

Blended activity on quantum mechanics knots for pre-service teachers

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Abstract

Training for innovation in teaching quantum mechanics (QM) in secondary school encounters some difficulties, like the teachers' styles, the traditional approach and methodology, the limited familiarity with the subject. In the initial training this requires more time than is available.

We have elaborated some strategies for the pre-service training of teachers on QM, centred on the use of educational instruments and materials. These strategies include experiential activities related to the educational path we developed in our previous research.

The first experiences with pre-service teachers have had positive results in various fields, showing that they understand and acquire the proposed educational path, but they have also pointed out their limits in allowing a critical reflection about conceptual knots.

In the last year, in order to overcome these limitations, the training activities have been integrated with web discussions, to improve the overcoming of conceptual knots.

1 Introduction

The formation in didactic innovation is a task which has to face various problems: the teachers' styles, the traditional approach and methodology, the limited familiarity with topics never dealt with before [1-4].

The teaching of Quantum Mechanics (QM) in secondary school particularly suffers from these difficulties, because the teachers' culture is mainly mathematic. These difficulties are emphasized during the initial period of training, when there is a stronger need to reflect on the disciplinary and methodological-didactical foundations [5].

In previous researches we experimented experiential methodologies in the teachers' initial training, using materials of critical discussion on the foundations of theory and Worksheets prepared for class activity [6] concerning our proposal to teach QM in secondary school [7-8]. The latter aims to build theoretical thought in a conceptual environment, where hypotheses concerning the construction of the meaning and representation of physical entities in simple experimental contexts such as polarization can be explored [8,9]. It concentrates on the elaboration of the concept of quantum state and the superposition principle, on the representation of physical observables through linear operators and the relation

between the possible outcomes of measurements and their eigen-values at a first level of formalization.

If, on the one hand, different indicators have confirmed that teachers during the first period of training acquire mastery of the proposed didactical path, on the other hand inadequacies have emerged in activating an autonomous critical reflection on conceptual knots [6].

To overcome these limitations, the two critical modules on QM foundations and the didactic laboratory held in 2003/2004 by the University of Udine, have been integrated with discussions and project activity on the web, the results of which we will now present.

2 The context and research problems

The activity was conducted with 23 postgraduates (students of the SSIS - two-year pre-service teacher training course). Of these, 14 had a degree in maths, 6 in engineering and 3 in physics. About half of them (12) the year before had followed 3 credits of QM foundations critics. In the same period of the academic year 2003-04 everybody followed two modules on: a) critical reflection on the fundamental theoretic concepts (CRT- 2 credits), b) experiential didactic laboratory (DL - 1 credit) with worksheets for the students, who translate in an operative way our didactic proposal [6-8].

The blended activity was integrated in the didactic laboratory (DL), which was started by handing out a test made of 15 items (7 open answer, 8 multiple-choice requiring a motivation of the given answer). It aimed to collect the ideas of the postgraduates on: the topics that should be chosen to deal with QM at school, the elements that change and characterize QM with respect to classical mechanics (CM), the field of validity of QM and its possible connection with CM, quantum indeterminism and the probabilistic interpretation of the results of measurements, the meaning of Heisenberg's relations, the possibility of associating a trajectory to microscopic systems, the meaning of the superposition principle, the formal representation of the quantum state.

The same test was then re-proposed on the web at the end of the work, to have an evaluation in variational terms of the forming action. Those attending the course answered in separate web forums: one for each question.

3 The initial situation

The analysis of the test stressed the following ideas: the "quantization" (discrete spectrum) of physical sizes, considered to be peculiar only to QM, and Heisenberg's

relations are considered more important than the concept of state and the superposition principle; the old theory of quanta is identified as part of the QM theory; classical mechanics (CM) is “the limit of QM for $h \rightarrow 0$ ”. The concepts of compatibility and measurement (which always causes a disturbance on the system) and the identification of vectorial properties and quantum state vectors were seen to be confused.

On the web a discussion was held concerning: a) the role of indetermination relations in QM; b) the meaning of disturbance in the measurement process; c) the admissibility of the $h \rightarrow 0$ limit; d) classical systems where there are variables with a discrete spectrum (frequency of a guitar string).

These elements were then re-processed in discussing the disciplinary knots confronted in the worksheets, used in the presence and during the planning phase of the didactic micro-paths.

4 Analysis of the web contributions

Everybody contributed with at least two interventions for each aspect discussed (a total of over 100 interventions, an average of around 16 per person in 2 months activity). The didactic projects and the educational tools presented, together with the critical discussion on the web, have shown a capacity to deal didactically with the various aspects, confirming what had already emerged in previous researches [6]. Also, a greater comprehension of the limitations of formalism based on bi-dimensional spaces and a stronger competence in extending formalism to general cases emerged.

The analysis of the web discussions stressed the following.

a) Heisenberg's relations, initially taken as a postulate of QM, were then recognized as an element included in the formalism of theory. For some, however, these relations remain the base for a didactic approach to QM.

b) The relation between quantum indeterminism and the measurement processes is clear. Certain assumptions remain, such as: “in the measurement there is always a disturbance of the system, since the system is initially in a superposition of states”, where the existence of definite cases is not taken into account (measurements on systems prepared in eigen-states); “the measurement disturbs the system”, accompanied by considerations which seem to understand an inevitable situation of strong coupling between the measurement apparatus and the observed system, which is not necessarily so.

c) It has been recognized by everyone that the $h \rightarrow 0$ limit is not admissible on the physical level, since h is a constant. The further considerations on the contexts of use of QM compared with CM can be divided into three groups: 1) CM (50%) can be applied for “small” h , with no further specifications or comparisons with other sizes (e.g. the mass of the particle!); 2) it is necessary to

compare the value of the system's action with that of h (25%); 3) within the limits of actions which are big respect to h the same results are obtained with CM and QM (25%); such assertions were then mostly reviewed at the moment of discussion.

d) It has been recognized that also in classical systems discrete spectrum variables can be found, and that this is basically connected to the imposition of surrounding conditions. Some, however, added that as well as frequency, energy is also quantified, in some cases associating a quantum operator to the energy of the string. From this comes the difficulty to move coherently in a definite theoretical scheme, and to distinguish between the system and its formalized representation.

The notations reported in points c) and d) identify well-known difficulties regarding the use of semi-classical treatments and the classical-quantum dichotomy [10-12]. They emerge next to difficulties regarding methodological aspects related to rigorous argumentation, to the modelling process and to the use of mathematical instruments in physics. This puts in a different perspective the basic difficulties encountered: the semi-classical models present complex conceptual problems (which aspects remain quantistic, which classical? What is the meaning of the model, considering that the theoretical reference is hybrid?), which are emphasized when put next to problems of a methodological nature.

5 Analysis of the final test.

The comparison between the results of the initial and final tests demonstrates a big change regarding:

- competence on the concepts of compatibility (even if with some lapses); epistemic/non-epistemic indeterminism;
- meaning of the indetermination relations and connection with the existence of incompatible observables;
- meaning of the superposition principle and its formal expression in contexts different from that of polarization;
- differences between the concept of state in QM and CM;
- impossibility to attribute a position/trajectory to a particle (even though in some cases statements like: “the position/trajectory is defined after a measurement” tend to emerge).

A big change in the importance given to the superposition principle and to non-epistemic indeterminism also emerges, to the detriment of the one given to “quantization”, in characterizing QM and therefore the relative didactic proposals.

6 Results and conclusions

The blended activity has produced a strong additional value in competence on some nodal points for the personal involvement in concept analysis. It has been an incentive for discussion between peers, especially

regarding the final test where they demonstrated competence and an interest in a mutual confrontation, also in the closed answers where no comment was required. It allowed to see that classical physics and quantum physics are based on radically different principles, highlighting the overlapping of pre-existent ideas concerning the relationship between the two theories. It has allowed to overcome the limits [6] in the use of concepts and formal instruments in different contexts. It proved to be effective in specifying concepts and correcting inaccuracies and mistakes (in over 90% of the answers). It was useful as an incentive to reflect on the work carried out.

Lastly, it clarified the origin and type of needs in training on particular crucial concepts, and it has stressed that the discursive style and the lack of ability to argue rigorously are indicators of conceptual difficulties.

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