Title: Teachers’ views on teaching quantum physics at junior college level
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Abstract
Nanotechnology, precise medical devices, quantum computers etc. no longer require classical physics as a physical framework. It rather needs quantum physics. As the implementation of quantum physics is quickly reaching out to every field of science, getting acquainted with quantum physics as early as at high school level is an important task to accomplish. That is why studies on teaching quantum physics in a more efficient and innovative way are on the rise. This paper addresses a part of this issue within the Singapore context. In this note, the views of Junior College physics teachers on quantum physics are sought. Teaching materials, resources as well as difficulties encountered at schools are investigated. Teachers' views on IT resources and experiments instructed in quantum physics are assessed. Since the current GCE A Level curriculum implemented in Junior Colleges in Singapore will be replaced with an enlarged version in 2006, teachers' preparedness and thoughts on possible curriculum changes are also evaluated. Finally, novel and more resourceful teaching strategies are proposed as far as teaching quantum physics is concerned.

Introduction
Ever since quantum effects were first observed in the beginning of the twentieth century, quantum physics has been shocking the world with its unbelievably successful physical framework. These earlier attempts had actually given birth to two new physical frameworks: Relativity and Quantum Mechanics. Relativity has changed our conventional views on space-time with the giant efforts of Albert Einstein. On the other side, Bohr led the group of quantum mechanics proponents. This group had even shaken the tenets of classical physics which promised a deterministic physical world view, by adding an indeterminism flavour into the physical phenomena.

Quantum physics explains a number of phenomena which do not have their counterpart in classical physics. Therefore it is perceived as unique and strange from the classical physics point of view. There is no convincing consensus between quantum mechanics and relativity either. It can be said that quantum physics is considered "weird" from the perspective of classical physics as well as from the perspective of relativity. This weirdness of quantum physics has been summarized by the great physicist Richard Feynman as...
follows: "I think I can safely say that no body understands quantum mechanics" (Feynman 1967).

One of the weirdness of quantum physics is the wave-particle duality of light. The disagreement over the issue of wave-particle duality of light became very serious. Niels Bohr (founder of quantum mechanics) and Albert Einstein (founder of special relativity) had ended up discussing whether God played dice or not in the physical world. Eventually Einstein died a non-believer in the quantum theory of light.

It is certainly not an exaggerated statement to claim that quantum physics is the most successful theory in the history of mankind to explain the phenomena happening in the atomic and subatomic world. And today, we are so grateful to the quantum physical phenomena for enabling us to build current precise technological instruments in every field even though there are still certain issues which have not been addressed. These issues have yet to be addressed because of the fact that we are not able to carry out experiments in the subatomic world with ease at this present time.

The latest technology boon is nanotechnology which produces devices at the nano (10^-9 m) scale for applications in medicine, engineering and life sciences. The physical framework needed to work in today's most popular research area is certainly quantum physics.

The quantum storm not only affected the physical sciences but also the social sciences. Social scientists such as philosophers and sociologists are now vigorously contributing to the conceptualization of quantum physics (Alm 2004; Magnus 2004). The people of this age and the future cannot live without feeling the effects of the quantum in their lives because quantum physics plays a great role in every field of science including philosophy.

Since curriculum designers and planners dedicate themselves to cultivating the next generation with useful and relevant knowledge, it obviously becomes a critical issue to infuse quantum physics into the high school curriculum and to enhance the objectives of quantum physics in the curricula.

The principles of classical (Newtonian) physics are still taking up so much time in teaching physics at schools. Unfortunately the time allocated for quantum phenomena is much less than that for classical physics. The new curriculum to be introduced in Singapore in 2006 promises greater coverage of quantum physics with sufficient teaching time. However, effective teaching and learning of quantum physics is crucial as the concepts of quantum theory tend to run counter to common sense. If these concepts are not communicated carefully, serious misconceptions and misunderstandings in both teachers' and students' minds could occur.

**Literature Review**

There is already a growing trend all over the world about how to familiarize students of quantum physics with relevant knowledge and expertise at secondary school and tertiary level.
Students' conceptions are quite important as pre-instructional conceptions mostly affect the performance of acquiring new concepts. Research studies on students' conceptions of quantum physics show that students are still holding their classical viewpoints (Mashhadi and Woolnough 1999; Ireson 2000). A number of thriving proposals were recommended to overcome this barrier (Fischler and Lichtfeldt 1992; Mashhadi 1996; Petri and Niedderer 1998; Olsen 2002).

Since the mathematical aspect of quantum physics is also responsible for poor understanding, the conceptual teaching of the content was suggested and successfully implemented (Mueller and Wiesner 2002). It was found that the proposed method is much better than traditional way of lecturing.

Students' links to classical physics could be reduced with the proposal of (Budde et al 2002) a new atomic model, 'Electronium'. This model was first proposed by (Herrman 2000) and is believed to give a good starting point to students to understand the accepted scientific view as far as quantum physics is concerned. The main suggestion in the Electronium atomic model was that the electron is considered as a kind of liquid around an atom. This approach was effectively acquired by students. It was shown that students retain the Electronium atomic model longer than other atomic models (probability, Bohr's and spatial shell atomic models).

**The Study**

In this study, we investigated teachers' views on quantum physics and the teaching and learning process of quantum physics by administering a questionnaire. Teachers were selected from various Junior Colleges (Grade 11-12) in Singapore. First of all, we wanted to find out their interest in quantum physics and their personal feelings on the current practice of teaching quantum physics. We also wanted to evaluate teachers' readiness for the new curriculum to be implemented in 2006.

**The Questionnaire**

One hundred and sixteen physics teachers from 15 junior colleges responded to our questionnaire. The questionnaire consists of 33 items. The first 13 items are open-ended questions and the rest of them reflect teachers' views on a scale of strongly disagree (1) to strongly agree (5). The items of the questionnaire were grouped accordingly to provide information on the following:

1) **Teachers' attitude towards quantum physics.** Items related to teachers' interest, confidence level and appreciation of quantum physics and its applications were analyzed.

2) **Teachers' views on the current curriculum.** Factors affecting teachers' views on the current curriculum as far as quantum physics is concerned were appraised under this theme. Their ideas over the issue of a probable new curriculum were also covered.
3) **Teachers' views on IT usage.** IT facilities used in teaching quantum physics were evaluated.

4) **Teachers' views on experiments.** Items focusing on the experimentation of quantum physics and the experiments carried out in the schools were checked.

5) **Difficulties encountered.** Items reflecting teachers' views on the setbacks of teaching quantum physics were evaluated.

6) **Teachers' views on professional development.** Issues on teachers' stand towards training, such as professional workshops on effective quantum physics teaching, were assessed.

### Results and Discussion

Difficulties encountered during the process of teaching and learning of quantum physics were identified. Teachers employed a variety of teaching strategies. We comment on these strategies and assess the effective usage of them in the allocated time frame for teaching quantum physics.

**Teachers' Attitude towards Quantum Physics**

Teachers who have confidence in their professional skills are more successful in terms of keeping up-to-date their teaching materials and implementing new educational ideas such as IT facilities in the classroom (Ehrlich 2002). In support of this finding, our questionnaire results showed that teachers appear to be very confident of themselves (86%) as far as accomplishing the current junior college physics syllabus was concerned. Teachers (89%) were generally interested in quantum physics. They (82%) believed quantum physics was a necessary content for students to learn at Junior College level. They (73%) also believed that quantum physics would have an impact on science and technology in near future.

They not only kept themselves updated with recent physical innovations and research studies (75%) but also helped their students (56%) updated on recent developments.

**Teachers Views on the Current Curriculum**

The current GCE A Level curriculum will be revised in 2006. This change will enable students to be exposed more to quantum physics and its implications. Let us find out what teachers think about the current practice and possible changes in the curriculum.

Teachers did not seem to be interested (42%) in accomplishing additional objectives on quantum physics in spite of the fact that they are well-versed on the GCE A Level syllabus. Possible reasons are as follows

- Heavy teaching load and administration work
- The stress of GCE A Level that they have to go through together with students.
Teachers did not agree with the idea of having a quantum physics paper in the GCE A Level examination (63%) but at the same time did not agree with the exclusion of the quantum physics from the syllabus (75%). They were quite happy with the current situation as the quantum physics questions in the examination are not very challenging for students. They preferred this examination-oriented trend to carry on.

Teachers disagreed (64%) with the idea that we start teaching quantum physics only at the university level. They think that students should be taught quantum physics, at least an introduction, at the junior college level so that they can delve deeper at university. They believed that the current practice for learning quantum physics is satisfactory for students before enrolling in universities.

Quantum physics was considered as one of the easiest sections as far as the GCE A Level examination was concerned (46%). Teachers (69%) believed that students were not having great difficulties in understanding quantum physics compared to other chapters with the current practice.

Teachers (81%) would only appreciate new changes towards better teaching and learning experiences but they preferred not to have a drastic change in the curriculum. This could due to the fact that there are serious issues like difficulty in carrying out quantum experiments, difficulty in finding daily life examples as well as the quantum concepts appearing to be against the conventional classical thinking.

59% of the teachers spent less than 8 hours to teach quantum physics. The 23% stated that they spent more than 8 hours including tutorial periods, IT activities and experiments.

Teachers (54%) neither disagreed nor agreed with increasing number of hours allocated for teaching quantum physics.

**Teachers' Usage of IT**

"Which IT facilities do you use in teaching quantum physics?"

Only 51% of the teachers responded to the IT related question above (Item #3). Teachers (56%) generally ran educational CD-ROMs and surf the relevant websites as an IT activity in teaching quantum physics. The main reason for not being able to benefit much from IT facilities was that the number of hours allocated for the section on quantum physics was limited to 8 hours on average. Another major setback was there were insufficient useful websites and educational materials available in the market. This resulted in the fact that teachers hardly use IT facilities for teaching quantum physics.

A few of them managed to name a website (29%) and an educational CD-ROM (21%) related to quantum physics. The CD-ROMs that they were using in the classes came with the textbooks. Some of the websites and CD-ROMs named by teachers are as follows:
Quantum physics is too abstract (31%),

Inability to carry out experiments (13%),

Lack of school resources (8%),

Lack of students' interest in quantum physics (8%).

Most teachers (77%) firmly believed in the conceptualization of quantum physics and they tried to implement this approach in their classrooms. However they had a hard time in introducing these quantum concepts to their students. One of the reasons is because students have been used to defining physical events through definite behaviours in classical Newtonian physics. The wave-particle duality in quantum physics suggests an indefinite behaviour of light and this is a great shock to them. In addition, some quantum concepts do not have their counterparts in classical physics.

**Teachers' Views on Professional Development**

Teachers usually prepare their own notes and set questions in line with the GCE A level syllabus. Few of them comprehensively follow a specific textbook. They were not happy with being unable to demonstrate hands-on activities and to find more complete CD-ROMs and websites. The majority of them supported the idea of producing new teaching resources. In fact some of them even made attempts to develop their own websites.

Teachers (47%) generally agreed to participate in professional workshops on how to teach quantum physics at Junior College level in more innovative and effective ways.

**Implications**

After the survey, we realized that the current syllabus for quantum physics is quite insufficient for students in order to gain a better understanding of the quantum world. Initially we thought of proposing to increase the number of hours and objectives. It is a timely move for MOE that the revised JC curriculum with greater emphasis on modern physics will be implemented in 2006. We believe that this enhanced curriculum will boost students' perception of quantum physics.

Students' conceptions on quantum physics are affected by their preinstructional knowledge of "classical physics". The conceptual shift from classical understanding to a quantum viewpoint is a difficult task to achieve. In order to visualize quantum entities, we may have to use a classical viewpoint as an anchor in the beginning. Moreover, one should not forget that quantum physics is still incomplete and we still do not know which interpretation is exactly correct. Students should therefore be exposed to a number of interpretations and explanations, including the classical worldview, to understand the quantum mechanical facts. This approach will significantly help them in constructing their own point of view and hence possibly find a complete justification.
activities and time spent on quantum physics should definitely be increased for a better understanding of quantum world.

Lack of experiments and IT resources are still the main obstacles in teaching quantum physics with greater ease. Designing more experiments and sourcing out for more IT activities to make the content more accessible to students are the main tasks to achieve.

Even though teachers are confident of themselves as far as the GCE A Level examination is concerned, their content knowledge should be enriched periodically with professional developments and workshops.

Since preconceptions also play a part in understanding a new subject, careful analysis is required to shun away from misunderstandings. For this purpose, small scale proposed sample teaching units should be prepared to make the content more accessible to teachers and students.

Researchers', teachers' and students' conceptions regarding with quantum physics are not the same. In order to speak the same language, activities bringing researchers, teachers and students together should be arranged in the format of mentorship, workshop, discussion groups etc. so that every member can understand the others very well.

References