The approach to Quantum Physics Teaching is more or less common to most textbooks and courses and follows what we call the “traditional approach to Quantum Physics”. Unfortunately, as it is generally known, this approach is not very effective, and it is probably responsible for most of the common teaching-learning problems and for most of the misconceptions of Student.s In the last recent years, in the context of the two Italian national Projects “SeCiF” (Teaching and Understanding in Physics) and “FFC” (Physics for Cultural Formation), we have developed (and are still improving) “QUANTA-MI”, a non-traditional approach to Quantum Physics Teaching. In the first semester of the Academic Year 2002-2003 this approach has been tested with 26 Student Teachers in two courses of the S.I.L.S.I.S.-MI (Inter University Lombard School of Specialization for Secondary Teaching-Section of Milan): a 18-hours training course on Quantum Physics Education and a 24-hours Laboratory course. Students’ responses have been evaluated through the analysis of the material they prepared during the courses and of the two oral examinations that they had at the end of the courses. In fact all the Future Teachers were asked to have a portfolio, to build a path on a chosen item of Quantum Physics that is suited for Secondary School and to answer to a written test and a questionnaire. The key-points of our approach will be highlighted here and the first (and very encouraging) research results about its effectiveness for Student Teachers will be presented and discussed.
• Construction of an undergraduate course in which the base concepts, picked up in the previous point, have a fundamental role. This point is very important because we want to be sure of the coherence of our path; we don’t want an approach based on a schema that seems coherent at the high-school level but cannot be read at a deeper (University) level.
• Deduction of a High-School path.
• Analysis of a case-study in High-School situation.
• Analysis of High-School Students conceptions and difficulties
• Construction of a new teaching path refined by the preceding analysis.

The last three points have been repeated cyclically, up till now, four times [3].

Four guide-lines emerged from this work [4]:
1. Physics is “one” and we don’t want to create a gap constructing Modern Physics against Classical Physics.
2. Our aim is to build a general coherent picture of Quantum Physics, “consistent” with Classical Physics. For this purpose we make a new reading of the discipline that even if it follows logical-historical criteria, it does not always respect chronology.
3. Quantum Physics is not equivalent to Quantum Mechanics and its ontology. The most complete Quantum Theory that we have now is the Quantum Field Theory, and it will be therefore our main guide, especially from the epistemological viewpoint.
4. Physics has not come to an end in the ‘30s and thus we would try to have in mind the whole last century and not only its first 30 years.

**The Approach**
The Quanta-Mi frame-work to Quantum Physics Teaching is divided into four parts [4], [5], [6]. The related the schema is shown in the Appendix, where the four different parts are colored in different greys.

I. **Analogy of behavior of free propagating light and matter pencils in similar circumstances (no self-interaction)**
In classical Physics matter can be described by continuous fields (density fields, pressure fields, …) and also forces are described by well known fields: electromagnetic field, gravitational field, ….. From the description of electromagnetic field one has the whole Classical Optics. We suggest to describe also the entire behavior of appropriately prepared matter beam in terms of “Matter Optics”. We thus discuss recent experiments on matter beam interference [7], [8] and diffraction [9] (or even the Kapitza-Dirac effect [10]) but at this stage, we do not interpret them, as it is customary, as single quantum experiments but as high-intensity “classical” experiments. From this viewpoint the wave behavior of matter is “classical” in the same sense in which electromagnetic optics is classical. We also derive a classical matter wave equation which is similar to Schrödinger equation but that does not contain the constant “\(\hbar\)” and that can be interpreted “classically” and that plays a role similar to that played by the electromagnetic wave equation.

II. **Birth of the quantum concept**
The quantum concept emerges in the description of interactions, both for force and for matter fields. It emerges to explain chemical laws that are simply understood in terms of interacting quanta (that, for Chemistry, are atoms, electrons, ions, …). For similar reasons chemical-like interactions of electromagnetic radiation with matter (i. e. Photoelectric Effect and Compton Effect) can be explained in terms of interacting quanta (photons).

III. **Quantum fields**
What we want here to emphasize is that the key point is the quantized field concept.
For this purpose double slit experiments (at low intensity), Which Way experiments and Interaction Free Measurements experiments are discussed. What we want to stress is that in our approach
interactions among fields are events in space-time obeying some conservation rules and that, roughly speaking, these events, for which a statistical description is needed, are the “quanta”; but we are not allowed to say that the World is “made of” quanta, otherwise paradoxes emerge... From the properties of wave-packets Heisenberg’s relations are then introduced.

IV. Structure of the atom
There’s no place in our approach for the introduction of the historical models of atomic structure, that are so often used in the “traditional path”; this is because, as we all know, they are very misleading for Students. In our approach the mismatch between theory and experiments is fundamental. So we start studying the famous Geiger and Marsden experiments on the deflection of alpha particles by thin targets, which imply the existence of an electronic field surrounding a small “nucleus”, and continue with the analysis of the behavior of a quantized field confined into a finite box, thus getting its discrete energy levels. With the help of Heisenberg’s relations, it’s then not difficult to go directly to the discrete energy levels of the atom.

Experimentation with Future Teachers
Our approach has been tested at S.I.L.S.I.S.-MI with 26 future Teachers in an 18-hours training course called “Quantum Theories” held by one of the authors and in its related 24-hours Laboratory Course on Quantum Physics Education. Of our future Teachers, 17 were Mathematicians, 8 were Physicists and 1 was an engineer. All the Mathematicians had previously followed two compulsory courses, of 30 hours each, on the “Structure of Matter” and on “Quantum Mechanics.”

An evaluation questionnaire has been given to the Teachers at the end of the courses.

The “Quantum Theories” Course
The evaluation of Students Teachers conceptions has been made by means of:

- Initial tests (where some data were collected; for instance: kind of degree, kind of teaching diploma they were studying for, expectations from the course, ...)
- Intermediate tests about matter optics experiments
- Portfolios done by Student Teachers
- Oral examinations
- Diary written by a dumb passive observer during lessons.

During, and also after the course, Student-Teachers showed great difficulties in understanding most of the key-points of the Quanta-Mi approach, and more generally, of most of the basic concepts of Modern Physics. Some categories, into which we could group together the sentences that they gave, emerged in our analysis. A sample follows.

1. Category: Quantum Physics is not suited for High School. “I don’t think we should teach modern Physics to High-School Students because at School there’s not enough time for it (after the teaching of Classical Physics) and because Quantum Physics is much away from our world”.

2. Category: Confusion among semi-classical models and Quantum Concepts. “I don’t understand why semi-classical models are misleading and why Bohr model is not correct”.

3. Category: Particles as micro-objects making things. “I cannot even speak about matter pencils beams without using particle terminology. I always say: an electron beam, a neutron beam and so on...”.

4. Category: Confusion between the Born interpretation of the wave function and the “classical” matter wave field. “I’ve always been taught that matter waves do not exist and we should speak only in terms of probability that is expressed by means of the wave function; so why do you always use terms like matter optics, matter waves and matter pencils to describe interference experiments?”
5. **Category: Difficulties with the meaning of “interaction”**. “Interference is a sort of interaction”.

**The Laboratory Course**
The laboratory course followed the “Quantum Theories” one. Its evaluation has been made through the analysis of the:

- Didactical paths on a chosen topic of Quantum Physics, one for each group of 3-4 persons
- Diaries (a sort of log-book), again one for each group
- Oral examinations (one student at a time)
- Memos written by the professors during in the lab.

Some sentences will be here shown, taken from the diaries that student teachers had to write and from the evaluation questionnaire at the end of the course. They are examples of very general ways of thinking among student teachers. (In brackets and in italics you can read a tentative inclusion into categories of analysis). Lower case

1. “After the lab I’ve understood that the fundamental ideas are not completely abstract, on the contrary they are very practical”. *(Quantum Physics can be taught at High School)*
2. “We decided to treat both Rutherford scattering and Franck-Hertz experiment from the unifying point of view of scattering experiment”. *(There is a general coherent picture)*
3. “At the end of the afternoon we have the sensation that we have understood new things, but we are also much aware of how many things we do not know…but now we know where they are. *(There is a general coherent picture)*
4. “We have understood that fundamentals ideas are decreasing in number: despite the variety of different experiments, few very simple but very impenetrable ideas stay below. It’s stimulating!” *(There is a general coherent picture)*
5. “We are now sure that Heisenberg Relations must precede the description of atomic structure...!” *(No more semi-classical models)*

**Conclusions**
A detailed analysis is still in progress but the first results are already clear.

In the evaluation questionnaire given at the end of the Quantum Theories course most of the students wrote that they had to study too much because the course was very difficult (about 90 hours of home study for a course of 18 hours of lessons). Given these difficulties most of them said they would never try a similar approach with their High School classes.

This situation drastically changed after the laboratory course. In fact, after that, nearly everybody (even those that got a bad mark at the end) said that the lab was very useful to better understand the key-points of Quanta-Mi and that, besides, they would probably try to teach Quantum Physics following the approach discussed in the lab. Most of them were satisfied and gave encouraging judgment about the laboratory, especially because the proposed approach “greatly helped to understand Quantum Physics and to bring it in the realm of Physics instead of putting it in that of magic phenomena”.

Although many questions, such as the importance and the following difficulties of an analogical reasoning in understanding our picture, have not yet been answered, we have clear indications that our approach is really effective in helping future Teachers avoid most of the common learning problems of Quantum Physics and that, in this sense, it opens a new way to Quantum Physics Teaching. To achieve this goal, it seems fundamental a great work in a laboratory course where future teachers can really try to construct a teaching path that is really “practicable” and that helps them to highlight fundamental questions, instead of hide them below a lot of mathematics or a lot of puzzling phenomena.
However this approach is still at the beginning and conclusions are not yet well established and a deeper analysis must be carried out. Besides much more material must be prepared (at teacher’s level and at high-school students’ level) both to be more effective in our teaching and to reach a larger audience.

Appendix: Schema of the Quanta-\textit{Mi} approach

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<th>MATTER AS A CONTINUUM</th>
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<td>WAVE PACKETS</td>
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<td>E. M. WAVE EQ.</td>
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<tr>
<td>E. M. INTERACTION AND E. M. QUANTA</td>
<td>CHEMICAL INTERACTION AND MATTER QUANTA</td>
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<td>ATOMIC STRUCTURE</td>
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References

[1] See, for instance, the entire Issue of March 2002 of the \textit{Am. J. Phys.}.


