THAI JOURNAL OF PHYSICS, SERIES 3, 172 (2008)

SPC2007
Nakhon Pathom

Developing a conceptual survey in fundamental quantum physics

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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 the distribution of students answers 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.

1. 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 [1]. In recent years, an increasing number of conceptual surveys covering many physics topics have been developed — such as the force concept inventory [2], the force and motion concept evaluation tool [3], the heat and temperature concept evaluation survey [4], the electricity and magnetism concept survey [5] and the quantum mechanics visualization instrument [6]. However, research into students' understanding of quantum mechanics has received, to date, only limited attention [7], 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 feedback from students has been used to produce the final version of the conceptual survey.

2. 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. [8] and are summarized below. This paper focuses on pilot testing and test revision.

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2.1 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 [9] and Photoelectric Effect Conceptual Evaluation test [10] to determine how the selected content areas align with students' difficulties.

2.2 Question Generation

To generate the conceptual survey, the questions were created based on data gathered during content definition, text books [11-14], literature [15] and websites [16]. All of the questions were reviewed and commented 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.

3. METHODS

The first version of the QPCS comprises of 20 questions covering the five themes listed in Table 1. The survey can be viewed at http://www.sc.mahidol.ac.th/scpy/penthai.

3.1 Pilot Testing

The pilot testing took place at the School of Physics, University of Sydney in the semester 1, 2006. The first pilot testing was conducted with 22 volunteer third year students who were informed two weeks prior to the testing that the

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

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.

3.2 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 feedback 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 changes of two questions were minor and were not expected to influence student choices significantly. The third question, Q20, 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

> Q20. 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.

4. 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, 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.

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 the 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.

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.

5. FURTHER 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. By completing these analyses, our test should be claimed as an effective tool for probing students' understanding in introductory quantum physics.

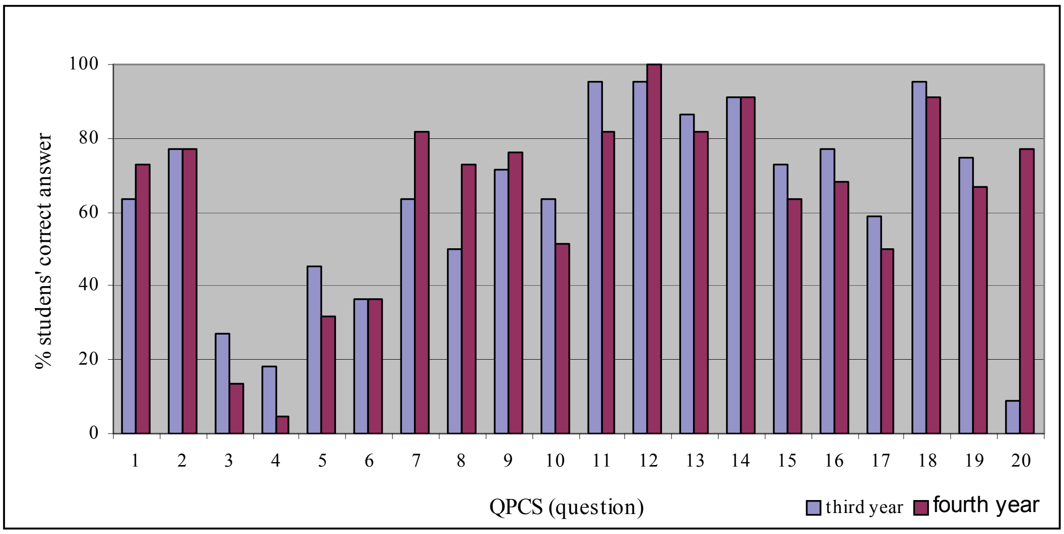

FIGURE 1. Percentage of students answering each question correctly.

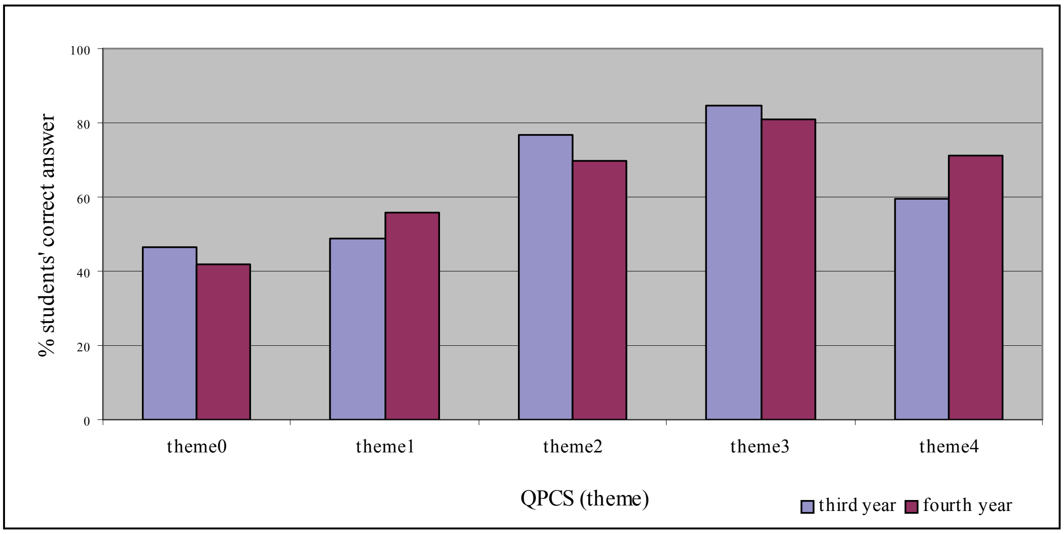

FIGURE 2. Percentage of students answering each theme correctly.

6. 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.

ACKNOWLEDGMENTS

This project could not have been carried out without support from PENThai (Physics Education Network of Thailand), SUPER (Sydney University Physics Education Research), and Institute for Innovation and Development of Learning Process, Thailand. The authors gratefully acknowledge funding provided by the Faculty of Science, Ubon Rajathanee University, Thailand.

1. B. G. Davis, Misconceptions as barriers to understanding science, in B. G. Davis (Ed) Science teaching reconsidered, A hand book. Washington, D.C: National Academy, 1997.
2. D. Hestenes, M. Wells, and G. Swackhammer, Force Concept Inventory, The Physics Teacher, 30, 141-151, 1992.
3. R. K. Thornton and D. R. Sokoloff, "Assessing student learning of Newton's laws", Am. J. Phys, 66, 338-352 (1998).
4. P. Laws, Assessment: Action research kit [Online] Available: http://physics.dickinson.edu/~wp_web/wp_resources/wp_assessment.html [2006, June 20].
5. D. P. Maloney, T.L. O'Kuma, C. J. Hieggelke, and A. V. Heuvelen, Surveying students' conceptual knowledge of electricity and magnetism. Am. J. Phys, 69, S12-S233 (2001).
6. R. Robinett, (2005) Quantum mechanics visualization instrument [Online] Available: http://www.phys.psu.edu/~rick/OUP/INSTRUCTORS/QMVI/alt_QMVI.htm.
7. L. C. McDermott and E. F. Redish, Am. Assoc. Phys. Teachers, 67, 755-767 (1999).
8. S. Wuttiprom, R. Chitaree, C. Soankwan, M. Sharma, and I. Johnston, Developing the prototype conceptual survey in quantum physics. Proceedings of the National UniServe Conference. Sydney. Australia, 2006.
9. E. F. Redish, R. N. Steinberg and M. C. Wittmann, (2006) Quantum mechanics tutorial [Online] Available: http://www.physics.umd.edu/perg/qm/qmcourse/NewModel/qmtuts.htm.
10. S. Wuttiprom, R. Chitaree, and C. Soankwan, Exploring students' ideas to develop a conceptual evaluation test in quantum mechanics. World View on Physics Education in 2005: Focus on change Proceedings of the International Conference on Physics Education. New Delhi. India, 2005.
11. P. Hewitt, Conceptual Physics (9th ed.). Addison Wesley, 2005.
12. D. Halliday, R. Robert and J. Walker, Fundamentals of physics (5th ed.). USA: John Wiley and Sons, 1997.
13. D. R. Knight, Five easy lessons: Strategies for successful physics teaching. Addison Wesley, 2003.
14. D. R. Knight, Physics for scientists and engineers with modern physics: A strategic approach. Addison Wesley, 2003.
15. P. Fletcher and I. Johnston, Quantum mechanics: exploring conceptual change. In D. Zollman (Ed) Research on Teaching and Learning Quantum Mechanics Research Proceeding of the annual meeting National Association for Research in Science Teaching. Boston, MA: 116 Cardwell Hall, Kansas State University, United States, 1999.
16. S. M. McKagan and C. Wieman, (2006) The quantum mechanics conceptual survey [Online] Available: http://cosmos.colorado.edu/phet/survey/QMCS/.