PRELIMINARY RESULTS FROM A NEW QUANTUM MECHANICS CONCEPTUAL SURVEY

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Abstract
Conceptual surveys have been used to probe various aspects of physics education research, such as the identification of students' misconceptions, and the evaluation of the efficiency of pedagogical material. They have also been used to compare gains in students' conceptual understanding across a variety of teaching methodologies, curricula, and course structures; and between instructors or universities. However, research into students' understanding of quantum mechanics has received, to date, only limited attention, and there is no unanimity on which are the best diagnostic tools in the area. Therefore, we have developed a concept survey on the basic ideas underlying quantum physics, which we call the Quantum Physics Conceptual Survey. This survey was initially developed from data gathered with students at Mahidol University, Thailand; followed by analysis of responses of third and fourth year students at The University of Sydney. This paper describes how specific questions have changed as a result of analysis of distribution of students answer to produce a conceptual survey ready for use with students. It will be used in the first instance to compare Thai and Australian physics students' understanding of fundamental quantum concepts at the start of their first serious course on quantum physics.

Introduction
There are many ways to identify misconceptions such as interviews, short questionnaires, concept maps and conceptual surveys. Conceptual surveys are paid more attention and have increasingly been used by a wide range of physics teachers to probe various aspects of physics education research not only for identifying misconceptions but also for the evaluation of the efficiency of pedagogical material. In addition, they have also been used to compare gains in students' conceptual understanding across a variety of teaching methodologies, curricula, and course structures; and between instructors or universities (Davis 1997). In recent years, an increasing number of conceptual surveys covering many physics topics have been developed — such as the Force Concept Inventory (Hestenes et al. 1992), the Force and Motion Concept Evaluation tool (Thornton and Sokoloff 1998), the Heat and Temperature Concept Evaluation survey (Laws 2006), the Electricity and Magnetism Concept Survey (Maloney et al. 2001) and the Quantum Mechanics Visualization Instrument (Robinett 2005). However, research into students' understanding of quantum mechanics has received, to date, only limited attention (McDermott and Redish 1999), and there is no unanimity on which are the best diagnostic tools in the area. Therefore, we have developed a conceptual survey on the basic ideas underlying introductory quantum mechanics, called the Quantum Physics Conceptual Survey (QPCS).

This paper describes the evolution of the conceptual survey questions and how feed back from students has been used to produce the final version of the conceptual survey.

Background
The initial development of the QPCS employed two main procedures: First, content definition and second, question generation. These aspects have been presented in Wuttiprom et al. (2006) and are summarized below. This paper focuses on pilot testing and test revision.

Content Definition
To define the pertinent introductory quantum physics concepts, we
- examined course syllabuses from eight universities in Thailand to establish content coverage,
- consulted with experts from the Department of Physics at Mahidol University to extract fundamental content areas, and
- trialed the University of Maryland Tutorial on the wave particle duality (Redish et al. 2006) and Photoelectric Effect Conceptual Evaluation test (Wuttiprom 2005) to determine how the selected content areas align with students' difficulties.

Question Generation

To generate the conceptual survey, the questions were created based on data gathered during *content definition*, text books (such as Hewitt 2005; Halliday et al. 1997; Knight 2003a, 2003b), literature (such as Fletcher and Johnston 1999) and websites (such as McKagan and Wieman 2006). All of the questions were reviewed and commented on by experts, postgraduate and undergraduate students at the School of Physics, University of Sydney. The questions were modified as we went through several iterations of the survey.

Method

The first version of QPCS comprises of 20 questions covering the five themes listed in Table 1. The survey can be viewed at http://www.physics.usyd.edu.au/super/QuantumSurvey/.

Table 1: Number of questions for each theme of the QPCS

Final themes of the QPCS	Questions on the QPCS
Theme 0: Photoelectric effect	1, 2, 3, 4
Theme 1: Wave particle duality	5, 6, 7, 8
Theme 2: de Broglie wavelength	9, 10, 11
Theme 3: Analysis of a double slit experiment	12, 13, 14, 15, 16
Theme 4: Uncertainty principle	17, 18, 19, 20

The pilot testing took place at the School of Physics, University of Sydney in semester 1, 2006. The first pilot testing was with 22 volunteer third year students who were informed two weeks prior to the testing that the test would be on introductory quantum physics. This trial was carried out in week nine just before a laboratory session. The students were not doing any concurrent quantum physics courses at the time of this trial. However, eight students were doing a Nanoscience course which does involve quantum concepts. The second trial occurred three weeks later with 20 fourth year students who were suddenly asked to do the test at the end of the last lecture of their Advanced Quantum Mechanics course. Both groups of students took no longer than 30 minutes to complete the survey.

Test Revision

The questions were analyzed in terms of ambiguity in wording and structural difficulties as perceived by students. We focused on comments made by students, anecdotal feed back and perusal of answers.

Three questions were changed as a result of the trial with third year students and in consultation with physics experts. First, the position of labels on an image of the diffraction pattern was repositioned. Second, the option to select "*none*" was added to the question. This was because some students were indicating that none of the available choices were correct. These two changes were minor and were not expected to influence student choices significantly. Third, question 20 was changed from having more than one correct answer, to having only one correct answer. This was done by simply asking students to select the *true* choice rather than the *false* choice, as shown below.

20. For the double slit experiment with electrons, which of the following statements is ***true*** according to the standard (Copenhagen) interpretation of quantum mechanics?

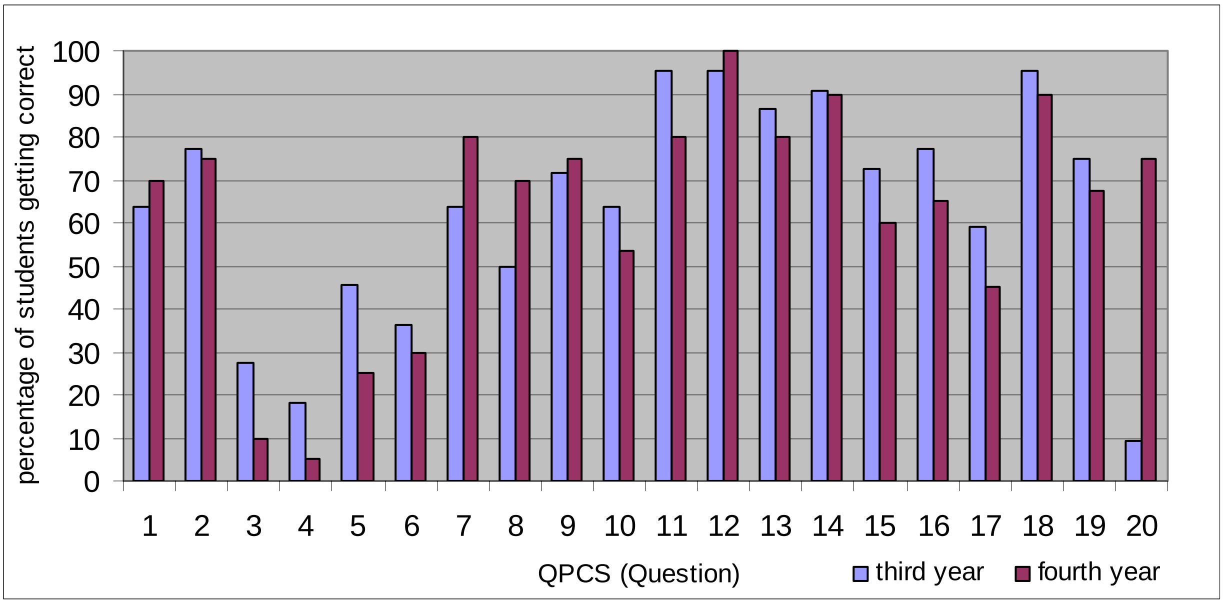
A. It is in principle possible to measure which slit an electron went through and still see an interference pattern, if the technology is sophisticated enough.
B. Each electron must have gone through one slit or the other, but it is impossible to measure which slit any one particular electron went through.
C. It is possible to measure which slit an electron went through, but if you make this measurement, the beam of electrons will no longer form the interference pattern.

Results and Discussion

Figure 1 shows the distribution of correct answers for the third and fourth year trials. Since the above changes affected questions 12 through 16 (these questions were related to the change in position of labels on an image), 19 and 20, these cannot be directly compared for the two cohorts. We note that as expected the first two changes had small effects on student answers. However, the change to question 20 resulted in many more students giving correct answers. This indicates that the ambiguity in question wording has been eliminated.

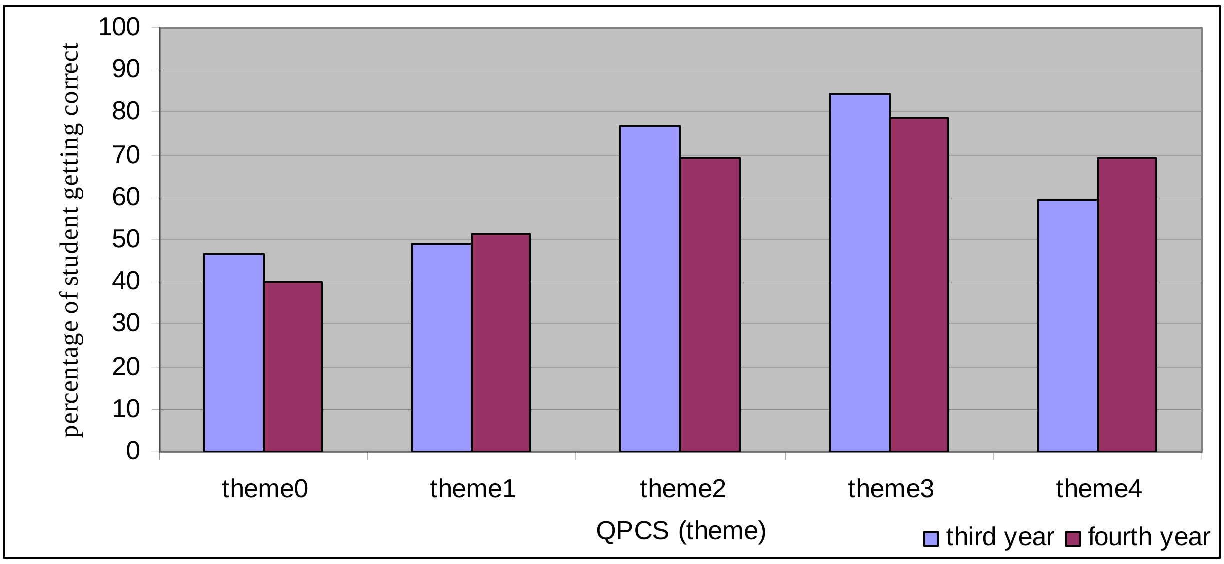
The overall distributions of students' answers are similar for third and fourth year groups. This consistency implies that the questions are interpreted in similar ways and the instrument is reliable.

Figure 1. Percentage of students answering each question correctly



It can be seen that students have particular problems with questions 3 and 4 relating to subtleties in the photoelectric effect. The percentage of students answering correctly decreases by nearly three times from third year to fourth year. This could be because the photoelectric effect is taught in first year and not revisited in depth in later years.

Figure 2: Percentage of students answering each theme correctly



The average score for the third year students is 63.69 (standard deviation of 5.76) and fourth year students is 62.29 (standard deviation of 5.93), that is, the scores are nearly the same. In order to compare students' performance on themes the data has been grouped into the themes identified in Table 1, see Figure 2. We find that the trends are the same in both groups of students. However, in most questions and themes, fourth year students score lower than third year students. This could be because the fundamental concepts are not revisited in fourth year courses. This trend needs further investigation, possibly with in-depth interviews and examination of instructional materials.

Future Directions

We now need to investigate the reliability of the test and carry out individual question analysis. We will be focusing on features such as item difficulty index, item discrimination index, item point biserial coefficient and Ferguson's delta. We will be administering the survey to first and second year Australian students and Thai second year students.

Conclusions

The results indicate that our survey is clear, easy to understand, at the right level of difficulty and the themes represent important concepts for students to know in introductory quantum physics.

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