Third Misconceptions Seminar Proceedings (1993)

Paper Title: MISCONCEPTIONS: A CONCEPTUAL OR METHODOLOGICAL DEFICIENCY? - A Case Study showing a Theory in Action

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Keywords:
General School Subject:
Specific School Subject:
Students:

Macintosh File Name: Braghiroli - Method Deficiency
Release Date: 6-16-1994 C, 11-8-1994 I

Publisher: Misconceptions Trust
Publisher Location: Ithaca, NY
Volume Name: The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics
Publication Year: 1993
Conference Date: August 1-4, 1993
Contact Information (correct as of 12-23-2010):
Web: www.mlrg.org
Email: info@mlrg.org

A Correct Reference Format: Author, Paper Title in The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Misconceptions Trust: Ithaca, NY (1993).

original publication of this proceedings was supported by a grant from the National Science Foundation, and the transformation of this collection into a modern format was supported by the Novak-Golton Fund, which is administered by the Department of Education at Cornell University. If you have found this collection to be of value in your work, consider supporting our ability to support you by purchasing a subscription to the collection or joining the Meaningful Learning Research Group.

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MISCONCEPTIONS: A CONCEPTUAL OR METHODOLOGICAL DEFICIENCY?
A Case Study showing a Theory in Action

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PROLOGUE

During my first years of teaching activity in the University my attention was focused, imperceptibly, by the most capable students of my classroom (I only had knowledge then ...). As time went by and, perhaps, half-way in my history, my interest moved towards those students showing the lowest performances (I had already gained experience ...). At present, after a long way gone through, I choose (full consciously) to put all my enthusiam on those students who, even having a learning potential, seem to have not found the means to develop such potential.

INTRODUCTION

The results of the Educational Research (ER) "don't come down to the classroom". This is the claim that we, teachers actively involved in the improvement of the quality in education as a means to improve our quality of life, constantly hear and produce.

For a Physics teacher that decides to tackle with the task of improving his day-to-day practice taking advantage of the ER results (decision taken due to recurrent problems in the classroom), instead of testing already developed teaching methodologies which have proved to have little success in general, the first impression might be discouraging. He will encounter such a huge load of information that it will be difficult for him to believe that all researchers are trying to undertake the same problem: how to learn and teach. In one sense, he will find the big theories about learning and teaching which don't seem to have, at least at first sight, much in common. In another sense, he will have an enormous range of researchs on specific learning and teaching areas which do not always explicitly explain the theoretical framework from where they were conceived; in fact, they often seem to obey the model "watch-measure-conclude-generalize". As Novak (1992) says, quoting Wilshire (1990): "Positivism is alive and well in universities, and so teachers are still being trained under positivistic influence".

Taking into account the success of the ER results during the last two decades, the new approaches from researchers of specific disciplines (specially scientific ones), and the enormous information flow circulating through specialized magazines, seminars and congresses, said claim must be considered and it suggests us some questions:

* Do the ER results constitute an organized body of knowledge accessible to the teacher?
* Can the ER results be directly transferred to the classroom?
* Are the teachers trained to interpret the ER results, which have the specific language of the Educational Sciences?
* Are the teachers, who have been trained to teach, able to diagnose the problems related to learning and, consequently, able to find solutions among the wide range offered by ER?
* Do we, teachers, know how to learn?

It's not my intention to answer these questions but to explain an experience which was born as an attempt "to put down to the classroom" the ER results and their consequences.

I. BUILDING MY OWN MEANINGS

I.1. FIRST PART: misconceptions

If we used a sifter to filter the most outstanding information about ER from the specialized magazines of the last two decades, we would soon see that the focus of the researchers, in accordance with the change of paradigm in education, has moved from the teacher "who teaches" (the conductist paradigm) to the student "who learns" (the constructivist paradigm).

As a consequence of the above mentioned a good portion of the 80s was characterized by the enthusiasm of the researchers in focusing their efforts towards the identification of the students' ideas about scientific phenomenon, before and after their formal instruction. Osborne and Wittrock (1983), lately reviewed by Driver (1989), arrived at the following conclusions:

1. Sciences students have previous knowledge.
2. Said knowledge is not composed of isolated ideas; it's made of conceptual structures which provide a coherent understanding of the world.
3. Those structures are maintained after the students' formal instruction, originating the juxtaposition of two parallel learning systems.
4. When the formal instruction is able to change the intuitive concepts, the new meanings acquired by the students differ from those expected by the teacher (bigger discrepancies are found between 13-15 years old students).
5. The students often ignore that their previous conceptions and the teacher's concepts might differ.
6. The differences appear even at vocabulary level: students and teachers don't share the same meanings of the words they both use to inter-communicate.

7. Misconcepts remain unalterable even in students who pass their tests, as a consequence of the instruction received.

According to Osborne & Wittrock, all these statements are due to the fact that "many researches and curricula designs from the past have been shaped with the intuitive notion: if we could obtain a well-designed explicit model of the basic knowledge used by an expert, we would only need to determine the specific differences of the students' knowledge with respect to that of the expert, and to teach in consequence". There exists here an obvious emphasis on contents.

As from our practice as teachers, we may add that teaching methods have ignored, in general, not only the students' meanings for the words they use in sciences and their points of view about how things happen, but, above all, the mechanisms through which the learning process takes place.

As a consequence of this line of research, we find a word clearly dominating the ER field up to the end of the 80s: MISCONCEPTIONS.

This phenomena always existed and it's known as the "student's typical errors"; it's favored by a new theoretical framework which proposes a new vision on how the knowledge is composed of.

The "misconcept" issue is closely associated to the Constructivist Theory of Learning, as the latter considers the subject of learning as confronting with the object of knowledge. The task of the learner consists of building meanings through understanding, transformation and storage of data processes. It doesn't get the meanings at once; it builds them step by step, adopting at the same time strategies to use said meanings (Rumelhart & Norman, 1981).

The student is seen as the owner of a previous structure of knowledge, determinant for the new learning process. The available cognitive structure, together with individual's strategies, determine the way in which a problem is solved.

According to this conception, to learn means "to become able to"; it's to have a skill and to develop same. Under the new approach, to learn "will be a process of building meanings, that is the acquisition or modification of concepts and relationships between them" (Novak, 1987); the misconception will not be an error but an approach to knowledge, an evidence of the particular way in which the individual knows the world that surrounds him through his senses and of the peculiar fashion in which he gets involved with the object of knowledge to take it from the external world (where he perceives it) to his internal self (where he thinks of it). This is a general process made by the subject; while being a process, the misconception must not be seen as a mistake but as the possible consciousness of the person learning (Braghiroli & Manganiello, 1987).

To emphasize this new concept of the student as an active thinker building personal meanings, some researchers have chosen, instead of the word "misconception", the "alternative framework" term (Driver & Easley, 1978). They thus point out that the students' cognitive growth implies a qualitative change in their respective conceptual frameworks.

As a consequence of this approach, the new didactic proposals within this constructivist method will tend, in a generic fashion, towards the conceptual change, organizing all activities (curricula ones as well as teaching ones) so as to help the student in the building of his own meanings for the material under study.

I.2. SECOND PART: the conceptual change

A new word enlightens the ER horizon: CONCEPTUAL CHANGE. But, through what means must we implement the change?; and before that: which is the change we must seek?

At this stage in the building of my own meanings I felt that, although having a more accurate language to express what was happening with my pupils, I still hadn't an operative answer to solve the problem of improving their learning process through an adequate design of the instruction; neither was I able to guide those students who had failed to the demands of the formal instruction (with the consequent loss of self-esteem).

I had the feeling that the research had been stopped by a wall. And while some of my colleagues "run ahead" with the fashionable conceptual change, others "run aside", widening the area of study of misconceptions. This study had fundamentally began in the domains of the Newton Mechanics to later move towards Optical Sciences, Thermodynamics and Matter Composition.

But where was the theory on how misconceptions are formed and, from there on, the possible interpretation of how we learn and its necessary consequence, how to teach?

I was calmed down by Kuhn's (1962) words (and I could then appreciate the enormous effort done by so many researchers): "I think that there are only three normal focuses for factual scientific research ... We first find the kind of events that the paradigm has shown as particularly revealing the nature of things. When using them to solve problems, the paradigm has made it worthwhile to determine them more accurately and in a wider range of situations". Misconceptions could be "that kind of events" and perhaps the answer to my worries would appear further on.

There are three perspectives from where to study the Conceptual Change or, at least, three approaches which, although do not diverge, choose starting points essentially different, representing each one partial views.

1. THE PHILOSOPHICAL PERSPECTIVE: Revolution or Evolution?

Different positions sustained by various philosophers within the Constructivist Theory of Knowledge give place to different orientations in relation with the teaching of sciences according to the bias followed.

Working with a quite enlightening paper by Nussbaum (1989) (I will use many of his words in my summary), I could establish that the proposals may be divided as follows:

* According to Popper, they emphasize the logic of experimenting; the student is induced to reject or accept theories or hypotheses under study, favoring the use of deductive logic to solve the cognitive conflict (this is the third relevant term in the ER scenery; it mediates between misconceptions and conceptual change).
* Following Lakatos, Toulmin and Kuhn, it's pointed out that "the idea of rationality is more directly involved with function and adaptation subjects than with formal considerations" : "the students can gradually 'move' towards a theory without requiring them to reach clear-cut conclusions" (Toulmin, 1972).

From this perspective we must decide, within the Constructivist Theory, whether to choose Kuhn's line (conceptual change as a revolutionary change producing structural changes) or Toulmin's line ("global conceptions never change as a whole but through changes in the individual concepts composing them"). This last approach understands that students evolve maintaining elements from their old conceptions while integrating elements from their new ones. Thus, their knowledge evolution would always come after the exhibition of the new elements offered by the didactic sequence, relevant tool for the teaching process.

Notwithstanding, beyond theoretical approaches that might define a framework to analyze a teaching methodology, there exists a wide range of experiments done in the classroom, which may or may not be oriented by a previous theoretical framework or by the hypothesis on how one learns.

2. THE EXPERIMENTAL PERSPECTIVE: Contents or Methods?

From this huge mass of information we may arrive to the following conclusions, as reported by Driver (1989):

1) The evolution of children's ideas within specific domains tends to follow certain conceptual paths, beyond level and culture differences. We must know those patterns.
2) Misconceptions function as "critical barriers" for further learning, which has implications for the instructive sequence.
3) We have recently noticed the need to look for conceptual change in order to promote more generical <u>metacognitive strategies</u> (and this was real news for me!).

4) In spite of how productive the already developed research lines might be, there will be no progress if teachers do not adopt these results in teaching and learning, linking the pedagogical practice with researchs' results.

It seems that in this point teachers and researchers agree: ER results must be "put down" in the classroom. Notwithstanding, this hasn't as yet arrived.

This synthesis is quite recent (1989) and it doesn't seem to have produce any outstanding progress in terms of new statements which may allow to go further in the misconception field and its punctual implications. As was to be expected, punctual experiments are obtained from partial information. We are still far from finding a theory that might explain the phenomenon from where a genuine didactic proposal could emerge.

As a result of the research on misconception's experiments, which we should called "experimental perspective", we may find several teaching proposals: while some authors maintain that historical aspects must be incorporated to improve the understanding of concepts, others insist on teaching the scientifical method; some prefer to favor the experimental aspects, while others choose the problems solving methodology and those more updated the use of computers. They all share something: they seem to forget misconceptions and the students having them. All proposals are oriented towards contents (or methods) and the different ways of putting them into the student. These proposals, which seem to raise from research, appear as the counterpart "to correct the defect". Those who believe that misconceptions reveal conceptual deficiencies will focus their proposals in contents; those who understand that they are methodological deficiencies will focus their efforts towards methods. Without doubt all these proposals are valuable, but they should be put as hypotheses and be validated with truly active students within some learning theory framework.

In this respect, J. Nussbaum (1989) states: "My educational experience suggests that if a problem regarding a natural phenomenon is raised in a stimulating manner, and if it's then followed by a discussion of students' beliefs and by an open debate, then even young children or those considered educationally disadvantaged would demonstrate genuine intellectual enthusiasm and good reasoning. Under peer pressure, the student's attempts to adapt the formulation of their beliefs could lay the basis for conceptual change".

That is, nothing conclusive nor excluding emerges from this perspective. Nevertheless, taking into account point 3), we may find several works related to children's visions about science.

Carey and his collaborators have implemented a program to develop students' understanding of the nature of knowledge. From the results obtained it might be suggested that “the promotion of the conceptual change implies the use of metacognitive strategies".

In this respect White and Gunstone (1989) state that "for effective learning to occur, including the learning process which implies conceptual change, students must be encouraged to <u>think about their own understanding and to take greater responsibility on their learning</u>".

Point 4) makes thus sense from studies effected in the classroom: they suggest that teachers will have to review their own roles and to invent a new repertoire of learning strategies.

This landscape, although seemingly promising, is not mostly developed. But we will meet again with the argument from a psychological perspective. At least, theory and practice seem to converge.

As a general comment, I wish to point out that most of the proposals raising from this approach of "classroom practice" alternates sequenced alternatives which go from the emphasis on contents to the emphasis on processes, considered as "a sequence of rules applied by the scientist in an hierarchic way to achieve his goals, event been repeated all through the last hundred years" (Millar & Driver, 1987). This is a debate not yet solved; in any case, Millar and Driver focus the attention on the need to carefully analyze and think about this point. They assume that this perspective, when referred to processes, reflects "an inadequate analysis on the nature of the scientific enterprise as well as an inappropriate vision of what learning means". Above all, she sustains that "there is not an empirical evidence to maintain the point of view of the existence of a scientific method clearly describable and consisting of an identifiable set of processes". She argues that the list usually presented as the method of science "only means aspects of our general cognitive performance, which we employ since our childhood and which science cannot claim for itself". And, what seems to be even more significant: "in no way this presumed scientific method reflects the way in which we learn, storage and remember information".

From the point of view of the possibility to teach such processes of science, they sustain that "the student's approach to the understanding of new situations, specially that of the novices, seems to depend much more on analogical reasonings with respect to other known situations which are being kept by them as similars than on the application of general processing rules". This argument is used by Di Sessa (1983) when he suggests that the analogical thinking plays an important role in the student's understanding in relation with simple physical phenomena.

During the same years, and from the opposed position, Gil Pérez (1983) thinks that there is a "certain parallelism between the productive process of scientific knowledge and the meaningful learning of said knowledge". He affirms that students "will make it possible the profound conceptual changes which, sometimes, the acquisition of scientifical knowledge demands, if they are repeatedly oblige to emit hypotheses taking into account their previous knowledge, to design experiments and implement them, to carefully analyze its results, etc."

From the point of view of assessing the progress achieved through a teaching method based on processes, the perspective is even more discouraging. According to Driver: "the idea of teaching a process surely implies the improvement of the student's potential for the process strategies. But we have no idea about what progress is in relation with the acquisition of the capacity to implement processes; therefore, we have no idea about how to teach said processes".

Nevertheless, we all know that there exists a certain way of doing certain things: how we work with science, philosophy, learning or teaching processes. Evidently, if it exists something similar to a processes learning, we are lacking an adequate tool to teach them and to evaluate them.

It is obvious that new practices demand new tools (fact not yet quite assumed), but if we don't clearly understand what may be considered as a process, perhaps the tool already exists and we simply do not see it.

Millar and Driver, in the same article, propose "not the traditional teaching (transmission of knowledge and passive reception) but a third option: "active learning" as opposed to the approach on processes. They start from pointing that "science is characterized by its purposes and not by its methods", to add afterwards: "the idea should be the development of a deeper understanding of science concepts and purposes".

Summarizing, all these authors point out that there are different general perspectives around teaching and learning:

1) The didactic approach: it consists on classes, exhibitions, lab exercises, which focus on the science content and present it as absolute and untroubled. The student is a passive recipient of the knowledge he's being transmitted.

2) The processes approach: contrasting with the first one, this method puts much emphasis on science as a body of knowledge, focusing rather on its dynamic aspects. Even though this perspective understands that the learning process is an active one, it doesn't take into account the individual's previous knowledge. This approach also presents knowledge as absolute and untroubled.

3) Learning through disclosure: this method, being used in the United Kingdom for the last 20 years, is seen as an extension of the latter. Notwithstanding, pupils find in it different things from the ones expected and there are written testimonies of its failure.

4) Finally, we have a different alternative, which better reflects the current understanding of learning processes and of science as men's activity: we are talking of the approach which

visualize knowledge as personal and socially constructed rather than as objective and revealed; at the same time, it considers theories as provisional and not absolute.

We may add that the student, in general, is seen as an intelligent, adaptable and problem-solving being, and these concepts define the basis to select learning experiences.

A pedagogy that helps students develop useful tools provides some understanding about the epistemological basis supporting certain knowledge and gives room to empirical work in the laboratory; but it also incorporates general considerations such as the history of scientific ideas and the interactions between sciences and social aspects.

Gilbert, Osborne and Fensham (1982), adopting a similar position, propose that "the purpose of teaching and learning science may be seen as the development of children's science ... We should make them conscious of the existence of another point of view, that of scientists, which is useful for them and may have a more general use ... We must achieve the goal of making these two visions explicit. This approach will help the development process in as much as the scientific perspective appears as a way of seeing the world at least in the logic, coherent, useful and versatile way students' do".

Although the last proposal, sustained by Millar and Driver (the four mentioned points are almost textual) agrees with what we have exposed at the beginning of this paper (the student actively builds meanings), in fact we still cannot find a concrete offer to instrument said proposal in the classroom daily work.

At this point of the ER development, it seems to be in force that "the researchers make reconnaissance raids behind enemy lines, and then issue bulletins to the troops about what the foe is up to"; and also "what is needed, in order to move education on, is not more additions to the mountain of examples of children's alternative frameworks, but a slightly less simplistic psychology of learning" (Claxton, 1986).

We can find many contributions to this experimental perspective through the years. They refer to "conceptual change" and may be classified, according to Niedderer, Goldberg and Duit (1991) as follows:

* going from one concept to another, either by exchange, or by reestructuring, or arriving at a peaceful co-existence: having students change their existing conceptions in terms of status, probability of usage, generalizability and consistency of use; and

* going from simple lower levels of thinking to more complex and interrelated higher levels of thinking; going through a process development in cognitive systems by constructing new meanings with higher complexity and growing stability.

According to the same authors, from this perspective we can obtain proposals related to instructional strategies; they include:

1) Starting with elicitation of student's ideas.

2) Using different forms and ways of introducing the scientific view.
3) Introducing conflict and confrontation between different views and different expectations.
4) Explicitly discussing intermediate concepts which lie in between naive and expert conceptions.
5) Following a "bridging strategy", using positive intuitions as a starting point, and using analogies to promote understanding of science concepts in more difficult cases.
6) Discussing explicitly the "status" of new physics concepts and related epistemological beliefs. And
7) Using several different representations of knowledge (hands-on experiments, interactive video, computer microworlds and models), especially in ways that help students to see connections between them.

No doubt, these are very valuable proposals to plan a physics class. But I have the feeling that something is still missing, and Glasersfeld's words (1991) support this idea: "In order to teach, one must construct models of those "others" who happen to be the students. Only by operating on the basis of a more or less adequate model of the student's conceptual structures can one present the required "knowledge" in ways that are accesible to the students".

We are lacking "models" on how human beings learn and it doesn't seem to have emerged as yet any search related to learning results. On behalf of constructivism, the researchers' "new glance" seems to have focused on objects; but the angle seems to be the same. A semi-transparent mirror seems to be still standing between researchers and learning subjects, whom are "observed" from behind it.

Does Novak intend to say the same thing in is book "Learning how to learn", when he expresses: "in most fields research is limited by the available measuring instruments. We believe that the serious limitations of the measuring instruments (basically objective tests with pencil and paper) represent one of the reasons for the relatively low progress of the ER during the last eighty years"?

Is it the same claim when Dykstra (1991) sustains: "action research is a good model here. We need to involve a number of people collaboratively trying to make sense of phenomena ... We, as researchers, need to be embedded in the settings so as to get an intimate look at the process as it occurs, as well as recording it. What better way than to attempt to teach for conceptual change?"?

It is possible that, by means of experimental research, this will be the next step. However, we still have one more perspective to evaluate:

3. THE PSYCHOLOGICAL PERSPECTIVE: New Instruments

Following Novak (1988), this perspective arises from the contributions of a renewed psychology: the cognitive psychology. Said perspective leaves behind 65 years of connectionist psychology and favors the rol of concepts and conceptual frameworks in the building of the meanings being effected by men; also, from a new epistemology that ceases believing science searchs the truth to conclude that the reason of its being is the building of explaining models which incorporate, each time, a bigger number of phenomena. As a whole, these transformations lead us towards "a new learning science with great transcendency for the learning of science".

As it comes from a theoretical frame, which provides a certain glance on the "thing", this approach seems to be the most productive one in terms of making a serious advance on learning proposals starting from one hypothesis (although provisory) about <u>how knowledge already built is incorporated</u>.

Under this perspective we may highlight David Ausubel's (1968) contribution, who summarizes this vision most clearly, implementing a <u>Significative Model of Learning</u> based on:

* Activities of significative learning
* Possession of a previous relevant knowledge
* Significative learning tools.

In spite of the different approaches whithin the same cognitive psychology, according to Novak it seems to exists consensus on the eight learning principles which are significant for the teaching of sciences:

1) Concepts are acquired early in life (regularities are noticed very soon).
2) Misconceptions are early acquired and are resistive to change.
3) The previous knowledge has influence on the rest of the learning process.
4) The capacity of processing information is limited (approximately seven information chunks at the same time).
5) Most part of knowledge is storaged in a hierarchic way.
6) Students are rarely conscious of their own cognitive processes.
7) The students' epistemological bond influences learning (those who feel the authors of their destinies have a greater adhesion to the constructivist theory).
8) Thinking, feeling and acting are integrated actions.

These principles, resulting from experience, arise as a consequence of a new attitude adopted by Educational Sciences which characterizes only the last years: the research promoted by theory, contrasting with the one promoted by method, which predominated for the last 50 years and which, in great manner, guided the above mentioned researchs (the experimental perspective).

Achievements are promising but, up to now, the gap between theory, research and practice subsists. In fact, for a theory to become practice, in the field of research as well as in the field of teaching, it's necessary to have the required tools (any tool materializes a theory).

In the case of the learning model we have described Novak, interpreting the premisses of Ausubel's Theory and favoring the idea of building meanings, develops an instrument which allows us to be in contact not with the individual's operational possibilities but with its conceptual background, that is, with the set of meanings he manages and the relationships between them. We are talking about the concept maps. He defines them as follows: "The conceptual maps are diagrams based on concepts (notions, ideas) and ordered according a meanings hierarchy; they are intertwined with the relationship of those meanings, which are made explicit through lines linking them ... They represent a direct expression of the elaboration that incorporated information has suffered up to the moment of the diagram composition, a snapshot of the organizational level where the conceptual background of the subject is. They are snapshots of the knowledge possessed and, consequently, they may vary with time. They make evident learning distortions (understood as the set of meanings the student has) and the projections they imply for progress. Their change, registered through time by the reformulation of diagrams, allow a reading of conceptual change".

"Concept maps might be seen as a strategy for externalizing one's conceptual and propositional understanding of a piece of knowledge. Of course, if this is true, when drawing a concept map the learner is likely to externalize his/her misconceptions and misunderstandings as well" (Moreira, 1987).

According to this perspective, to learn is not only to acquire knowledge but to learn meta-knowledge, that is, to learn how each individual builds his own knowledge. Taking this approach into account, Gowin develops an heuristic technique known as the "Gowin's Vee"; its purpose is "to help students understand the structure of knowledge and the way human beings produce said knowledge" ... "as a general rule, student's methodological or proceeding activities are not governed in a conscious way by the same sort of conceptual or theoretical ideas used by scientists in their researchs" (Novak, 1984).

"Vee diagrams represent the structure of knowledge and the epistemological elements that are involved in new knowledge construction. The Vee heuristic represents a constructivistic view of knowledge and illustrates the dozen or so epistemological elements that interact in the process of new knowledge construction. The Vee heuristic can also be used to dissect an existing domain of knowledge and to see its structural elements" (Novak, 1990). This view must not be mistaken with the scientifical method "receipt"; we are here talking of an instrument which hierarchically organizes the elements structuring knowledge.

Concept maps and Vee diagrams, used as learning instruments, allow the learner to be in touch with his own knowledge and the way of producing same; therefore, they become the first instruments of meta-cognition. If they are used as learning instruments developed by the teacher, they make it possible to explicit the teacher's meta-knowledge, to go from the level of knowledge transmission, structured according to discipline codes, to the exchange of meanings; thus the learner, being in touch with already incorporated meanings, might modify them through strategies which should be conveniently defined.

This perspective, indeed promising and attractive, doesn't solve the problem entirely: there still exists enormous room to be filled, as it says nothing about learning strategies to be develop in order to implement meta-cognition. Nevertheless, it represents without doubt a significant qualitative progress from the moment it discusses the need, and the possibility, to change the communication field between teacher and learner.

If this is so we might certainly say that "we are facing a new synthesis in education" (Novak, 1988) which is sending us, although in a fragmentary manner, signals from the experimental perspective. Again, if this is so the results on experimental research should be framed, sooner or later, within theory, which in turn should predict them. We could then guide our educational researchs towards the "second normal focus for factual researchs: a second habitual kind of factual determinations, although of less importance, are directed towards facts which, although not having often much intrinsic interest, may directly be compared with predictions about the paradigm theory" (Kuhn, 1962).

If this is really so it will be worthwhile to focus all our efforts in the task of filling, with creativity, the gap this new approach has made evident.

I.3. THIRD PART: my beliefs

All the above mentioned is in no way a data-based synthesis of all the researchs effected during the last 20 years of ER studies in the field of sciences. The publications to be processed are so abundant, the selection of papers reaching us is so partial and hazardous and my meetings with the persons who have crucially influenced my learning route are so casual that I feel unable to undertake such a task.

Instead, I had tried to show part of my own learning, which is also partial, fragmentary, full of personal accents and, above all, charged with emotions. They are neither good nor bad; they simply are my meanings, in the organizational state in which they are and which, explicitly or not, have determined my perceptions; consciously or not, they will inevitably determine my future elections.

I had only tried to present my point of view, with quick strokes of colour, stressing here and there (a little at random and a little by mere instinct) the quotations which might support my approach. Otherwise, I would be in debt with many well-known authors whom I haven't quoted and with many others whose words I have made mine.

Finally, I had wanted to support my belief on the fact that, for the last ten years, the terms "misconception" and "conceptual change" have dominated the scene of ER and concentrated the effort of many investigators, generating the belief that these terms designate particular phenomena of the process of learning which must be studied to establish better teaching strategies. These strategies, in turn, will "remedy the defect" and "promote the necessary change". In the light of Ausubel's Theory of Learning, "misconception" and "conceptual change" appear as normal steps in the process of learning, which is taken to be a continuum that goes from one state of conceptual organization to another state of greater hierarchy. This process can be reinforced by improving the strategies of acquisiton and processing of information on the part of the learner by means of instruments of meta-cognitive nature derived from theory. It will be thus evident that, in the building of knowledge, it is impossible to divide the concepts from the methodology.

Above all, I had wanted to set up the theoretical framework which guided my proposal:

II. A CASE STUDY: Showing a Theory in Action

My pupils don't learn Physics in the way I now conceive what an useful learning is. In this connection I share Novak's (1992) vision: "We see a bright future for improving achievement of all learners through the design of better instructional material and better facilitation of learning, using not only assimilation theory and new epistemological ideas, but also learning heuristic that can help students learn how to learn". I feel touched by his claim: "We urge researchers to explore further studies that include learning heuristics to facilitate meaning making". I see, just like him, "a need for more studies on the nature of affect and values in selecting research questions and guiding inquiry".

Change is produced as from the raising of new ideas; but, no doubt, appropriate instruments are required to make said change possible, as well as a great amount of love to make it a reality.

I have decided to tackle the issue due, among others, to the following ideas:

* Teachers don't produce learning; students do it (Gowin, 1981).

* Learning is also a loving experience: it's the Pain and anguish of confusion and the joy and emotion experimented when recognizing that new meanings have been acquired (Novak, 1991).

* A new conception of learning requires new approaches for its research. If we consider knowledge as socially built, it will be necessary to adopt a qualitative perspective to understand the way in which it's built (Firestone, 1987).

* A research in itself, in any area (quantitative or qualitative ones), cannot put aside the conceptual domain (Moreira, 1988).

* To understand the essence of a phenomenon it's necessary to be involved with it, modifying it and modifying oneself. "The qualitative researcher is immersed in the phenomenon he is interested in" (Firestone, 1987).

* In qualitative research the words "validity" and "reliability" are replaced by "credibility" (Eisner, 1981).

* The instruments used are not independent from the ones we intend to measure. They are the researchers' extension and they operate as an element in their attempt to build or shape reality (Smith, 1983).

Consequently, I have chosen Ausubel's Theory as the theoretical framework for my research, as it's the theory which best understands the phenomena I've been studying throughout many years in the classrooms: the acquisition, by my pupils, of a formal knowledge already strctured.

I've chosen the qualitative research approach because, through it, I can analyze the characteristics of the phenomenon, to be able to understand them afterwards. I've chosen a case study because same allows me to follow the evolution of the learning process, with its distortions and the effects of different interactions.

I've chosen concept maps as a learning and assessing instrument because they allow to put theory in action. As actual radiographies, they allow me to capture different moments of said process, as some sort of "stroboscopic pictures" of the knowledge's trajectory.

I've chosen to use the Gowin's Vee (see last page of Appendix) as a planning instrument for my research to help the interaction between my feeling, my thinking and my doing, evaluating at the same time its coherence.

II.1. THE CASE STUDY

My pupil Gastón had 20 years old and was on his first year in the Engineering Career. Besides attending my classes of Physics I, he was also attending Chemistry and Linear Algebra. Up to that moment he had always gotten good grades and he had no difficulties to learn. He had chosen said career freely and with much interest. He liked Physics and this was his third Mechanics semester.

1. DIAGNOSIS. Classes started with a diagnosis test (open and closed, paper and pencil test) on chapters about Kinematics, Dynamics and Conservation Laws for Free Particles (Newtonian Mechanics), in order to detect misconceptions and to assess problem-solving skills.

2. RESULTS. Gastón showed no intuitive misconceptions (known as Aristotelian) in the closed portion of the test (true or false and multiple choice questions). However, he handed an interesting solution for the following problem (open portion of the test): "Calculate the minimum velocity a particle of mass m needs to go from the lower point (A) in a frictionless circular rail, vertically placed, to its upper point (B), without falling before reaching (B).

When checking his solution (see Figure 1 of Appendix) I found the problem wrongly solved, with significant mistakes:

* he supposed that the particle reaches point (B) with $V_B = 0$ as a minimum value;
* he tried to solve the problem applying the mean velocity definition, which he afterwards annuled (he realized it was useless);
* he solved the problem with a translational kinematic approach, ignoring that the particle moves in a circular path.

From a traditional point of view we could say this student hasn't learned a thing; from a more updated approach, we could consider him as having a misconcept (V_B=0), which he might have acquired during his former instruction; we would recommend him to change his resolution strategy and to study theory with more exercises as well.

In more sophisticated terms, we would think his methodological problem isn't at an operative level but at a level of hypothesis formulation. Indeed, he supposes V_B=0 without any support, and also the equivalence between rectilinear and circular movements. We would recommend him to get more training in the formulation of hypotheses.

But, what does Gastón actually "know"? Why his way of solving the problem? What is he translating when producing the solution for the problem? Is he conscious of his elections? And, from there on, what can we offer him to improve his learning?

Education is not a science; it's a problem to be solved with the help of science. If misconceptions are learning problems and conceptual change is the result of learning, they must be solved and assessed through a learning theory which considers them as being included in the model. Why not search the answers in them?

"If you want to go ahead, get a theory" (Inhelder, 1975). How can we consider my case study taking into account Ausubel's Theory?

In a recent article by Novak (1992), we can read in connection with Ausubel's Theory applied to instruction:

* "Working initially with an information processing model of teaching, we assumed that problem solving was function of two independent traits, knowledge stored in the mind and information processing capability. What we found suggested in Ausubel's Theory was that this two processes are counfounded in the process of new learning which is a function of both the quantity and the quality of cognitive structure organization".

* "Limitations in conceptual understanding and problem solving were primarily determined by the adequacy of relevant frameworks, and not by general cognitive operational stages as proposed by Piaget" (Novak, 1977).

* "... the question is frequently asked about what happens when learners have no relevant concepts or propositions ..."

* "... rote learning could be more efficient in early stages ... students can avoid the difficulties associated with misconceptions if they are in a rote learning mode".

* "Ausubel defines rote learning as arbitrary, verbatim, non substantive incorporation of new ideas into cognitive structure. Information does enter cognitive structure, but with no specific relevance to existing concept/propositional frameworks. Partly for this reason, rote learning may involve interference with previous similar learning and exhibit some of the difficulties in patterns of recall, including misassociations".

* "The working memory is severely limited in terms of the number of 'chunks' that any individual can process at a given time" (Miller, 1956).

Considering above mentioned statements and the basis of the Theory (cf. Ausubel, D., "Educational Phsychology: a Cognitive View", 1968), we may infer the following:

3. HYPOTHESIS. Gastón's apparent inability to solve the problem is the consequence of an inappropriate conceptual structure (LIPHS), not functional, which is replaced in its operative function by the use of analogy in relation with situations previously learned. From this perspective there exists another interpretation for his answer:

4. CORROBORATION. "Concept maps can be seen as hierarchical diagrams that attempt to reflect the conceptual organization of a piece of knowledge. Concept mapping is a flexible technique that can be used in variety of situations for different purposes ... concept mapping is basically a non traditional qualitative technique of evaluation" (Moreira, 1987).

The learner is asked to prepare a concept map of concepts operationally defined and related to the Mechanics chapters considered in the test. The diagram handed (see Figure 2 in Appendix) shows that: the list of concepts is not complete, the organization is lacking hierarchy, the time variable seems to represent another dimension and there is only one organized sub-structure corresponding to translational kinematics.

An analysis of the correct resolution shows that kinematics and dynamics concepts are required with reference to circular movement and the laws of energy conservation. The map only shows concepts about kinematics and translation dynamics, lacking the energy concept. Consequently, it's completely coherent Gastón's attempt to solve the problem taking it as a vertical launching, for which he does dispose of a conceptual structure; he only "sees" from the problem what he "can". It seems the problem is "read" from the meanings structure of the learner. Although it's true that the method used isn't the correct one, we cannot talk of a methodological deficiency; according to his own words, the deficiency is conceptual: "I was having difficulty to include the last issues on quantity of movement and energy; I could not find the correct hierarchy for the latter".

In this case study it seems that we don't need to improve the capacity to build knowledge (the solution of a problem) but to enhance the information used to build said knowledge.

II.2. THE TEACHING STRATEGY

Gastón attends a semester of conventional instruction (9 hours/week) with theorical classes, problem solving sessions and lab experiments. He is evaluated twice a year and he has the possibility to do each partial tests two times. The basic text for the course is "Physics", Volume I by Halliday and Resnick.

1. RESULT. Gastón didn't approve his tests in any of the two occasions.

2. INTERPRETATION. Gastón maintained the same working pattern as in his diagnosis test: his difficulties are conceptual, not operative, in spite of having received a "good instruction" and having been a "good student" (in the traditional sense). "Rote learning may take place in either a discovery or reception instructional mode, and meaningful learning may also occur or fail to occur under any mode of instruction" (Novak, 1992).

We could conclude that a "good" teaching has not resulted in a "good" learning and that Gastón hasn't done a significant learning (Ausubel's way) but a routine one. Afraid of not approving his test, he asked for help. Testimony: "I'm having difficulties and I don't know why … what can I do? ... At the beginning of the year we saw that maps issue ... I didn't understand very well what was all about, but I thought there was something important there ... I don't know ... it seemed something serious ... Can you help me?"

3. DIAGNOSIS. "Concept maps provided for an explicit way to illustrate changes in cognitive structure that could be described with these principles" (Novak, Musonda, 1991).

Gastón was asked to prepare a new concept map showing the changes in the cognitive structure throughout the course in order to find out elements to interpret his difficulty and find a solution. "The fundamental process involved in meaningful learning is the incorporation of new concepts and propositions into hierarchically arranged frameworks in cognitive structure".

This second concept map (see Figure 4 in Appendix) showed very little improvement. Gastón had only incorporated some new concepts, of greater hierarchy (energy, work, impulse), but the "momentum" was not modified. He didn't mention rotational concepts. He seemed to be still having a great difficulty to articulate his conceptual structure. According to his testimony: "Trying to include the before mentioned issues, I tried to change the map structure, dividing it in three columns or sub-maps, but still I didn't understand either the energetic concepts in all their significance or the transcendency of Newton's Second Law". In effect, Gastón had made previous attempts before elaborating the second concept map, trying to order his ideas but using a rather operative criterion (see Figure 3).

"The principle of integrative reconciliation applies when instruction is organized so that concepts and propositions previously unrelated are brought together in a sequence that integrates their meanings and leads to a sharpening of the distinctions and similarities between previously learned concepts and propositions ... Integrative reconciliation of concepts and propositions in cognitive structure is required for elimination of misconceptions (or "alternative conceptions")".

"Ausubel proposed that instruction should be organized in such a way that more general concept/propositional material is introduced in a concise fashion prior to more specific less inclusive propositional material".

Gastón showed good understanding of individual concepts, but we could conclude that he failed in the integrative reconciliation, perhaps due to the way in which he received the instructional material in terms of sequence. That is, the first condition for significant learning to happen has failed: that information be potentially significant. Gastón's new concept map was qualitatively equal to the first one, except for the incorporation of a few new concepts. We there see an instruction which doesn't modify the student, who is still a passive receptor. We may then conclude the following

HYPOTHESIS: The level of the conceptual structure's hierarchic organization maintains a direct relation with the problem solving capacity, being impossible to separate concepts from methodology.

According to Ausubel's Theory it seems evident that Gastón needs to improve his strategies for data acquisition and processing in order to improve the organization of his cognitive structure and to incorporate in a significative way all the information he has been piling up in his memory. To do so he's been offered the following

II.3. PROPOSAL

"The concept maps and V heuristic permit an individual to 'hold in place' conceptual elements that are needed for new meaning making ... We see epistemological issues as inextrincably tied to the facilitation of meaningful learning".

Consequently, I asked Gastón to resignify his experience, working on his own knowledge at a meta-cognitive level and using concept maps as learning tools, in order to reorganize and finish his conceptual structure in the domain of classis mechanics. The work is presented to him as follows:

* A diagnosis is effected to him on his acquired learning level, considering the evidencies he has offered and the difficulties he seems to have.
* He is informed about the theoretical framework from where his case will be analyzed, in order to obtain his consensus and his commitment in a significant learning process.
* A period of 15 days (the only available time) of work is decided. Six meetings took place and it was decided to:

- Consider Physics as a discipline characterized by his contents as well as by its particular way of building knowledge.

- Propose the "model" concept as organizer: Physics is seen through the models it builds and through the kind of phenomena it produces.

- Describe the mechanic model properties and its reach as explaining instrument; its objective and production. Gastón received specially prepared material (information potentially meaningful).

- Work with examples and counter-examples from the intuitive (misconceptions) and formal (using the model) point of view.

- Require concept maps during the progress of the work. From them on, and through the provision of new information, the conceptual hierarchies are worked on.

- Not working on any problem solving strategy in order to specially influence one variable: the acquisiton of meanings at conceptual level. The problem solving strategy was considered as another instrument to improve the concepts meaning (instrumental use of the problem). Only some problems were solved in an occasional way.

1. REGISTERS. After two sessions Gastón constructed his third concept map (Figure 5), with the following testimony: "To incorporate the rotational part of the particle ... This map was like a landmark separating the previous stage (formal instruction) from the second one (remedy treatment), where not only rotation appears but the concepts take an almost definitive hierarchy. This map "opened my mind" and I understood many concepts which I had only used to solve problems in a mechanic way. I think this stage was like a 'hinge' in my learning process. The map was quickly incorporating to me concepts

which were already in my head but which I couldn't use because they were lying hided in my "information bag". At this point I felt as if a comb would have disentangled the "concepts puzzle" I had on my head. I felt "more free", I had greater mobility, relationship capacity and also I felt like having more criterion to face a completely new problem".

From my vision, what Gastón was able to express in this map was the equivalence, the symmetry between the translational movement and the rotational one. He discovered the meaning of the analogy between concepts, in terms of their functionality, thanks to a simple hint which suddenly connected him with what he knew but he could not associate with the rest: I made him notice that the uniform circular movement had a regularity "similar" to that of the uniform rectilinear movement, but that if we were to describe it from the cartesian system, said regularity was lost. Nevertheless, we were able to recover it making a change in the reference system (polar system), taking advantage of the equivalence between arch, angle and ratio ($s = R\theta$), through which we could obtain movement equations of similar shape than the ones corresponding to the rectilinear movement. From there on, concepts referred to the rotation movement mechanics were placed, in his map, in front of each equivalent concept of the translation movement. His surprise was immense when he verified that there was exactly one rotational concept for each translational one and when he realized that he was able to recapture information whenever he couldn't remember something. He had discovered the play rules! ... and, together with them, the clear perception that Physics, as any other knowledge, is the result of a construction and not "the truth lying under the stones waiting for our discovery". As such, it has its rules and if we know them on time the road of their acquisition gets shorter. I think that from there on Physics became for Gastón something possible of being apprehended.

The change shown in this third map came together with a nice change at personal level: Gastón moods were transformed and a new brightness lightened his regard. He showed a more trustful, cheerful and dynamic attitude, which demonstrated he was recovering his self-esteem as results of his possibility to feel, his capacity to think and his necessity to do.

After one week he produced his fourth map (see Figure 6), where he gives a definitive hierarchy to concepts, which are not any more interrelated through formulas but through their meaning links. He also handed a new testimony: "This is the most elaborated map. It includes concepts correctly hierarchized. I was impressed by the simplicity and the potential of the new map. But, above all, by its simplicity, which, as it's well known, gives neatness to thinking".

When the treatment period was over and with his new conceptual structure, Gastón gave his final exam. He was faced with a problem requiring the same knowledge as that of the diagnosis test (kinematics, dynamics and conservation), but this time referred to the rototranslation of a rigid body, through surfaces with and without friction, in a situation never seen before. He demonstrated that he has overcome the resolution by analogy and is thus using his theoretical framework, supporting each decision through his reasoning. He passed his exam with the maximum grade and he handed me his last testimony: "I think it was simply fantastic the power of the map. Perhaps that was just what I was needing, that is, an instrument which could give me the possibility to think on what I'm studying and to order with criterion all acquired concepts. But the most important thing was that, besides learning Physics and Methodology, I've learnt a lot of other things ... I put an end to this experience with the satisfaction of having accomplished a task which I will never repent of ... Many, many thanks!".

2. CONCLUSIONS. If we think of misconceptions as knowledge bodies with a certain explicit power (intuitive theories), we will be tempted to think that they are due to methodological deficiencies referred to the formulation of hypotheses with which we pretend to undertake certain scientifical phenomena. If, from other conception, we understand that having knowledge implies having conceptual structures which determine meanings, we may think misconceptions as the result of incomplete conceptual structures with deficiencies in the hierarchies and links between concepts.

The conceptual change may be understood as a reorganization of the conceptual structure, which would necessarily imply the acquisition of new meanings and, consequently, the availability of new production strategies which would not be independent from them.

The reorganization would be reached through the access to potentially significant data and activities, with the learner's affectionate commitment to become the actor of his own learning; this would be facilitated by the use of meta-cognitives instruments which allow the conscious process of learning.

Gastón has been the actor of this unique and impossible-to-be-repeated Case Study. I could never intend to give general validity to my conclusions, which are just mere readings effected through a theory, from a singular event. But if there are other students with similar characteristics to those of Gastón, it will be quite worthwhile to concentrate our efforts to make the significant learning a possible enterprise.

"Things are not as we see them but as we are" (TALMUD)

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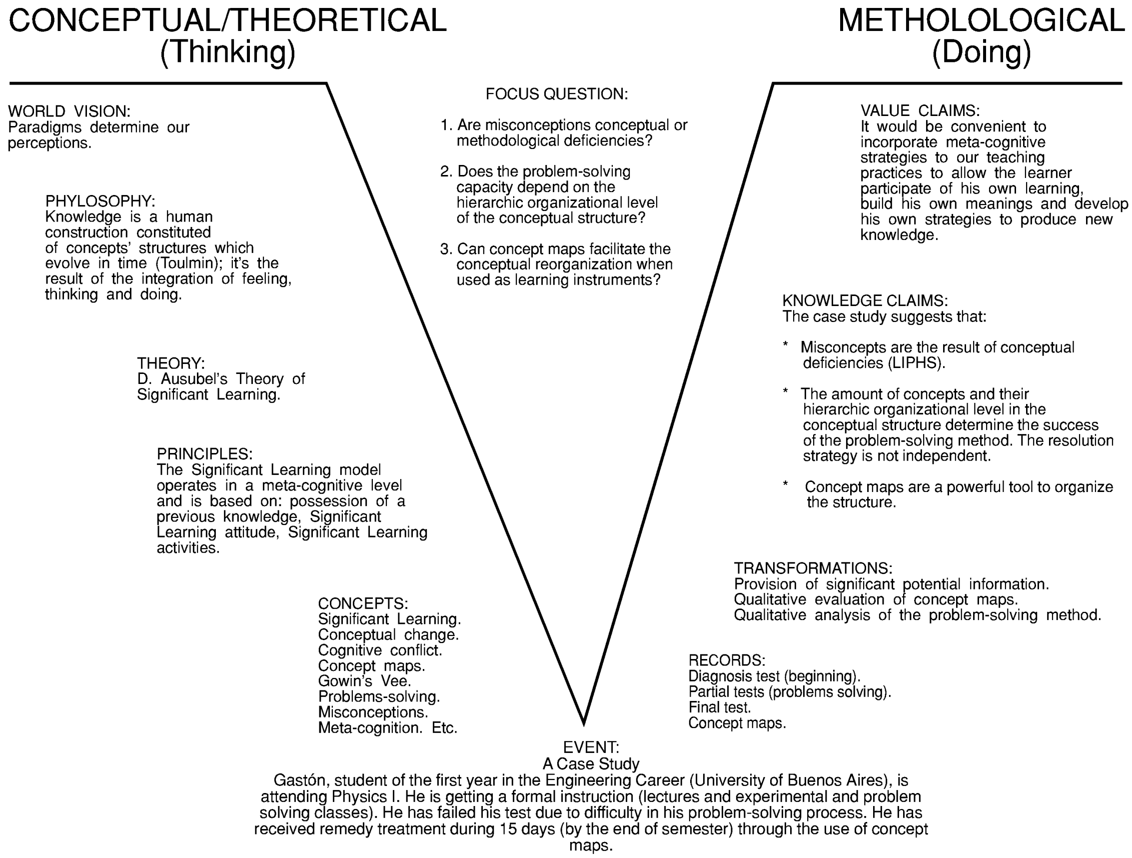
CONCEPTUAL/THEORETICAL
(Thinking)
METHOLOLOGICAL
(Doing)
FOCUS QUESTION:
1. Are misconceptions conceptual or methodological deficiencies?
2. Does the problem-solving capacity depend on the hierarchic organizational level of the conceptual structure?
3. Can concept maps facilitate the conceptual reorganization when used as learning instruments?
WORLD VISION:
Paradigms determine our perceptions.
PHYLOSOPHY:
Knowledge is a human construction constituted of concepts' structures which evolve in time (Toulmin); it's the result of the integration of feeling, thinking and doing.
THEORY:
D. Ausubel's Theory of Significant Learning.
PRINCIPLES:
The Significant Learning model operates in a meta-cognitive level and is based on: possession of a previous knowledge, Significant Learning attitude, Significant Learning activities.
CONCEPTS:
Significant Learning.
Conceptual change.
Cognitive conflict.
Concept maps.
Gowin's Vee.
Problems-solving.
Misconceptions.
Meta-cognition. Etc.
VALUE CLAIMS:
It would be convenient to incorporate meta-cognitive strategies to our teaching practices to allow the learner participate of his own learning, build his own meanings and develop his own strategies to produce new knowledge.
KNOWLEDGE CLAIMS:
The case study suggests that:
* Misconcepts are the result of conceptual deficiencies (LIPHS).
* The amount of concepts and their hierarchic organizational level in the conceptual structure determine the success of the problem-solving method. The resolution strategy is not independent.
* Concept maps are a powerful tool to organize the structure.
TRANSFORMATIONS:
Provision of significant potential information.
Qualitative evaluation of concept maps.
Qualitative analysis of the problem-solving method.
RECORDS:
Diagnosis test (beginning).
Partial tests (problems solving).
Final test.
Concept maps.
EVENT:
A Case Study
Gastón, student of the first year in the Engineering Career (University of Buenos Aires), is attending Physics I. He is getting a formal instruction (lectures and experimental and problem solving classes). He has failed his test due to difficulty in his problem-solving process. He has received remedy treatment during 15 days (by the end of semester) through the use of concept maps.

APRIL 5

$v_B = 0$

$\cancel{\Delta v = \frac{\Delta x}{\Delta t}}$

$\cancel{v_A - v_B = \frac{2\pi r}{2} \cdot \frac{1}{\Delta t}}$

$\underbrace{v_f^2}_{0} - v_o^2 = 2 \cdot a \, \Delta y \rightarrow 2R$

$0 - v_A^2 = 2(-g) \cdot 2R$

$\boxed{v_A = \sqrt{4gR}}$

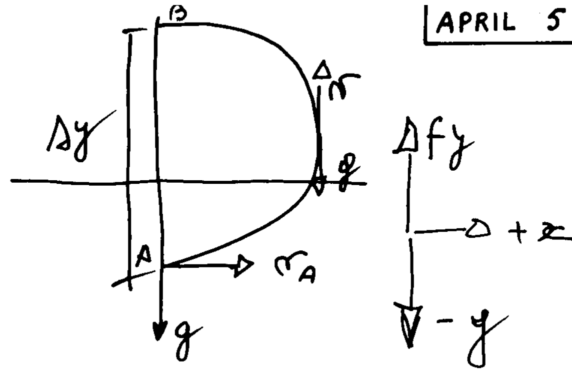

FIG.1

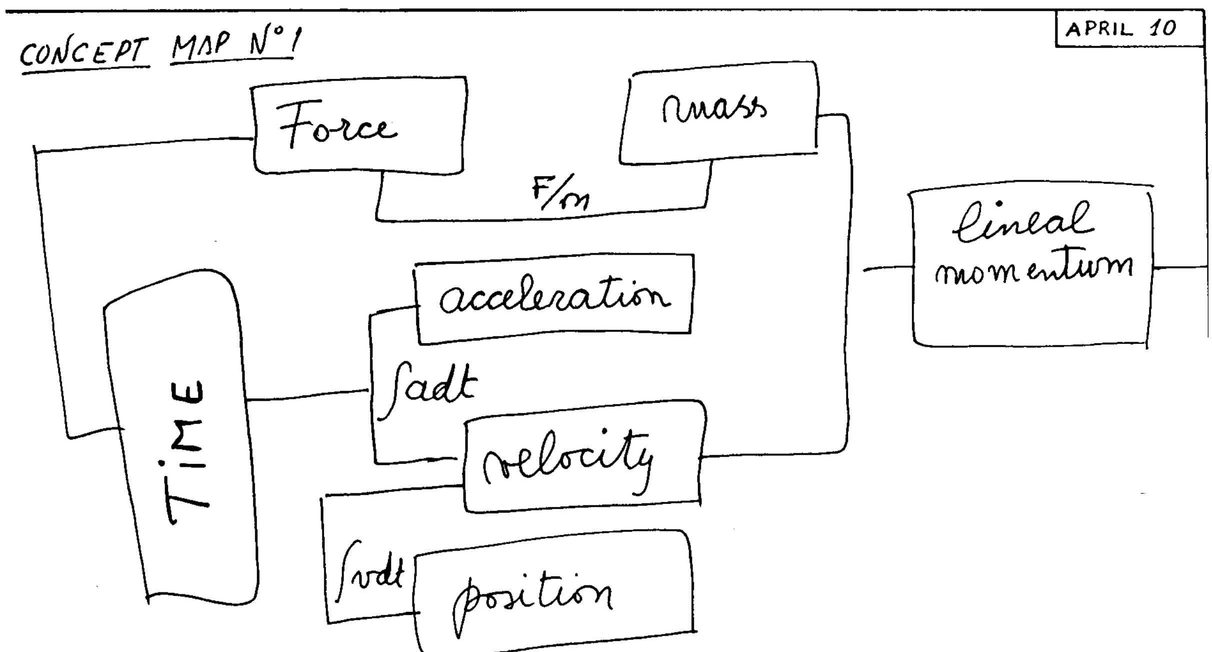

FIG. 2

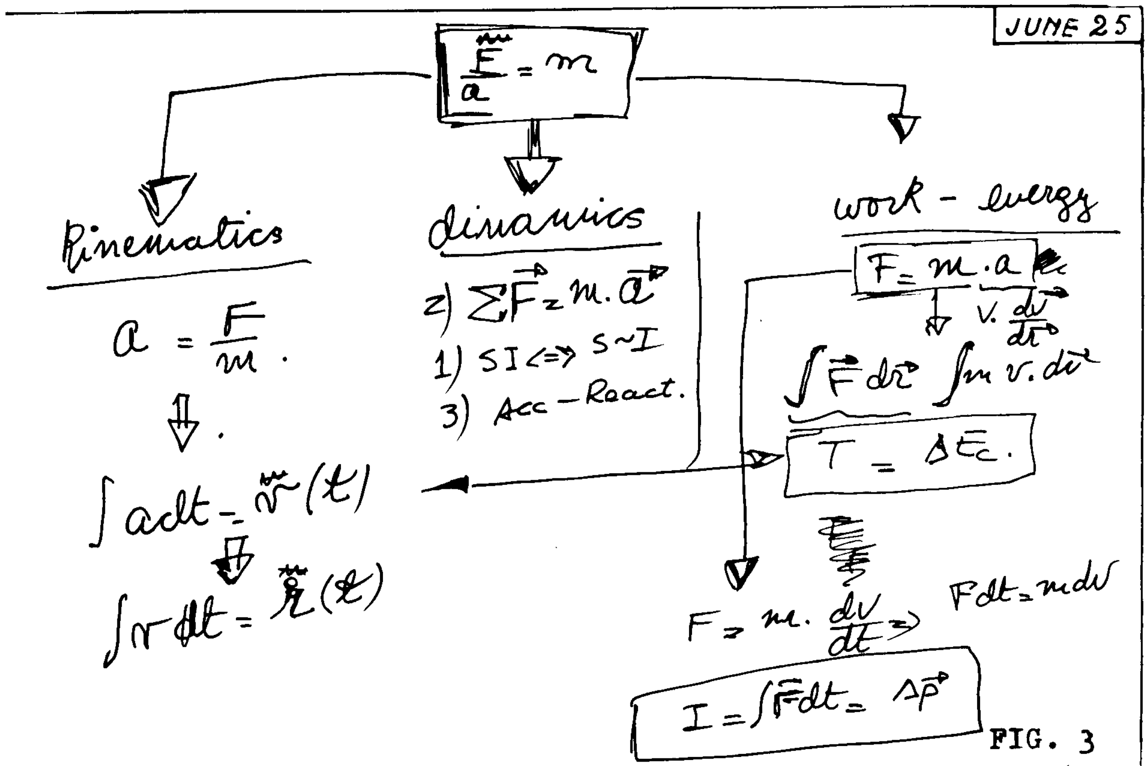
JUNE 25
F/a = m
Kinematics
a = F/m
∫ a dt = v(t)
∫ v dt = r(t)
dinamics
2) ΣF = m.a
1) SI <=> S~I
3) Acc – React.
work - energy
F = m.a
v. dv/dt
∫F dr ∫m v. dr
T = ΔEc.
F = m. dv/dt =>
Fdt = mdv
I = ∫Fdt = Δp

FIG. 3

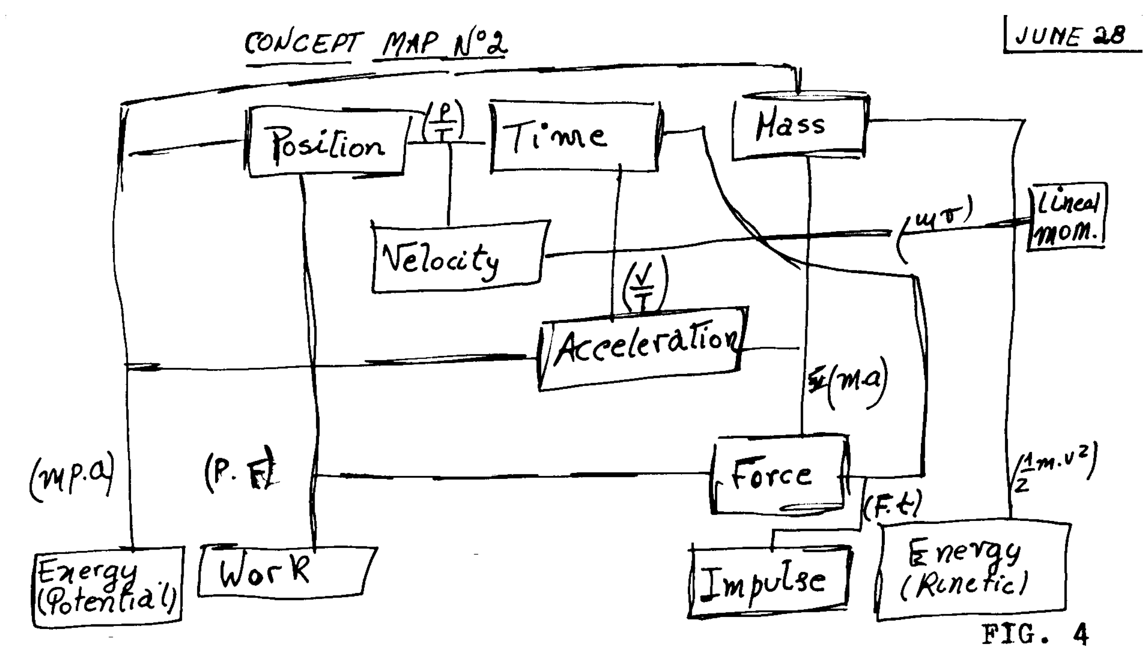
CONCEPT MAP N°2
JUNE 28
Position
(P/T)
Time
Mass
Velocity
(m.v)
Lineal mom.
(V/T)
Acceleration
Σ(ma)
(mp.a)
(P. F)
Force
(F.t)
(1/2 m.v²)
Energy (Potential)
Work
Impulse
Energy (Kinetic)

FIG. 4

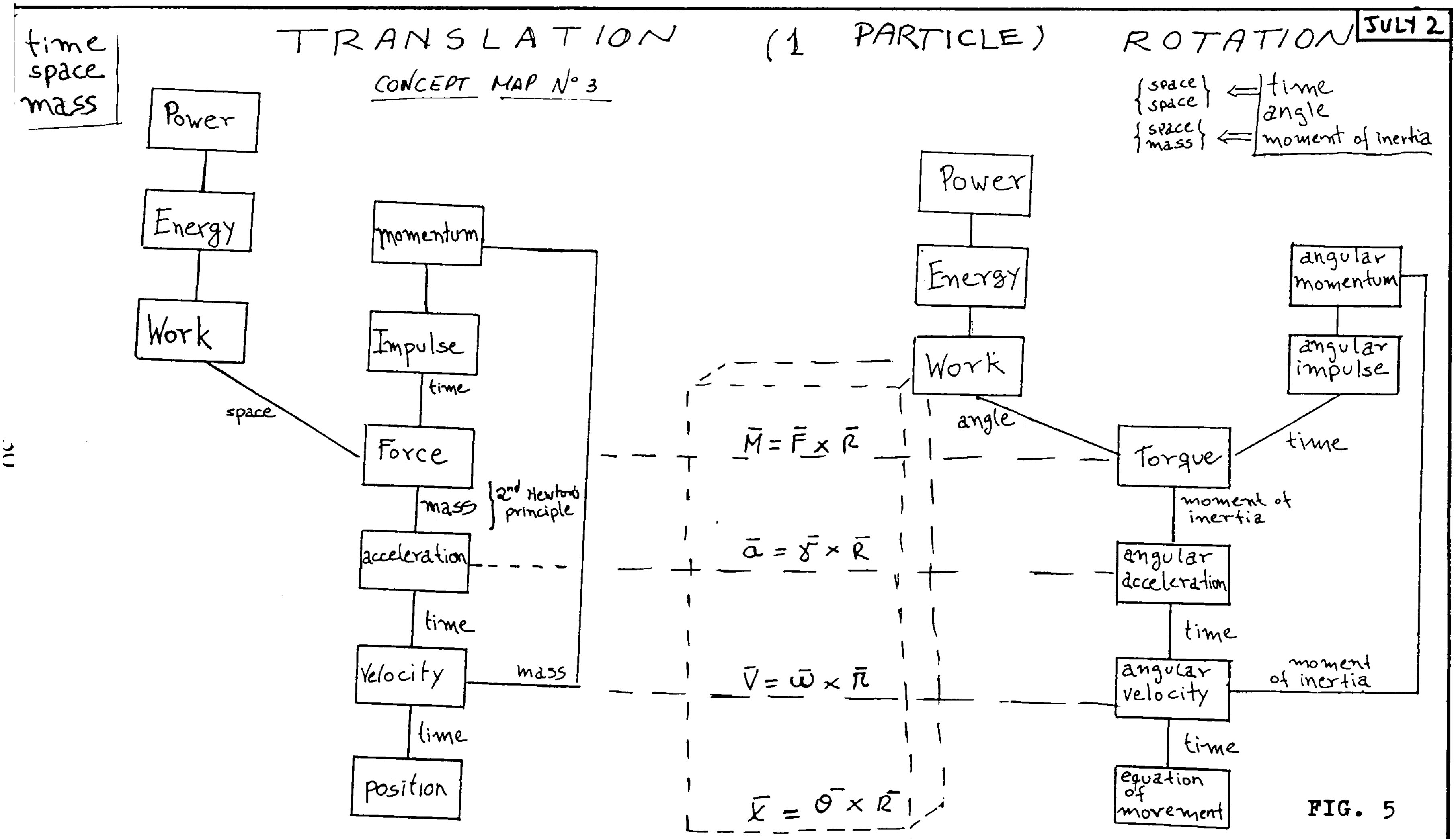
JULY 2
time
space
mass
TRANSLATION (1 PARTICLE) ROTATION
CONCEPT MAP N° 3
space
space
space
mass
time
angle
moment of inertia
Power
Energy
Work
space
momentum
Impulse
time
Force
mass
2nd Newton's principle
acceleration
time
Velocity
mass
time
Position
Power
Energy
Work
angle
$\bar{M} = \bar{F} \times \bar{R}$
$\bar{a} = \bar{\gamma} \times \bar{R}$
$\bar{V} = \bar{\omega} \times \bar{R}$
$\bar{X} = \bar{\theta} \times \bar{R}$
Torque
moment of inertia
angular acceleration
time
angular velocity
time
equation of movement
angular momentum
angular impulse
time
moment of inertia

FIG. 5

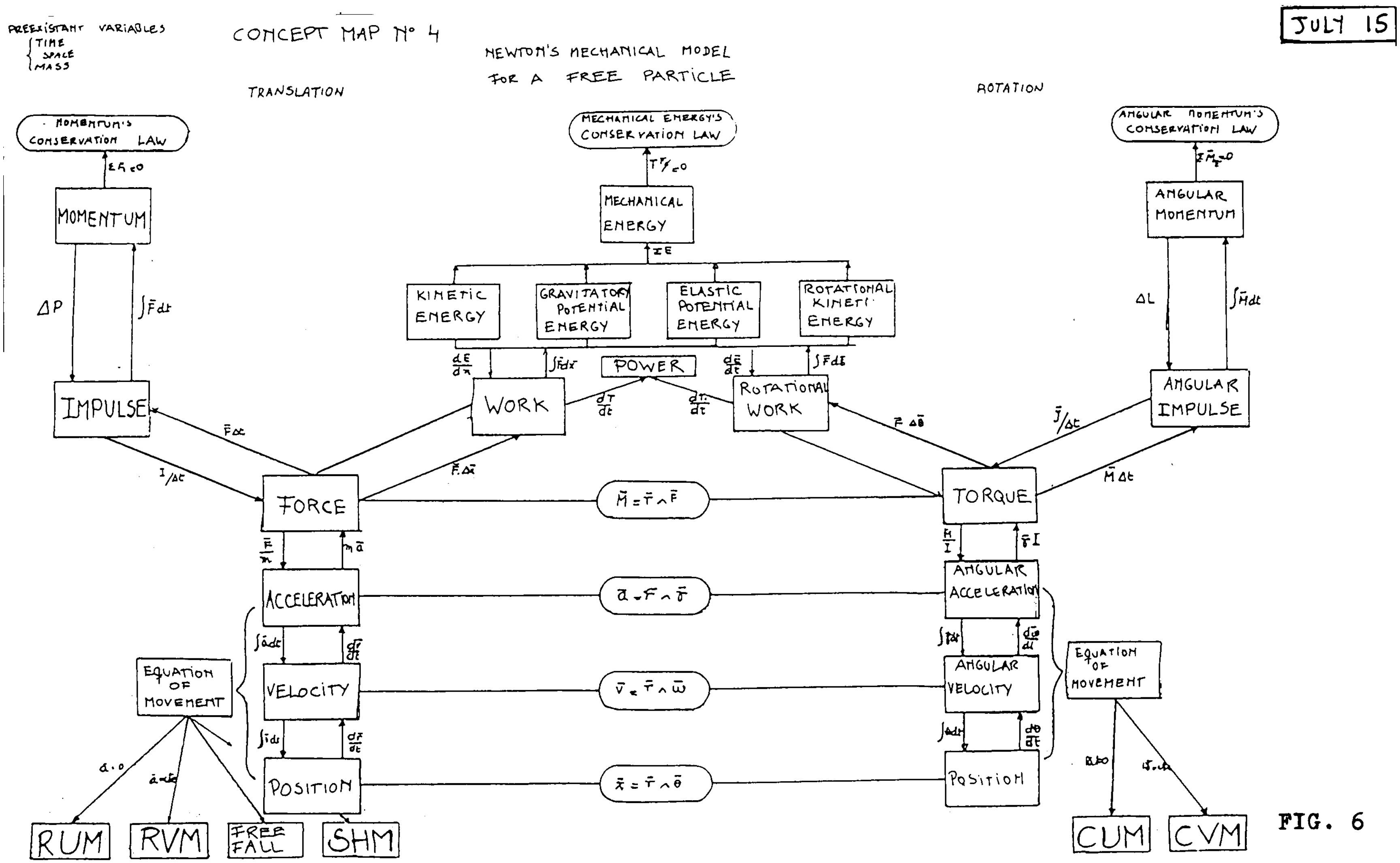
JULY 15
PREEXISTANT VARIABLES
TIME
SPACE
MASS
CONCEPT MAP Nº 4
NEWTON'S MECHANICAL MODEL
FOR A FREE PARTICLE
TRANSLATION
ROTATION
MOMENTUM'S CONSERVATION LAW
MECHANICAL ENERGY'S CONSERVATION LAW
ANGULAR MOMENTUM'S CONSERVATION LAW
MOMENTUM
MECHANICAL ENERGY
ANGULAR MOMENTUM
KINETIC ENERGY
GRAVITATORY POTENTIAL ENERGY
ELASTIC POTENTIAL ENERGY
ROTATIONAL KINETIC ENERGY
ΔP
ΔL
IMPULSE
WORK
POWER
ROTATIONAL WORK
ANGULAR IMPULSE
FORCE
TORQUE
ACCELERATION
VELOCITY
POSITION
ANGULAR ACCELERATION
ANGULAR VELOCITY
POSITION
EQUATION OF MOVEMENT
EQUATION OF MOVEMENT
RUM
RVM
FREE FALL
SHM
CUM
CVM

FIG. 6