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Exploring Student Understanding of Quantum Mechanics through QMCS.

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Abstract— Quantum mechanics is undoubtedly a set of challenging theories developed to explore the microscopic world. Quantum interpretations of subatomic world are fascinating due to its challenges posed to the classical intuition. The students have some preconceptions and misconceptions about quantum mechanics based on their previously acquired classical experience. Conceptual surveys have become popular tool for probing student conceptual understanding and assessing the effectiveness of pedagogical teaching learning strategies. In Indian educational system, fundamental issues of quantum mechanics have incorporated in curriculum at secondary level. A separate full length core/elective course on fundamentals of quantum mechanics/modern physics has been introduced at under graduate level (junior quantum course). The Quantum Mechanics Conceptual Survey (QMCS), a validated set of 12 questions have developed for probing the conceptual understanding of quantum mechanical of undergraduate students. In order to probe various aspects of student's conceptual understanding of quantum mechanics and measure the effectiveness of teaching strategies in imparting the knowledge, QMCS is used. It measures student's understanding of quantum mechanics in general, with an emphasis on misconceptions and threshold concepts that may block a deeper under-standing of quantum mechanics. QMCS was circulated to more than hundred students of second semester undergraduate physics core and elective course of Govt. Post Graduate College Chamba (H.P.), India. On the basis of pretest results of QMCS it has been concluded that the students faced many conceptual difficulties in understanding the fundamentals of quantum mechanics after secondary stages. We have speculated that our teaching learning strategies and peer-instruction tools can significantly reduce the difficulties but still the posttest results of performance of students are less than 70%. Thus more effective teaching strategies are required for proper conceptual understanding of the subject matter.

Index terms -Physics Education Research, Quantum Mechanics Conceptual Survey, Teaching learning strategies.

I. INTRODUCTION

In recent years, the subjective conceptual education research has gained lot of prominence in effective delivery of subject matter. Generally subject experts are better equipped and capable to draw strategies for effective learning of a subject with well-defined subject based learning outcomes [1]. Quantum mechanics is one of the core courses in undergraduate physics curriculum. Conceptual visualizations of fundamental concepts of quantum mechanics are very important for understanding of physical phenomenon at subatomic level. Most of the advanced level physics courses involve application of the concepts taught in quantum mechanics. In addition to the lack of direct visualization to microscopic phenomena described by quantum theory and its counter intuitive nature, the required mathematical understanding may increase cognitive pressure on students and make learning quantum mechanics more challenging [2]. It is well known that pre-existing knowledge and beliefs strongly influence the further learning of concepts. The fundamental importance of quantum mechanics is that it can express the limitation of our classical concepts in a precise mathematics from. Our classical notion is not adequate to explain the phenomenon at microscopic scale. Quantum mechanics is undoubtedly one of the most challenging theories in modern physics. It is one of the important courses that an undergraduate student takes before they complete their bachelor's degree. The course draws a significant amount of material from other upper division courses in mathematics and physics. Whilst it allows us to describe phenomena at the atomic scale, it is probably also one of the most philosophically challenging theories with which our students come into contact. Since it has a wide applicability, it is important for physics students to develop a thorough understanding of the subject. The upcoming field of quantum mechanics has revolutionize the technique of secured information exchange requires an in depth understanding of basic concept of quantum mechanics.

Today, it is accustomed to investigate student's difficulties in understanding conceptual quantum mechanics. Several findings indicated that they do face quite challenges in learning quantum mechanics [3].The number of conceptual difficulties and their remedies has been proposed by studies conducted in the different parts of the world. One key goal of Physics Education Research (PER) is to provide research-based instructional techniques and tools for assessing the complex learning goals associated with conceptual understanding of quantum mechanics.

In newly adopted choice based credit system in Himachal Pradesh university Shimla, a course on quantum mechanics has been introduced in undergraduate classes as a core/elective course. In Indian education system the basic concept of quantum mechanics has been incorporated in the syllabus at secondary level. On one hand in western countries most of the studies on student's conceptions of quantum mechanics have been carried out primarily at the first year level, using the common quantitative assessment tools. On the other hand, the ineffectiveness of the traditional instructional method has been least tested on Indian physics students in undergraduate contexts. Thus, there is a need for exploration of college student's conceptual understanding of quantum mechanics in Indian educational system. Furthermore, an important notion of improvement with regard to specific quantum mechanics learning and teaching is to be aware of the difficulties students typically face while learning and using the results to develop strategies to improve students' understanding.

It is important for assessing student's difficulties and for evaluating curricula and pedagogies that strive to reduce the difficulties. The reliable, validated quantum mechanics conceptual survey can be used to evaluate the effectiveness of teaching learning strategies for conceptual understanding of quantum mechanics. In the present study, we aim to explore student's conceptual understanding and knowledge of the fundamentals of quantum mechanics in context to Indian educational system in general and choice base credit system (CBCS) adopted by H.P. University, Shimla in particular

B. GOAL OF THE SURVEY

In most of the Indian colleges and universities, the structure of a typical introductory physics course has remained essentially static for almost 40-60 years. Traditional teaching of quantum mechanics generally involves one of two distinct approaches to introducing students to the basic concepts of quantum mechanics. Teaching programs for the physics or quantum physics degree courses at the university and college level traditionally operate within the framework provided by the triad of lecture, laboratory and tutorial/ recitation. These are routinely designed to cover an impressive list of topics conceived to be of core importance in the learning of the subject. The traditional course structure and teaching style has a number of problems. Unlike classical physics, the area of quantum physics has little relation to experiences of students in everyday life. This makes quantum physics very difficult to teach. The teacher taught ratio is very high; it is generally above 1:60. The newly adopted CBCS system in H.P. University Shimla has very short teaching hours of semester for teaching students. Often, there is so much material to cover that students do not have time to develop a solid understanding of any single part. Also in present examination system it becomes difficult for a teacher to develop one to one interaction and evaluate their performance in continuous and comprehensive manner. Furthermore, the traditional examination system uses only the fixed set of problems repeatedly. Therefore even after getting high grade in the examinations students generally lack in their conceptual understanding. In addition, delivering whole syllabus in very short time inhibit teachers to use advanced classroom teaching learning techniques which can promote student learning. As a result, students do not get a sense of physical concepts, and after taking one course in physics, many students never take another course of same topic in physics. The traditional course, based on pure lecture, neither helps students to develop good critical thinking skills nor improves their intuition to overcome their misconceptions. The broad development of the applications of quantum technology makes it desirable to introduce some basics of quantum phenomena to a larger population of students early on. However, the abstract nature of quantum mechanics concepts and high level of mathematics involved in this requires different approaches in teaching the course at the introductory level.

Thus in order to evaluate or get feedback about the previous knowledge of the subject, well established QMCS was operated as the pretest. The same QMCS was also circulated after six month on completion of the syllabus. The aims of this research were to use the QMCS in Indian educational system in general and H.P. University in particular to test student's understanding of quantum mechanics, identify areas of poor performance in quantum mechanics and effectiveness of prevail teaching strategies in understanding of quantum physics. The QMCS has been used as a formative assessment tool to measure the effectiveness of teaching methods used for improving students' conceptual understanding of quantum mechanics. As per the standard practice for research-based PER conceptual test, we have protected the security of the test by keeping it away from the students. After administering it in respective class we do not allow students to take the tests home. It can only be procured from the referred authors of the QMCS.

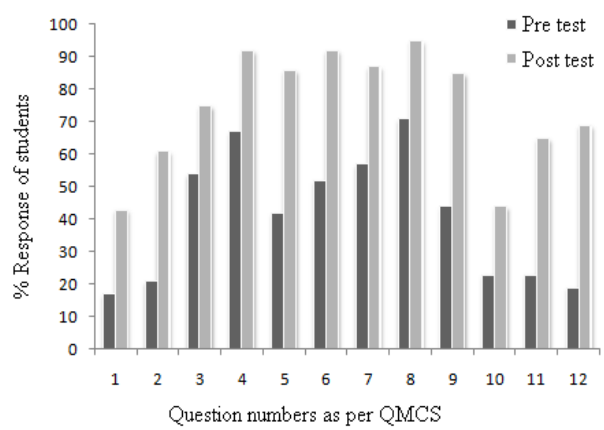

Figure 1. The percentage response of pretest and posttest of the respondents**.**

II. RESEARCH REVIEW

The physics education research aims at improving the teaching learning strategies by finding the difficulties of learner and developing teaching learning pedagogies for further improvement in the learning level. A different conceptual inventory has been developed by researchers for different fields. Although the conceptual inventories are developed in different parts of the world based upon their curriculum and reliability and validity testing in their institutions or respective areas. This conceptual test can also be applied in other countries if the curriculum of the topic is same.

Many conceptual surveys have been developed and 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. However, research into students' understanding of quantum mechanics has received, to date, only limited attention.

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 is the best diagnostic tool 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).

A. METHODOLOGY:-

Quantum PER into the concepts held by students is insufficient and specific in only few topics of quantum mechanics. The few studies that have been carried out, have concentrated on secondary school education and first year university students. The condition with regard to undergraduate physics students is, again, such that little or no research is present within the Indian context. Specific well-documented examples of physics student difficulties in depicting quantum concepts are often lacking, and the exact nature of the difficulty is often uncertain. Indeed, context-specific research is necessary at a time when the physics departments in Indian universities and colleges is faced with multiple pressures from the government and employers, from social economic and technological changes, and finally from the specific and changing demands of our undergraduate students.

Being a teacher and researcher it is our responsibility to notice students who have difficulties of understanding in various concepts of physics in every step of education system. Especially, in college and university education one of the most complicated disciplines for students is quantum physics. The aim of this study was to analyze these challenges and investigate students' understanding of quantum physics.

In order to uncover which topics are most important in quantum physics, we began by analyzing the syllabi of core course in quantum mechanics (BSCPHY0203) as per newly adopted choice based credit system offered in second semester for students of major and minor physics. It has been found that important basic topics covered in the syllabus are wave function and probability, wave-particle duality, Schrödinger equation, quantization of states, uncertainty principle, superposition, operators and observables, tunneling and measurement. After carefully reviewing the literature it has been found that number of conceptual inventories on the topics has been developed by many physists. We did a literature search on the themes and found two conceptual inventories on quantum physics Quantum Mechanics Visualization Instrument (QMVI) (Robinett 2005) and Quantum Mechanics Conceptual Survey (QMCS) (McKagan and Wieman 2006). The QMVI questions have not been used because it contains questions which are at an advanced rather than introductory level. Over viewing all theses it has been found the QMCS developed by S. B. McKagan, K. K. Perkins, and C. E. Wieman is most appropriate as per the syllabus adapted to India educational system in general and H.P. University Shimla in particular. The main intention of the study was to investigate students' conceptual understanding of quantum physics. They have also been used to compare gains in students' conceptual understanding.

B. CONCEPTUAL SURVEY

The QMCS has been developed as a formative assessment tool for faculty to measure the effectiveness of different teaching learning pedagogies for improving students' conceptual understanding of quantum mechanics. Authors believe that it is useful for this purpose in modern physics courses as well as junior quantum courses. Version 2.0 of the QMCS was administered as pretest and posttest to the students of undergraduate IInd semester students of core/elective fundamentals of quantum mechanics (junior quantum mechanics) course.

III. RESULT AND DISCUSSION

The use of research based multiple choice tests about quantum mechanics is important for assessing students' difficulties and for evaluating teaching learning pedagogies that strive to reduce the difficulties. Research into students difficulties, misconceptions, or alternative conceptions must be a starting point for research into how students learn a quantum mechanics Indeed, once we are familiar with the prior knowledge of the students, we can consider effective strategies to help them build on their prior knowledge and construct a hierarchical knowledge structure and develop skills in applying relevant knowledge in various situations. The difficulty in conceptual understanding and visualization of fundamental concept of quantum mechanics are reflected by the result of the pre-test survey based on QMCS is represented graphical in figure 1. The percentage of pretest and post test scores of 134 students of fundamentals of quantum mechanics is tabulated in table 1 for comparison and critical analysis of the difficulty level of the concept and learning of the topic. Out of these 134 students 48 were girls and 54 have physics as a major subject in undergraduate courses. Due to rural background of Himachal Pradesh more than 60% investigated students have pre education in Hindi medium govt. schools. We have listed all students who took the QMCS version-02 as pretest and posttest in the one semester course. Uncertainties are standardized on mean as errors.

Q. No	Learning goals of QMCS	Pre-test	%	Post test	%
1.	Wave particle duality, Quantization of states	17	12.6	43	32

2.	wave-particle duality, wave function and probability, uncertainty principle, operators and observables	21	15.6	61	45.5
3.	Quantization of states	54	40.3	75	55.9
4.	Wave function and probability, wave-particle duality	67	50	92	68.6
5.	Wave function and probability, wave-particle duality	42	31.4	86	64.2
6.	uncertainty principle, superposition, operators and observables, measurement	52	38.8	92	68.6
7.	Quantum tunneling	57	42.5	87	64.9
8.	Schrödinger equation, quantization of states	71	52.9	95	70.8
9.	Schrödinger equation, quantization of states	44	32.8	85	63.5
10.	Schrödinger equation	23	17.2	44	32.8
11.	wave function and probability	23	17.2	65	48.5
12.	wave function and probability, measurement	19	14.2	69	51.5

Pre-Test Analysis

The results show that the on average the results of the pretest are below 50%. The range of correct response is 54 with average correct response rate of 40.9. The average deviation of the correct response calculated to be 16.85 with standard deviation of 18.8. The pretest results of students shows that they have far fewer preconceived ideas about the fundamentals of quantum mechanics. On the basis of pre-test data it can be speculated that the students face major difficulty in question 1, 2, 10, 11 and 12. As the pretest score of these questions is lowest it means students are lacking in proper conceptual understanding in these concepts. Question 1 is based on the application of fundamental concept of quantization of energy levels to determine the relationship wavelength and energy in electronic transition from higher energy state to lower one. The spread out of electronic energy level around the nucleus based on the interpretation of the solution of Schrodinger equation is reflected by question 2. Question 10 and 11 are correlated with the qualitative shape of solution of the Schrodinger equation and probability distribution of a function. Question 12 is based on model of quantum mechanics may be used to explain the Young's double slit experiment. All these questions are based on the fundamental understanding and visualization of wave function, wave particle duality, quantization of states, operators and observables. Students certainly have preconceived ideas that a particle can have a well-defined position and momentum, but at the same time, they do not have preconceived ideas of wave functions and many of the fundamental conceptual topics of quantum mechanics. The low response may be due lack of awareness of teaching learning strategies and thereof low learning level of students in Indian education system. Most of the students face difficulty in understanding basic concept of quantum mechanics on the basis of curriculum and pedagogical knowledge received at secondary level. Although in Indian 10+2+3 educational system the basic concept of quantum physics like wave particle duality, Born interpretation of wave function, photoelectric effect, matter wave, Davison and Germar etc are incorporated in the curriculum of physics at secondary stage and also a part of the national level competitive examination for entry into the medical and engineering services. In spite of all these, it can be speculated that most of the students lacks in proper conceptualization and visualizations of the concepts of quantum mechanics. Analysis of the results of this questionnaire does indeed reveal areas of weakness in student understanding of time-dependence as well as of other fundamental quantum mechanical concepts.

Post-test analysis

The results show that the on average the results of the posttest are above 70%. The range of correct response is 52 with average correct response rate of 74.5. The average deviation of the correct response calculated to be 15.08 with standard deviation of 17.5. The posttest responses shows the improvement in the learning level of students by said teaching learning pedagogies but still the understanding of problematic questions as already discussed in the pretest section is still no to the level of required level. It means the power point assisted conventional lecture method is not capable of improving the teaching learning pedagogies.

IV.RECOMMENDATIONS FOR FUTURE RESEARCH

Several recommendations for further research are generated as follows:

1. It is recommended that a study may be conducted to investigate the relationship between student's mathematical skills and their physics achievements in QMCS.

2. It is recommended that a qualitative study need may be conducted to get more information in reference to gender differences, social and educational background, language of learning.

3. Teaching learning in reference to specific topic and teaching pedagogies should be analyzed separately.

V. CONCLUSION

As an instructor, we must have a desire to explore efficient and effective ways to support improved conceptual understanding. For this purpose the QMCS survey was conducted on the students of major and minor course in fundamental of quantum mechanics to prove into their preconceptions, misconceptions and alternative conceptions about quantum mechanics based on their previous experience of classical mechanics. Our aim was to analyze the conceptual understanding of quantum mechanics and assessing the effectiveness of pedagogical teaching learning strategies in the context of Indian educational system. Unlike classical physics, the area of quantum physics has little relation to experiences of students in everyday life. On the basis of QMCS survey conducted it has been concluded that the conceptual understanding of the students of basic quantum mechanics after secondary stages is quite weak. The post-test results suggest improvement in the basic understanding of the quantum mechanics but still the results are less than 70%. Thus more effective teaching strategies are required for proper conceptual understanding of the subject matter. Thus some simulation or more effective teaching strategies are required for proper conceptual understanding of quantum mechanics. Further, special attention of tutor is required in the topics of poor gain.

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Appendix

We reproduce here, as examples, four questions from the latest version of QMCS

Q. 2. The electron in a hydrogen atom is in its ground state. You measure the distance of the electron from the nucleus. What will be the result of this measurement?

A. You will measure the distance to be the Bohr radius.

B. You could measure any distance between zero and infinity with equal probability.

C. You are most likely to measure the distance to be the Bohr radius, but there is a range of other distances that you could possibly measure.

D. There is an equal probability of finding the electron at any distance within a range from a little bit less than the Bohr radius to a little bit more than the Bohr radius.

Q.7 The total energy of an electron after it tunnels through a potential energy barrier is…

A. …greater than its energy before tunneling.

B. …equal to its energy before tunneling.

C. …less than its energy before tunneling.

Q.12. You shoot a beam of photons through a pair of slits at a screen. The beam is so weak that the photons arrive at the screen one at a time, but eventually they build up an interference pattern, as shown in the picture at right. What can you say about which slit any particular photon went through?

A. Each photon went through either the left slit or the right slit. If we had a good enough detector, we could determine which one without changing the interference pattern.

B. Each photon went through either the left slit or the right slit, but it is fundamentally impossible to determine which one.

C. Each photon went through both slits. If we had a good enough detector, we could measure a photon in both places at once.

D. Each photon went through both slits. If we had a good enough detector, we could measure a photon going through one slit or the other, but this would destroy the interference pattern.

E. It is impossible to determine whether the photon went through one slit or both.

Authors Profile

Dr. Hemant Pal is presently working as assistant professor of physics in govt college chamba (H.P.). He received his **M.Sc.** degree in physics as gold medalist from H. P. University Shimla, India, in 1999 and **Ph.D**. from NIT Hamirpur in 2015. His research interest includes nanotechnology, Physics education research and teaching pedagogy.

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