Quantum Physics Course for future secondary school teachers: active learning approach and visualization tools

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Abstract. This contribution describes aims and implementation of the Quantum Physics course specially designed for future physics teachers at secondary and high schools. Although the course syllabus is the same as for the courses for future physicists, emphasis is placed on understanding of basic concepts and students’ ability to discuss about them. The active learning methods and various means of graphical representations are used to meet this goal. The course has been tuned to its present form for about ten years and reaches very positive feedback from students.

1. Introduction
We have seen shift from traditional teacher-centred teaching approach to student-centred active learning (AL) approaches; there are various researched-based AL methods and physics education research has confirmed their higher effectiveness. [1] This paper describes rebuilding of undergraduate Quantum Physics course specially designed for future physics teachers which gives us unique opportunity to let them experience the complex use of AL approach personally in order to inspire them in their own future practice.

2. Course characteristics
The course is included in the 4th semester, usually includes 13 weeks of instruction. The course consists of two sessions per week (270 minutes long in total, divided to 180+90 minutes or 135+135 minutes per session). All sessions have the same organisation, that means primarily that there is no traditional distinguishing of lectures and problem-solving seminars. In addition to the compulsory lecture there is an optional seminar, which is quite popular among the students and they attend it typically in their 3rd or 4th study year. The seminar content is focused on issues connected with teaching quantum phenomena at lower level. In past few years, our study groups are relatively small, not more than 20 students. Students have to pass a short test aimed at basic terms in the middle of semester, a final test based on solving quantitative problems and an oral exam focused on their ability to explain and discuss basic concepts and solutions of selected problems.

3. Teaching methods
We have taught this course for more than ten years and the used methods are still changing to meet our goals better. The course syllabus is nearly the same as for future physicists (see table 1). However, teaching methods and aims are different.
Table 1. Course syllabus – main topics

| Topic                              | Topic content summary                                      | Approx. weeks |
|------------------------------------|------------------------------------------------------------|---------------|
| Introduction                       | Experiments leading to QM                                 | 1             |
|                                    | Characteristic features of microscopic systems             |               |
| Basic postulates and formalism     | Description of quantum state (wave function and two-state system) | 3             |
|                                    | Physical observables                                      |               |
|                                    | Measurement in QM                                         |               |
|                                    | Schrödinger (nonstationary and stationary) equation        |               |
| One dimensional problems           | Rectangular step and barrier (including tunnelling)        | 2             |
|                                    | Rectangular well (finite and infinite)                     |               |
|                                    | Harmonic oscillator                                       |               |
| Particle in central field          | Angular momentum                                          | 2             |
|                                    | Hydrogen atom                                             |               |
| Spin                               | *Formalism is included in the second chapter*              | 1             |
|                                    | Experimental discovery of spin                             |               |
|                                    | Pauli equation                                             |               |
|                                    | Zeeman effect                                              |               |
| Approximate methods                | Variation methods                                          | 2             |
|                                    | Stationary perturbation theory                             |               |
|                                    | Nonstationary perturbation theory and quantum transitions  |               |
| Many-particle systems              | Specificities of systems of identical particles            | 1             |
|                                    | Pauli principle                                            |               |
|                                    | Spin component of many particle wavefunction              |               |
|                                    | Periodic table                                             |               |
|                                    | Helium                                                     |               |
| Chemical bond.                     | Quantum explanation                                        | 1             |
|                                    | Simple two atoms molecule                                  |               |
|                                    | Hybridization                                              |               |

In our course we place great emphasis on understanding the basic concepts and the ability to talk about them without using advanced mathematics and awareness of possible misunderstandings. Generally, our teaching approach can be shortly expressed like “Less math, more words”. As secondary school teachers, our students do not need to be very experienced in solving Schrödinger equation for various systems, however they definitely should be able to express basics ideas of quantum physics by simple words, models and examples without unacceptable misrepresentation. Aspects we put special attention to are

- deficiency of common language for talking about quantum phenomena
- history and experiments ("the stories behind great ideas")
- duality and uncertainty principle (especially Heisenberg’s one)
- measurement in quantum mechanics (difference in comparison with classical mechanics)
- etc.

The instruction consists of lecturing parts (e.g. formulations of theoretical principles, mathematical derivations of formulas etc., 10-30 minutes long) and AL blocks following one another. These AL blocks include answering simple questions that test basics idea grasping, dealing with ConcepTests using the Peer Instruction method [2], small group and whole class discussions, collaborative problem solving and small project creation (see fig. 1).

We have successfully integrated regular Just-in-Time teaching home assignments [3] and for time-to-time reading assignments and online chat, we use Perusall environment (http://perusall.com/).
Our intention is to gradually implement the flipped classroom approach. Nowadays we are limited by the absence of an appropriate study text in Czech. Not only for this reason, we are preparing study text specially designed for our course with passages for home reading, many simple conceptual tasks, solved sample problems and great emphasis on graphics – graphical representation of problems solutions and accompanying interactive components (prepared in GeoGebra, Mathematica, etc.).

4. Visualization and other graphical methods
To meet our goals – understanding of basic concepts and ability to speak about them – we use various “picture-based” activities. Emphasis on graphics is the most-visible difference between our course and other lectures.

Very beneficial are interactive simulations; we use some well-known ones like Physlets Quantum Physics [4], PhET simulations (https://phet.colorado.edu/) and simulations in QuVis project (https://www.st-andrews.ac.uk/physics/quvis/). Selected of these are now being translated into Czech to increase the impact on our students. In case there are not any suitable simulations available, we create our own ones in software like MS Excel or Wolfram Mathematica.

Furthermore, two large-scale projects arose from needs of this course. The first and older one is called Orbitals [5] for hydrogen eigenfunction visualisation and exploration. Four interactive programs (for Windows, prepared in LabView software) are accompanied by workbook (10 pages, approx. 30 problems with explanatory text). Students work it out as a home assignment. They appreciate mostly the step-by-step approach and the possibility to correct their mistakes by themselves (using these programs).
The second project was a reaction to the situation after termination of use of Java applets in browsers rendered many useful Java applets unusable. One student of this course, Tomáš Škraban, programmed the so called “1D Quantum Potentials program” displaying solutions of various 1D problems (see figure 2) – infinite and finite rectangular well, rectangular step and barrier (with changeable shape, not necessarily symmetric) and linear harmonic oscillator. The probability density or both parts (real and imaginary) of wave function can be displayed as well as their time development. In case of system with bound states it is possible to show superposition of up to ten eigenstates. For teaching purposes, it is also possible to display the solutions of Schrödinger equation for energies different from eigenvalues (see figure 2 bottom left).

5. Feedback
For four years, this course has been among the best rated courses in official student survey at our faculty. We have also obtained a very positive feedback in our own surveys, e.g. students described the course as attractive, unusual, amusing and less organized than traditional lectures. They appreciate that they learn to express their thoughts during the sessions and that the teaching methods work as an inspiration for their future teacher career. We can illustrate the students view by a few quotations:

- “I like variety in instruction – tasks, flashcards, discussions, lecturing, …”
- “Applets were very helpful in building an idea what problem we were solving.”
- “I think that the small whiteboards are a great idea, however I faced one disadvantage – no permanent notes from lecture.” (note: small A3 whiteboards are used mainly during conceptests and other problem solving periods in the sessions)
- “I appreciate the great number of pictures, animations and applets we worked with. Without them, I cannot imagine understanding what quantum physics is about.”

As negative aspects, students typically mention unusualness, less arranged notes and higher time demand during the term. The course success is proven by students’ behaviour as well, i.e. students willingly fulfilling voluntary tasks. From several students who had already finished their studies we have received reports that they have tried to use those teaching methods they had experienced in our lessons.

From teacher’s point of view we conclude that active learning approach requires teachers’ deep orientation in students’ learning difficulties besides very good knowledge of the subject itself. Teacher has to ensure safe class environment to enable productive discussions. We have experienced that students changed their attitude – they were willing to understand, not to just pass the exam. Probably because the students learned to understand the problems from various perspectives, they expressed the feeling that their knowledge was deeper and more permanent.

6. Conclusion
We have a unique opportunity to have a course tailored to the needs of future teachers. We have good student feedback and excellent results in the official faculty students’ assessment of lectures. We are also preparing a research to compare the test results of our students and students of other courses.

7. References
[1] Hake R 1998 Interactive engagement versus traditional methods: A six-thousand student survey of mechanics test data for introductory physics courses Am J Phys 6664
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[4] Belloni M, Christian W and Cox A J 2006 Physlet Quantum Physics: An Interactive Introduction (Pearson Prentice Hall)
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