Research on Teaching and Learning Quantum Mechanics
Proposal for a Poster Session at the 1999 NARST Meeting

"I believe that any lover of nature should study quantum mechanics -- not its mathematics but its ideas."

--Douglas Hofstadter

Until recently the main purpose for students other than physicists and chemists to study quantum mechanics was for a better appreciation of its influence on modern thought. Now people who will be making decisions about business and technology need an understanding of modern physics. Recent developments in miniaturization of electronics and nanotechnology bring into the business and engineering world devices that can be appreciated only through the principles of quantum mechanics. Likewise, in the past few years experiments have directly analyzed some of the fundamental paradoxes in quantum mechanics. Thus, an understanding of quantum physics beyond the level of a coffee table book is needed for the well-informed citizens and all types of professional in the 21st Century.

As the need for students to understand quantum phenomena increases, so does our need to understand the learning process for these abstract and counterintuitive concepts. In recent years research in student understanding of quantum science has increased greatly. Some researchers have investigated traditional methods of learning while others have developed and assessed techniques such as hands-on experiments and interactive computer visualizations. (Hands-on experiments should not be considered non-traditional. However, the usual method of teaching quantum science is with little of no experimentation.) Over the past ten years a small number of researchers have been involved in these efforts. Their work is now showing some good results which can help us understand how to teach quantum mechanics and, perhaps, other abstract scientific concepts.

Most of the studies have concentrated on conceptual understanding of quantum science. The primary question is, Can students learn the ideas of quantum mechanics every if they are not familiar with the advanced mathematics that forms the basis of the topic? By studying the learning process researchers have been able to determine some techniques are effect and some that are not. Modifications in learning materials and suggestions for improvements in traditional approaches have been created as a result of these studies.

In this proposed poster session seven different groups who are addressing the learning of quantum mechanics from different perspectives will present their findings. Two of the groups have relied heavily on interactive computer visualization and other minds-on activities. One group has assessed a learning technique that uses a commercial computer problem solving technique has a foundation. The other three have relied primarily on more traditional approaches to learning/teaching although they have moved beyond the lecture and textbook. In all cases research data have been collected about the process that students use. Thus, each of the groups can contribute to our general knowledge about how each approach is valuable for student learning.

Below we present short summary of three of the seven projects to be presented at the poster session. These project represent the range of research and development efforts of all seven projects involved in this session.

Project 1: Significant use of visualization and hands-on activities

One of the projects which uses visualization and hands-on activities has created a series of teaching/learning units which provide a way to learn quantum physics without much knowledge of mathematics. The project staff has investigated students' understanding of concepts in quantum physics, then built instructional units to address the students' needs. All of the instructional materials are based on the Learning Cycle. The learning units combine written materials, interactive computer programs and digital multimedia to provide a learning environment in which students obtain more than a cursory view of quantum physics.

One set of materials help students learn to analyze situations in terms of potential and total energies and to use qualitative steps to sketch wave functions of objects moving under the influence of forces represented by these energies. Included in the development will be an understanding of such important consequences of quantum physics as energy states in atoms quantum tunneling. Through interviews, written questions, classroom observations, and concept maps the researchers have followed the students' learning process and gained insight into how to teach these abstract ideas.

A second group of materials aid students in their understanding of the application of these fundamental principles to physical phenomena and modern technology. By completing these units students learn how devices such as a scanning tunneling microscope work and the importance of quantum principles to objects such as light emitting diodes. Some of the research on students who use these materials includes how their attitudes change when they learn that quantum mechanics has some practical application in everyday technology.

Project 2: Use of modeling software for teaching quantum physics

Another teaching approach uses a moderate level of mathematics and has been under development for about ten years. The basic idea is a modern representation of atomic physics using the Schrödinger equation as a theoretical basis. The main focus here is on qualitative understanding and interpretation of the ψ-function, not on mathematical capabilities. The computer is used for modeling the Schrödinger equation for special cases like hydrogen atom, higher atoms (He, Li) and molecules.

The Research questions of this evaluation study include:

1. How far are students achieving the objectives related to this new approach? Do they develop a deeper understanding of atomic physics as it is defined by this teaching approach?
2. How are conceptions and understanding of students changed during instruction?

Data were gathered from questionnaires before and after teaching, from interviews after teaching, and from observations during teaching. There were altogether 26 students in three classes.

The results show that students in one class achieved better results than in two other classes. From our observations of the classes there are several preconditions that have influenced the outcome.

One of the most important objectives for our approach was to enable students to see a connection between results of theoretical modeling and results from measurements, such as size of the atoms or frequency of spectral lights. The results show that this aim was achieved to a good average level in two classes, whereas the average level of students in a third class was only sufficient.

Some results about students' conceptions (research question 2) related to electron orbits, electron cloud, concept of state, concept of shell, distribution and movement and their change from the pre test to the post test are displayed in fig. 1.
More than 20 students change from an electron orbit view of electrons in an atom to a charge view. Nearly all students develop a good notion of an electron distribution. Nearly 50 % of the students develop some good notion of a state and abandon a description of electrons, which includes the notion of motion.

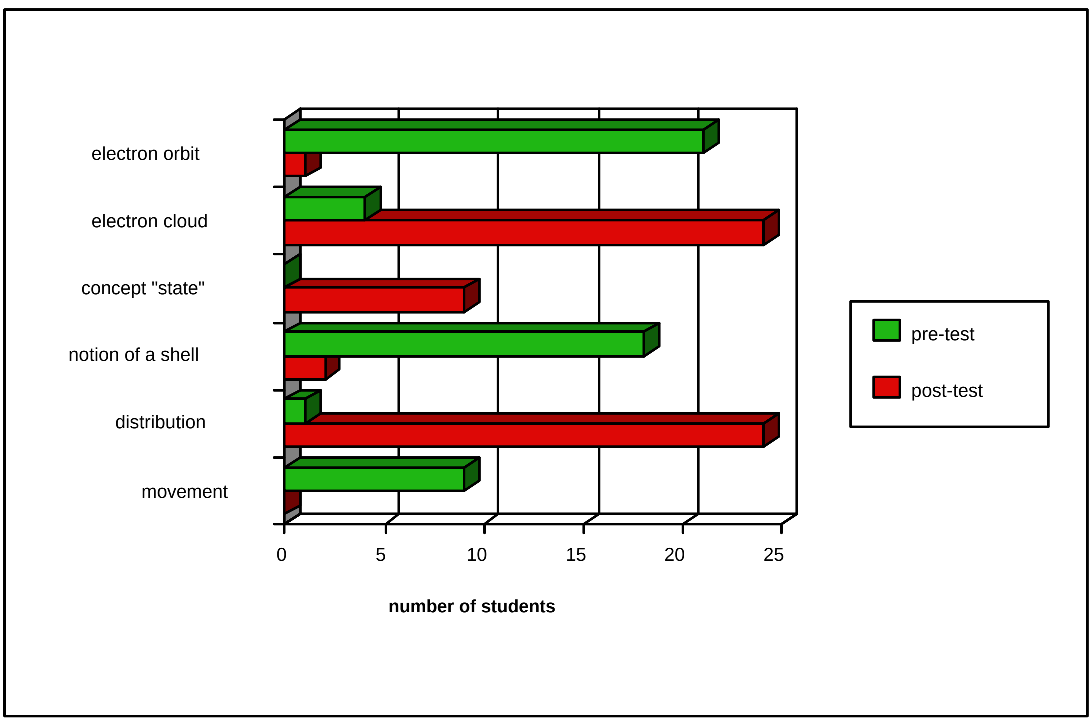


Figure 1

This new approach to teach quantum atomic physics in upper high school has been transmitted to three teachers of ordinary high school with partial success. In one of the three classes all but one objective have been reached by many students. Only the mathematical understanding of the Schrödinger equation got less average level than 1.0. In two other classes some of the objectives also have been reached with good success, for instance achieving a new atomic model or understanding some relations between theoretical model and results of measurement. Other objectives failed to reach a sufficient level. The researchers conclude from these results that although it was not possible for most of the students to develop a deeper understanding of the theoretical description they achieved an average to good understanding of the basic quantum mechanical concepts.

Project 3: Quantum Physics without Instructional Technology

A third of the studies represented by the posters in this session does not use technology as the medium for any of the instruction. Instead it concentrates on understanding of several important concepts by comparing traditional instruction with a newer approach that involves somewhat traditional methods.

In this study the researchers again began with students' conceptions which has developed during the period of some years before. Their investigations show that already in grade 7 students have an idea about an atom that is very closely oriented at classical mechanistic models. This orientation becomes stronger from grade to grade as a result of instruction in physics and chemistry. (See figure 2.)

"Electrons move around the nucleus on special trajectories"

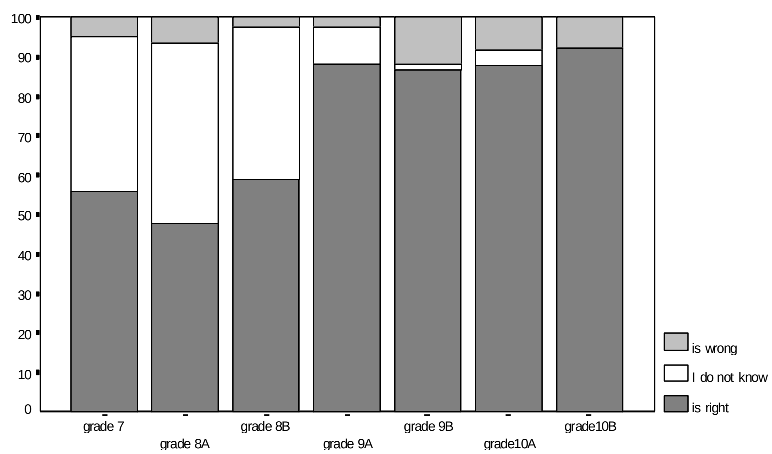
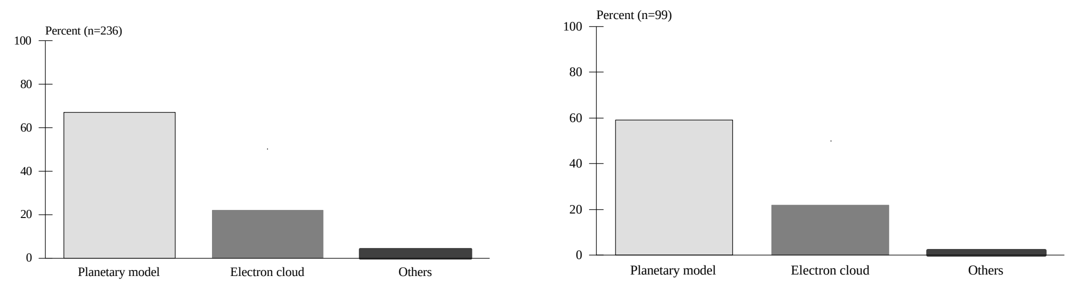


Figure 2.

It is not surprising that before the teaching unit "Introduction into quantum physics" students' conceptions of atoms show mechanistic features. But it is more than surprising that after the teaching unit students still have the same conceptions. The Figure 3 shows the results of an investigation with 236 students before the teaching unit and with 99 students in 6 classes in which quantum physics was taught in a traditional way.



Prior to the teaching unit ***after the teaching unit***

Figure 3: Students' conceptions of the structure of an atom (H). In this figure the following definitions are used: **Planetary model**: Students draw an electron on an orbit, **E-cloud**: Students draw a continuous electron cloud around the nucleus, **Others**: Students draw various representations

As a reaction to the results shown in the diagram a new approach to teaching quantum physics was developed which prevents students from attempting to understand the phenomena of quantum physics in terms of the conceptions of classical physics. This approach proceeds from the following basic premises:

(a) Reference to classical physics should be avoided.
(b) The teaching unit should begin with electrons (not with photons when introducing the photoelectric effect).
(c) The statistical interpretation of observed phenomena should be used and dualistic descriptions should be avoided.
(d) The uncertainty relation of Heisenberg should be introduced at an early stage.
(e) In the treatment of the hydrogen atom, the Bohr model should be avoided.

A comparison of the conceptions of the students from the two groups (test and control group) after the lessons demonstrates that different changes in conceptions have taken place. Within the range of topics discussed, a clear dependency on the teaching experienced by the students can be observed: 68% of the students in the test group oriented themselves toward the conception of localization energy *(Loc.)* while the students of the control group persisted in the conception of *circle* and *shell*.

Summary

As can be seen from these three examples, the research of each group is closely related to the others. At the same time each group's approach is sufficiently different that their research complements the others. Similar statements can be made about the remaining three groups. Further, different groups have focused on different groups of students. The students include university-bound students in science classes, physical science students in both high school and college and physics majors at universities. Thus, overall the poster session will provide meeting participants with broad view of the research and development for the learning of quantum science.

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