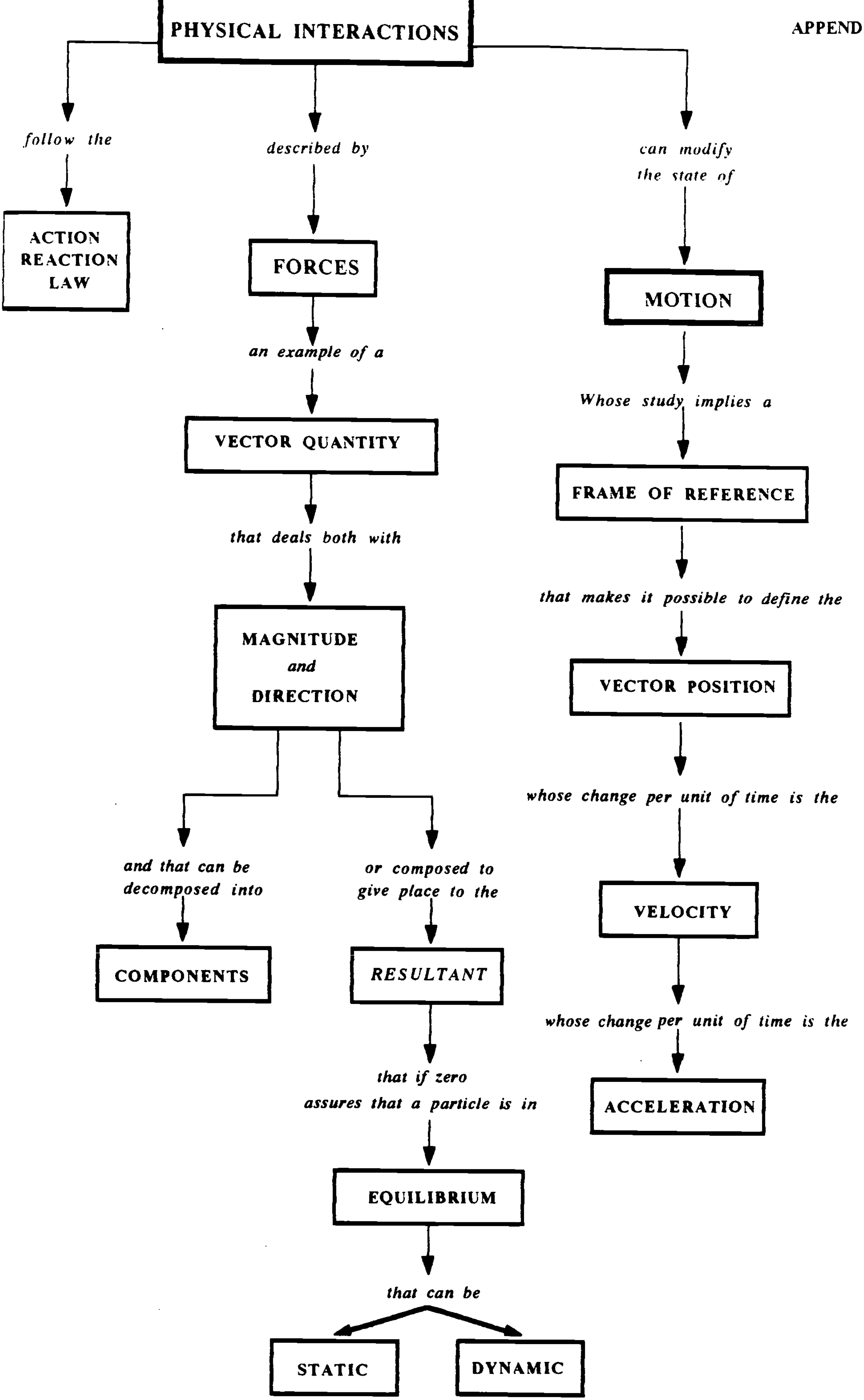
APPENDIX 1


PHYSICAL INTERACTIONS
follow the
ACTION REACTION LAW
described by
FORCES
an example of a
VECTOR QUANTITY
that deals both with
MAGNITUDE and DIRECTION
and that can be decomposed into
COMPONENTS
or composed to give place to the
RESULTANT
that if zero assures that a particle is in
EQUILIBRIUM
that can be
STATIC
DYNAMIC
can modify the state of
MOTION
Whose study implies a
FRAME OF REFERENCE
that makes it possible to define the
VECTOR POSITION
whose change per unit of time is the
VELOCITY
whose change per unit of time is the
ACCELERATION

SYSTEMATIC METACOGNITIVE WORKSHEET: *A SKETCH*

A LONG STATEMENT PROBLEM...

1. DIAGRAMMING THE SITUATION

2. ANALYSING THE PROBLEM

- Read the problem statement carefully. Try to *underline* those passages you think are the most important ones. Are there any words or phrases whose meanings you don't know? If so, write them down:

- What is for you *the very problem* in question? Make an attempt to *formulate* it clearly.

- What are the *physics concepts and laws* that are closely related to the problem you have identified?

- What in your opinion are the *key-words/phrases* on the statement?

- Are you able to formulate a *prevision* for a possible answer to the problem? Try and describe it below as full as you can.

- Can you *explicit the most relevant information you have to retrieve from memory* in order to have the problem solved?

3. PLANNING AND ORGANIZING THE STRATEGY

DATA

STRATEGY

INCOGNITS

EQUATIONS

QUANTITATIVE PROCEDURE

ANSWER

4. EVALUATING THE SOLUTION

- Try to verify if:

  - *the steps taken appear to be adequate;*

  - *the answer done appears to make any sense;*

5. IDENTIFYING DIFFICULTIES

- What were the *stages/aspects* on which you have experienced *greater difficulty?* Can you explain your very trouble?

- What were the problem related *subjects you didn't know* quite well?

6. EVALUATING THE OVERALL SOLVING PERFORMANCE

SOME COMMON MISTAKES AND SHORTCOMINGS WHILE PROBLEM SOLVING

*Place a **check mark** on those items which denote the most important problem solving faults you made while performing the previous task*

1. I guess I didn't read the problem statement carefully.

2. I was too much concerned with the mathematical equations and calculus.

3. I experienced much trouble in identifying the very problem in question.

4. I was not able to construct a suitable mental representation of the problem.

5. I was not much concerned with planning the solving strategy.

6. To be honest, I didn't study the subject quite well.

7. I was not able to relate the problem to the topics I have been learning

8. I made too much reasoning and calculus mistakes .

9. I was not enough concentrated on the task.

10. I was not much concerned with evaluating and controlling my problem solving progress.

PHYSICS METACOGNITIVE PROBLEM SOLVING ASSESSMENT SHEET

School .... **Class** ....

Name .... **Date** ..../..../....

1st PART[2]

PROBLEM 1

Two friends (weighing both 75 kgf) were spending their summer holidays at Albufeira Beach in Algarve. One of them owns a quite sophisticated Japanese speedboat made of glass fibre, and weighing about 300 kgf.

They used to spend all the time on the sea, in an attempt to keep beating their nautical previous speed record. For that, they used to register the interval of time needed to reach a certain buoy, floating 0,8 km away from the coast. The best they had ever been able to do was 40 s. One morning, when their holidays were about to finish, they created the feeling that once more their nautical record would be beaten. It was a nice day with a flat sea and a pleasant breeze. Just on the first run, they verify from the boat speedometer that in the first ten seconds the speed had uniformly been increasing from zero to 36 km/h. Then, they decided to keep moving at the same rate of speeding along the remaining part of the run. When they got to the buoy *how do you think the two friends' emotive reaction was? Real delight? Obvious disappointment?*

1. The statement you have just read is likely to be a problematic situation for you. What is, then, the *very problem* in question?

---

[2] The 2nd Part is in all similar to this one with the exception of the problem presented which is obviously different although it is also a long statement one.

2. Before starting the formulaic approach, try to get adequate answers to the series of qualitative questions suggested.

2.1. *What are the* physics concepts or laws *which the problem is related to* ?

2.2. *What are the* key-words *you think are absolutely necessary to solve the problem* ?

2.3. Place a *check mark* on the scales below, at the position that better indicates:

a) *your* comprehension level *of the problem proposed;*

very high ____ : ____ : ____ : ____ : ____ : ____ : ____ *very low*

b) *the* level of difficulty *the problem seems to offer to you;*

very high ____ : ____ : ____ : ____ : ____ : ____ : ____ *very low*

c) *the* level of confidence *in your capability to solve the problem;*

very high ____ : ____ : ____ : ____ : ____ : ____ : ____ *very low*

d) *your* level of competence *on the subjects the problem is related to;*

very high ____ : ____ : ____ : ____ : ____ : ____ : ____ *very low*

2.4. Try to formulate a *prevision* for the answer to this problem. Describe your reasoning.

2.5. Try to give an idea of the *main mental steps* you are going to take, in order to have the problem solved. Be organised and consistent on explaining your *mental plan.*

2.6. Once you have probably developed a qualitative analysis of the problem, feel free to engage on the *quantitative formulaic stage* of the approach. Try to organise your material and make an effort to provide an illustrative *diagram* of the physical problematic situation.

2.7. Make a list of the *most relevant information you had to retrieve from memory* (physics facts, concepts, laws, equations, ...)

2.8. Once you might have got an adequate solution to the problem, please try to answer the questions below:

a) *Did you really read the problem statement carefully? How do you classify your* attention level *on this task* ?

*very high*____ : ____ : ____ : ____ : ____ : ____ : ____ *very low*

b) *Did you really understand the problematic situation suggested* ? *How do you classify the* level of comprehension *you think you have really achieved* ?

*very high*____ : ____ : ____ : ____ : ____ : ____ : ____ *very low*

c) *Have you been really concerned with* monitoring *and* evaluating *your thinking processes and products? What* level *did you attained on this task?*

*very high*____ : ____ : ____ : ____ : ____ : ____ : ____ *very low*

2.9. Place a *check mark* on the scales below, at the position that better indicates the way you evaluate the task that is related to each unfinished sentence:

a) "In my opinion, this problem proved to be..."

very easy ____ : ____ : ____ : ____ : ____ : ____ : ____ *very difficult*

b) "My commitment to the task was..."

very high ____ : ____ : ____ : ____ : ____ : ____ : ____ *very low*

c) "My confidence level in the answer done is..."

very high ____ : ____ : ____ : ____ : ____ : ____ : ____ *very low*

d) " My approach to the solution was..."

very efficient ____ : ____ : ____ : ____ : ____ : ____ : ____ *quite inefficient*

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