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AUTHOR Crimellini-Tomasini, N.; And Others
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ABSTRACT

Issues critical for research on conceptual change in students are reviewed, drawing on a body of research with children and adolescents aged 5 to 16 years. Issues are examined in light of science education. It is proposed that science education should aim at fostering in students the development of ways of looking at phenomena that are as close as possible to those identified by scientific disciplinary knowledge, and that the process by which this happens can be described in terms of the restructuring and structuring of students' conceptual networks. The role of metalearning requires further study, since it is apparent that conceptual change requires that the student reflect on his or her own learning. The process of metalearning can be stimulated by discussion with peers and the teacher, but it also requires the individual's independent action. Metalearning activities should be started at the elementary school level. Another research issue is the evaluation of conceptual change. Not all methods are suitable for evaluating conceptual change. Accurate monitoring of change will require a wide range of different types of data. Implications of these findings about conceptual change for classroom practice, learning environments, testing strategies, the design of learning paths, and teacher education are considered. There is a 23-item list of references. (SLD)

REASONING, DEVELOPMENT AND DEEP RESTRUCTURING

N. Grimellini-Tomasini, B. Pecori, M. Gagliardi
Physics Department, University of Bologna, Italy

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N. Grimellini-Tomasini, B. Pecori, M. Gagliardi
Physics Department, University of Bologna, Italy

Introduction

Research on the issues related to conceptual change has greatly developed in the last decade. The different perspectives at the basis of the research choices and their implications on classroom practice (Driver, 1989) have gradually become clearer as the number of research works available to discussion have increased and the theoretical backgrounds of the research works have been made more explicit. An example of this trend is given by Strike and Posner who recently revisited their well known theory of conceptual change in order to take into account new information and, in particular, to better define its boundaries through the analysis of how other researchers have applied it (Strike & Posner, 1990).

The set of contributions to the round table symposium confirms that research on topics related to conceptual change can be looked at from different perspectives and that the field of research is very rich and open to future development. It is also interesting to notice that the many aspects of research on conceptual change are strictly interwoven so that one can find common points in the topics chosen by the different researchers who contribute to the symposium.

In our contribution to the discussion we will try to express our position on some of the issues that appear to be critical for research on conceptual change (features of the process, role of metalearning, evaluation of C.C.), drawing our reflections from the research data collected in various research works with children and students from 5 to 16 years, carried out on-line with classroom activities (Grimellini & Pecori, 1983; 1987, Gagliardi, 1987; 1988; Grimellini et al., 1989; 1990; 1992a,b). We shall finally discuss the implications of our reflections on classroom practice and on teacher education.

Conceptual change and science education

When we think of conceptual change we do not focus on the different knowledge states of the individual. On the contrary we focus on the process of change in terms of a continuous process by which the individual becomes able to look at phenomena from a perspective that differs from the one he/she held before.

Assuming that knowledge is constructed by the individual in his/her effort to cope with the events, the process of change is characterized by a continuous re-structuring and structuring of dynamic structures that involve conceptions, reasoning schemes and strategies, ways of looking, ways of doing, ways of communicating, etc. We shall call this kind of structures "conceptual networks".

For the purpose of this contribution we shall not discuss the structure of such conceptual networks; we shall only stress our point of view that knowledge can be seen as a network and that perturbations on network elements will involve, though in different ways, all the other elements connected in the network.

Our view of conceptual change has developed according to our view of science education. We believe, in fact, that science education should aim at fostering in the students the development of ways of looking at phenomena as close as possible to those identified by scientific disciplinary knowledge and that the process by which this may happen can be described in terms of the re-structuring and structuring of the students' conceptual networks. From this perspective science education should be seen as a continuous process of conceptual change requiring a long-term intervention and should be dealt with consistently from the elementary to the university level.

Within this view of science education it may be interesting to compare some features of the individual spontaneous networks with some features of the networks that corresponds to scientific accepted knowledge. Both kinds of networks can be seen as the product of a process of meaning construction, both work well for the purposes they have been constructed, and therefore resist to change, but both evolve in time in an everlasting process of conceptual change.

The different features of the two kinds of networks are related to the different aims of the construction and to the different contexts in which the construction occurs.

In the construction of the spontaneous networks a fundamental role is played by the search of a fit between the external inputs and the ability of the individual to interpret them, the fundamental aim being that of coping with ordinary life. The spontaneous network is constructed mainly unconsciously and its application is mainly automatic and intuitive. Only rarely is the individual required to make his/her spontaneous networks explicit.

The disciplinary networks are the product of the consensus achieved among a scientific community and are therefore intentionally as explicit and internally consistent as possible and are generally used by the individual in a conscious and rational way.

The awareness that characterizes the process of construction of disciplinary networks appears to be important in differentiating this kind of networks from the individual spontaneous ones and may suggest trends in designing teaching strategies that can foster the re-structuring of spontaneous network. We shall come back to this point in the Implications section. We shall first discuss some features of the process of becoming aware of one's own conceptual change as it occurs in the individual and its role in fostering the process of conceptual change.

The role of metalearning

According to our view of conceptual change as a continuous process, conceptual change appears to be an evolutionary rather than revolutionary process (this feature of the process is emphasized by other authors, e.g. Nussbaum, 1989; Chi, 1990; Villani, 1992).

Nevertheless there appear to be moments of apparent discontinuity marked by some kind of "sudden" change (we all experienced this at times during our career of students and hopefully sometimes still have this experience as researchers: it is the moment when "the bulb lights up"!). At these stages of the process the individual appears to become "suddenly" aware of having achieved a new way of looking at things which works and gives him/her satisfaction.

It seems that the individual becomes aware of the new state of his/her knowledge when the process of re-structuring of his/her conceptual network is deep enough to entail the production of a new way of looking. The awareness of the new knowledge state is important and necessary but even more important appears to be the awareness of how and why the change has occurred. This kind of awareness of the process seems in fact to induce an attitude favourable to change by making the results of the process more stable and by giving a feeling of satisfaction that can foster future conceptual change (Grimellini et al., 1990; 1992b).

The role of the feeling of satisfaction and intellectual pleasure associated to the process of reflection on one's own conceptual change is not to be overlooked: it appears to be one of the most powerful motivating factors that can support the process and keep it going (von Glaserfeld, 1989; Zanarini, 1992).

The social and cultural background of the individual appears to affect the possibility to trigger the process of becoming aware of one's own learning process and of drawing intellectual pleasure from the process itself. The role of school learning is therefore fundamental.

The role of metalearning in fostering the process of conceptual change in the school context has been investigated by White and Gunstone (1989) who associate to conceptual change a phase of deep reflection of the student about his/her own learning, emphasizing that the absence of such phase may preclude the possibility of a permanent change.

The importance of the role that reflection seems to play in making more stable the changes in the students' knowledge suggests that metalearning activities should be started at the elementary school level. Research data point out that younger children, who are in general less inhibited in expressing their ideas, can be stimulated to reflect on their own processes of knowledge construction and that this activity seems to improve the quality of the process of construction itself (Grimellini et al, 1990). The same kind of reflection activities may prove more difficult if started at higher levels of instruction, although reflective abilities increase in general with age, because at that time students may have already developed a more conventional attitude towards scholastic learning (White & Gunstone, 1989).

The process of metalearning can be stimulated by the discussion among peers and with the teacher but it also requires an activity of the individual on his/her own (Grimellini et al., 1989; 1990). Interaction with others is fundamental in triggering and nourishing the process of evolution of the conceptual networks but what has been constructed at collective level does not always automatically correspond to knowledge restructuring at the individual level (Chi, 1990; Grimellini et al., 1992b). This should not surprise given the highly idiosyncratic nature of the re-structuring and structuring process associated to conceptual change.

In learning physics the process of knowledge formalization seems to play an important role in connection to the process of becoming aware of one's own conceptual change. Qualitative reasoning is always necessary and fundamental in the process of re-structuring of conceptual networks. At low age levels and/or in the description/interpretation of some sets of phenomena qualitative reasoning may be also sufficient for generating new ways of looking. A transition from qualitative to formalized knowledge may help to generate new ways of looking by making the process of change more explicit but only if the necessary level of re-structuring has already occurred at the qualitative level. On the contrary, if the appropriate level of conceptual re-structuring has not yet occurred, a short cut to formalization may hinder the process of conceptual change by providing a rule to apply automatically. This accounts for what physics teachers mean when they say: "He doesn't understand and seeks refuge in the formulae". This is specially true at university level.

The evaluation of conceptual change

Not all evaluation instruments and methods are suitable for evaluating conceptual change. For example, traditional instruments to assess student knowledge that may seem appropriate for deciding whether a student should be admitted to higher studies will prove inadequate for assessing and evaluating the results of researches aimed at designing and experimenting teaching strategies for conceptual change.

According to our view of conceptual change as a continuous process in which individual awareness plays an important role, the kind of evaluation that looks appropriate, for research and/or classroom practice purposes, is an accurate monitoring of the process both at collective and individual level. The monitoring of conceptual change is important both from the teacher and the student perspective. For the teacher, monitoring is necessary in order to be able to identify the conditions that help student's knowledge re-structuring and to support the process of conceptual change. For the student self-monitoring of his/her own knowledge re-structuring can foster the process itself by helping him/her to become aware of the process of change. Other authors too emphasize that the development of the ability of monitoring and managing the process should be encouraged in the students in order to create conditions favourable to conceptual change (Hewson & Thorley, 1989).

Because of its very nature the process cannot be evaluated simply by performing measurements of single states in the conceptual change process, because they can give us information about the knowledge state at that moment but cannot do justice to the continuous structuring and re-structuring of conceptual networks (see also Duschl & Gitomer, 1991). The research that we carried out at different school levels has shown that, in order to follow the process of evolution of students' ideas, it is important to collect a wide range of data of different kinds: written answers to both qualitative and quantitative tasks, essays, recordings and videorecordings of discussions among the students and with the teacher and of lab work and discussion in small groups, etc. (Grimellini et al., 1989; 1990; 1992b). It has also pointed out the difficulties in making a global analysis of the results, given the different nature of the information that can be obtained from the different sources (Grimellini et al.,1992b).

Implications

Implications of the reflections about conceptual change and science education will be discussed at two levels: classroom practice and teacher education.

For classroom practice

Implications for classroom practice can be seen from three different perspectives that will be discussed separately for the sake of clarity, although they are obviously interwoven. The first one concerns the learning environment, the second one the teaching strategies, the third one the learning path.

It is rather obvious that not all **learning environments** can be suited for teaching that aims at conceptual change. In our research works we identified a set of features that seem to characterize the learning environment that can help the process of re-structuring and structuring of conceptual networks (Grimellini & Pecori, 1987; Grimellini et al., 1989; 1990; 1992b).

- All opportunities for helping the students to make their own ideas explicit should be fully exploited and the choice of the activities should be made in order to make the best of the potentialities of students' ideas. The comparison among the students' different perspectives should be systematically fostered and the discussion on how to design experiments and interpret the results obtained as well. Experimental activities should include both qualitative and quantitative experiments and not only pre-schematized experiments but also experiments where the student is required to choose how best to design the investigation by carrying out on his own the necessary schematizations.

- A special care should be taken in designing the activities that concern those conceptual steps that are known to correspond to critical barriers to knowledge construction, requiring deeper re-structuring of students' ideas. In order to allow each student to find a meaningful approach from his/her perspective, activities should be put forward that can be tackled by the students according to their different cognitive styles so that each student could find his/her way to give a meaning to the concepts under investigation. Therefore fundamental steps in the learning path should be allowed enough time for the individual learning needs and pacing to be respected.

- Data about individual and collective knowledge development should be gathered continuously so that monitoring of conceptual change could be carried out both from the teacher and the student perspective. Real time feed-back from the activities carried out in the classroom and from the process of individual construction appears fundamental in order both to allow the teacher to adapt the learning path to the students' cognitive needs and to foster the individual reflection on one's own process of conceptual change.

As far as the **teaching strategies** are concerned, we identified three different phases in the classroom activities that requires different roles to be played by the teacher and different activities to be performed by the pupils within the learning environment described before (Hawkins, 1974; Grimellini at al., 1990).

Working with students about a particular set of phenomena always requires a first phase of *messing about* which gives the students opportunities for exploring, observing, discussing, planning, constructing, experimenting and using objects and materials freely, making the best of the potentialities implicit in their own conceptions, reasoning schemes and strategies, ways of looking, ways of doing, ways of communicating, etc.. The role of the teacher is fundamentally to listen to the pupils and record very carefully what happens in the classroom, asking questions that help the students to express their ideas as clearly as possible and to stimulate the discussion among the students by creating situations that allow each student to reveal the potentialities of his/her own ideas. This phase of classroom activities is too often neglected by the teacher or is given too little importance being considered as a waste of time. In our opinion this phase should be seen by the teacher as a sound basis for all the other kinds of activities.

When different ideas have been explored it becomes necessary to start "putting things in order". The teacher can take advantage of the opportunities, offered by the previous activities, to invite the students to reflect on their ways of looking at phenomena by developing some kind of *external intervention* aimed at fostering the process of knowledge re-structuring. The information collected during the first phase are fundamental for the teacher in order to choose the activities that can help the students in the process. It is usually during this phase that experiments are collectively designed in order to check hypotheses and experimental activities are performed also at quantitative level.

The discussion of the results obtained opens a phase of *reflection* that aims at constructing a more general frame that allows a description/interpretation of the phenomena from a perspective closer and closer to the scientific one. The teacher can support the process of re-structuring by emphasizing the potentialities of the new ways of looking and helping the students in the individual metalearning process connected to the re-construction of their learning paths and by pointing out the questions that are left open. Open questions can become the starting point of a new cycle of activities.

The three phases recur many times during the same investigation according to the idea of conceptual change as a continuous process of construction. Conclusions are always somehow tentative and can become the starting point of a new step in the investigation. The pattern identified by the three phases should be seen as flexible as possible: a new phase of messing about, for example, may become necessary in the middle of a phase of external intervention and more in general subcycles of activities may become necessary during the development of the main cycle.

Our reflections on the learning environment and the teaching strategies are the product of a long-term commitment to science education at different age levels and we were really happy to find that other authors, working in other countries and in different contexts have developed similar perspectives about how to design classroom activities that can foster conceptual change (Easly, 1990; Wheatly, 1991).

As far as the design of **learning paths** is concerned, research results about the kind of difficulties that are found in trying to match disciplinary knowledge and students' ways of looking and about the kind of minimal re-structuring of spontaneous networks required, in a given context, for generating new ways of looking suggest criteria for designing learning paths that could satisfy both the cognitive needs of the students and the constraints imposed by the disciplinary structure (Grimellini et al., 1992a,b).

From a long-term perspective of science education it becomes important to think in terms of a whole curriculum from the elementary to the university level and to identify criteria for selecting the curriculum contents according to the different school levels. From this perspective the problem of giving the students the idea of the structure of each discipline as a complete and systematic construction could be neglected at the lower school levels and put off to the higher levels. This choice would allow superficial learning of a wide range of facts within each school level and repetitions at the different school levels to be avoided (Gagliardi, 1992).

If we focus on physics education, it seems important that science teaching should start at the elementary school level by investigating a variety of phenomenologies that can be described/interpreted from the children's spontaneous perspective. For this purpose the field of investigation should include a wide range of "ordinary facts" that are relevant for the children, because of their evidence at the perceptive level and because of their implications at the sensorimotor level, that can be described/interpreted by constructing elementary logical relationships. The phenomena should be selected so that the space-time scale could be accessible to the children in order to allow direct manipulation to be performed by the children and a meaningful description/interpretation to be constructed even on a purely qualitative level. The systems involved and the variables that allow a schematic description of the phenomena should be easy enough to be identified so that experiments could be designed by the children in order to test hypotheses or to obtain further information (Gagliardi, 1992).

From a long-term perspective of physics education the level of knowledge formalization should be one of the elements that characterize different stages in the learning path corresponding to different school levels: from a global and qualitative description at the elementary level of instruction, to a more analytical and quantitative description at the higher levels.

For teacher education

Our view of the process of conceptual change has relevant implications also on the problem of teacher education. In this contribution we shall focus the discussion to one aspect that we think to be particularly important.

In a constructivist environment the teacher has to play a very special and difficult role. The teacher should be able to understand the student perspective in order to foster the process of conceptual networks re-structuring, following the process of change both at collective and individual level. In particular the teacher should act as a model for the students by taking all opportunities to make the process of construction explicit and therefore to help the students to reflect on their own process of change (see also Strike & Posner, 1990).

Good teachers play this role mainly intuitively, without the benefit of an explicit model of knowledge construction, but in order to increase the number of good teachers some particular aspects of teacher training should be emphasized (von Glaserfeld, 1989).

It appears to be important that the teacher experiences on him/herself the same kind of learning and reflects on it, both because this experience provides him/her with a model of how to behave with the students and because it gives him/her the opportunity to experience and explicitly analyse his/her own process of conceptual change, at least on a restricted topic within the subject he/she teaches. This step appears fundamental for the teacher in order to be able to reflect on his/her role in the classroom and to re-define his/her teaching style by a process of conceptual change (Grimellini & Pecori, 1983; 1988).

Some final remarks

Conceptual change has proved a very rich and interesting field of research, whose results extend their influence beyond the group of researchers who are specifically interested in investigating the conceptual change process. But a lot is still to be done.

We would like to end our contribution to the symposium by recalling three topics already mentioned in this paper on which, in our opinion, more research is needed.

The first one concerns the design of instruments for evaluating conceptual change and criteria for combining data from sources of different nature. The second one concerns the design of long-term curricula for science education. The third one concerns teacher education for conceptual change.

On these topics we are personally interested in continuing the research in the future.

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