

Students' Understanding of Quantum Numbers: A Qualitative Study

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Abstract. Quantum physics involves counterintuitive abstract concepts and complex mathematical procedures that are difficult to understand by physics and chemistry students at university level. This study employs case study- one of the methods of qualitative study- and it aims to determine the difficulties prospective chemistry and physics teachers encounter in understanding quantum numbers. 17 students in total were included in the study. The data were collected via a test of three open-ended questions developed by the researchers. The collected data were then analysed by using the content analysis method. It was found accordingly that both prospective chemistry teachers and prospective physics teachers had difficulties in understanding quantum numbers. The findings obtained in this study were compared with the ones obtained in similar studies and were discussed accordingly.

1 Introduction

Quantum Theory is a theory explaining sub-atomic particles behavior and the laws about the particles successfully. Because of the abstract concepts the theory contains and mathematical basis of it, it has cause educators to encounter many problems in teaching the relevant subjects. The major problem encountered is the understanding difficulties and misconceptions that both prospective chemistry and physics teachers have about the concepts of this theory [1 – 4]. Understanding difficulties related to the important concepts of the theory such as quantum numbers emerge as an important problem in teaching quantum physics/mechanics. The misconceptions and understanding difficulties in relation to basic concepts such as quantum numbers indicate that students cannot learn those concepts very well.

Only a limited number of studies are available in the literature aiming to reduce or eliminate the learning difficulties in quantum numbers [5 – 9]. Even though several materials such as making analogies were developed in those studies, the materials did not work very well in eliminating the learning difficulties. Apart from that, another concept student had difficulty in understanding is the concept of “spin”. The concept is magnitude related to quantum numbers, and it has no counterparts in classical physics. It may be considered normal for students not to understand intuitively the concept that has no counterparts in classical physics but the situation is not so simple in reality. The reason for this is that students consider “spin” as a rotation movement [10]. A limited number of

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studies on the difficulties of understanding and misconceptions directly related to this and such quantum numbers constitute the reason for this study.

1.1 Purpose of the study

Understanding difficulties in quantum numbers and in matters directly related to this and misconceptions about it all form the base on which this study is conducted. In other words, this study sets out to determine the understanding difficulties of prospective chemistry and physics teachers have in relation to quantum numbers. In this context, the following research questions will be answered:

- How do the prospective chemistry and physics teachers understand and use the quantum numbers?
- What are the prospective chemistry and physics teachers' difficulties related to the concept of quantum numbers?

2 Method

The current study that was conducted by using case study method was one of the qualitative research methods included 17 pre-service teachers in total [11].

2.1 Participants and the course setting

The participants were chosen in purposeful sampling method. The questions on which the study focused were demonstrated in greater details in this way. All the participants, who were in the 19-23 age range, were included in the research on the basis of volunteering. Eight participants (4 females and 4 male) were prospective chemistry teachers whereas nine (6 females and 3 male) were prospective physics teachers. All of the participants had taken all the courses involving the fundamental concepts about quantum numbers. The courses were mostly teacher-centred and special teaching techniques such as concept maps or demonstration experiments were not employed in those courses.

2.2 Data collection tool and analysis

The data for the study were collected by means of three open-ended questions prepared by the researchers. The participants were allowed 20 minutes to answer the questions. The data were then analysed by using content analysis. The analyses done by the researchers separately were compared and the differences emerging were re-considered. The understanding difficulties prospective teachers had been determined on the basis of the analyses both researchers had done. Then the initial results of the researchers' analysis results compared and discussed. So, the inter coder reliability coefficient was archived to be 0.92 in first time. After discussing the contradictions between the researchers, the full agreement was reached finally.

2.3 Validity and reliability

Validity and reliability are very important especially in qualitative research studies. Data collection tools and the process of data analysis were clearly explained to the participants in this study for the purpose of validity. Thus, the participants' characteristic properties, data collection instruments and the way pursued in analysing the data will be clearly known in case a similar study is conducted. Intercoder reliability was calculated in obtaining the

findings for the purpose of reliability [12]. The reliability coefficient was found by comparing the results for data analysis performed by the two researchers. While the reliability coefficient was found as 0.92 in the first analysis, full agreement was attained between the two researchers in the second analysis.

3 Findings

This section includes the findings obtained through the analysis of the data collected. First, the findings for the first research question are summarised in Table 1. As is clear from Table 1, prospective teachers' levels of understanding are considered in three categories labelled as "complete understanding", "incomplete understanding" and "no understanding" [10]. The way prospective teachers use quantum numbers, on the other hand, was coded as "correct use" and "incorrect use". The participants giving no answers to the questions were labelled as "no answer".

3.1 Students' understanding and usage of quantum numbers

According to Table 1, there is only one prospective teacher using quantum numbers correctly and making correct explanations (coded as P16).

Table 1. Students' understanding of quantum numbers.

Participants (P)	Quantum Numbers			
	n	l	m _l	m _s
P1	+, IC	+, IC	+, IC	+, IC
P2	+, IC	+, IC	+, IC	+, IC
P3	+, IC	+, IC	+, IC	+, IC
P4	+, CU	+, CU	+, CU	+, IC
P5	+, IC	+, CU	+, CU	+, NoU
P6	+, IC	-, IC	-, NoU	-, NoU
P7	+, IC	+, IC	-, NoU	NA
P8	+, IC	-, NoU	+, IC	+, IC
P9	+, IC	+, IC	+, IC	+, IC
P10	+, IC	+, IC	+, IC	+, IC
P11	+, IC	-, NoU	-, NoU	+, IC
P12	+, IC	-, NoU	+, IC	+, IC
P13	+, IC	+, IC	+, IC	+, IC
P14	+, IC	-, NoU	NA	+, IC
P15	+, CU	-, NoU	+, CU	+, CU
P16	+, CU	+, CU	+, CU	+, CU
P17	+, CU	+, NoU	+, NoU	+, NoU

+: Correct use, -: incorrect use, CU: Complete Understanding, IC: Incomplete Understanding, NoU: no understanding, NA: No Answer.

Prospective physics teacher coded as P15 both used three quantum numbers correctly (n , m_l , m_s) and had the level of “complete understanding”. However, P15 used angular momentum quantum number incorrectly and made incorrect explanations about the quantum number. Besides, six prospective teachers- three of whom were prospective chemistry teachers and three of whom were prospective physics teachers- could not make correct explanations despite using quantum numbers correctly. In other words, they could find the names of quantum numbers correctly but they could not offer scientific explanations on what they are for or what their functions are. Only P7 and P14 could not answer the questions about spin quantum number and angular momentum quantum number respectively. That is to say, these two prospective teachers mentioned only two of the four quantum numbers; and they could not write even the name of the other quantum numbers.

3.2 Students' difficulties related to the quantum numbers

Answers are sought to the second research question in this section. It was found in this context that prospective teachers had difficulty in understanding the situations corresponding to certain values of quantum numbers given in the questions. For instance, three prospective chemistry teachers (P1, P2 and P3) had incorrect answers about angular momentum quantum numbers and spin quantum numbers although they guessed the quantum numbers correctly for the situations given in questions two and three. P1 made operations only for $l=2$ angular momentum quantum number for $n=3$ principal quantum number. Thus, the prospective teacher did not take other probable values that angular quantum number can take on into consideration. Besides, P3 had difficulty in determining the type of orbital and the spin quantum number and thus determined the two quantum numbers incorrectly. P3's explanation about question three is quoted below:

“We can say d-orbital for $n=3$, and nothing can be said for spin value because spin quantum number is not given” (P3).

A similar comment was made by P1. The participant (P1) stated that no comments could be made for the spin of electron since the number of spin quantum was not given. P1's explanation was as in the following:

“ l can take on values until $n-1$ for $n=3$... since m_s value is not given, we cannot make comments about the situation of the electron. It is 3d orbital...” (P1).

On examining the above quoted statements, it can be said that the three prospective chemistry teachers had problems in the meaning of quantum numbers and that they had difficulty in how to use the numbers on determining the situation of an electron. In other words, they had conceptual difficulties about angular momentum quantum number and orbitals or the way an electron is placed in orbitals.

On analysing the answers prospective physics teachers had given to question two, it was found that only the participants coded as P15 and P16 had given correct answers to the question. The prospective physics teachers coded as P10, P11, P14 and P17 made operations in the question by considering the value $l=2$ and they determined the values for spin quantum number incorrectly. The statements made by them were as in the following:

“It is determined according to the orbital corresponding to $l=2$ ” (P10)

“By using $l=n-1$, $l=2$ for $n=3$. Thus, $m_s = 2n+1$, and $m_s = 7$ ” (P11)

“ $l=n-1$. $m_l=2l+1=5$. $m_s=1$ ” (P14)

“ $l=2$ (orbital d) for $n=3$. $M_l=-2,-1,0,1,2$ (5 value). $m_s=2l+1=2.2+1=5$ and the number of electrons is 10” (P17)

On analysing the answers prospective physics teachers had given to question three, it was found that they could usually determine the types of orbitals correctly. On the other hand, six of them (P10, P11, P13, P14, P15, P17) could not say the electron value of spin correctly for the situation given in question three. They wrote spin values as $+1/2$ or $-1/2$. The prospective physics teachers apart from those six, could give correct answers in relation to the types of orbitals and the probable spin values of electrons. Some of the statements made by prospective teachers who could not answer question three completely are as in the following:

“It takes on the values of -2, -1, 0, 1, 2 and orbital d is - orbital because $n=3$. Yet, magnetic quantum number is the minimum value due to the value of -2 and nothing can be said about spin.” (P109)

“We can say two electrons are available in d-orbital; because these values indicate the position of the electron” (P11)

“It is d-orbital. It takes on the values of -2, -1, 0, 1, 2. We have determined the place of the electron in accordance with the values given” (P14)

The electron is in d-orbital and $m_s = 5$ (Spin quantum number)” (P17).

As is clear from the above-mentioned quotes, prospective physics teachers have significant conceptual difficulties about quantum numbers and their meanings. Prospective physics teachers coded as P10, P11, P14 and P17 in particular had incomplete knowledge about the concept of spin and they could not make sense of the concept of spin.

4 Discussion and conclusions

Quantum theory is not easy for students to understand since it involves abstract concepts and difficult mathematical operations. On analysing the findings for the first research question it can be said that prospective physics and chemistry teachers both have incomplete knowledge and understanding in relation to quantum numbers. Almost all of the prospective teachers used quantum numbers correctly but only a limited number of them could explain the meaning of those numbers. A close examination of Table 1 makes it clear that the number of prospective chemistry teachers who could use quantum numbers correctly and who could explain them correctly is six whereas the number of prospective physics teachers who could do them is seven. Many students cannot explain these two quantum numbers correctly and they have difficulty especially in explaining angular momentum quantum numbers and spin quantum numbers and have misconceptions or alternative concepts for quantum numbers due to the abstract structure of sub-atomic world [2, 3]. Ways of thinking especially about spin quantum numbers cannot go beyond the thinking style of classical physics. That is to say, prospective teachers try to explain quantum numbers by using the laws of classical physics. The reason for this is that the presentation of the concept of spin in general chemistry, organic chemistry and physico-chemistry course books is contradictory and misleading for students [13, 14]. Such course materials cause students to develop misconceptions or alternative concepts and lecturers' false analogies also cause misunderstanding.

The prospective physics and chemistry teachers were asked to make operations representing a quantum situation given by using quantum numbers within the scope of the second research question. The prospective teachers were expected to offer solutions by analysing the given quantum situation both mathematically and conceptually. As is clear

from the participants' statements quoted in the findings section, prospective physics and chemistry teachers have incorrect conceptual understanding and mathematical difficulties. For instance, relation $2l+1$, used for magnetic quantum number, was also used as it was for spin quantum number. Moreover, the prospective teachers interpreted the results (numbers) they had obtained in their calculation in the two ways of usage and they explained their finding as the total number of electrons in the relevant quantum situation. The numbers (the results obtained by using the relation $2l+1$) do not mean the number of electrons but they mean space quantization. In other words, m_l has different angular momentum components for each value it has. Therefore, these two quantum numbers are not used to find the number of electrons. Thus, prospective teachers have important misunderstanding and conceptual difficulties especially about the use of magnetic quantum numbers and spin quantum numbers. On comparing the findings obtained in this study with those obtained in other relevant studies, we see that the results are similar [2, 3]. According to [15], the main difficulty for students to understand quantum numbers is that the concepts are abstract and incomprehensible. Additionally, difficult mathematical operations also cause students and teachers to display negative attitudes towards quantum physics [16]. Niaz and Fernandez (2008) also state that most of the students face significant difficulties in understanding quantum mechanics and quantum numbers.

5 Implications for Teaching

Concepts related to quantum mechanics are the concepts that we cannot experience in daily life. That is to say, it is quite difficult to picture them in mind. In this context, it is also difficult to teach them. It would be beneficial to prepare rich in-class activities and course books in a manner to support their complete learning of such abstract concepts as orbitals and quantum numbers. In addition to that, visuals can also be used heavily during in-class activities. Concepts difficult to understand intuitively can be made visible by using computer software. Activities that are probable to lead to misunderstanding on the part of students or to develop false models in students' mind should be avoided in doing this. Arrangements or activities of this kind that are to enrich the lessons can help students to make sense of the knowledge and they can also increase retention in learning; and thus meaningful learning can occur.

Appendix: Questions about Quantum Numbers

1. What does the quantum numbers (n, l, m_l, m_s) mean? What do you think about it? Explain your reasoning?
2. For $n=3$ quantum state, please write down the possible values of l, m_l , and m_s ? Explain your reasoning?
3. What could be say about an electron's spin and orbital quantum numbers when it is found at the quantum state such as $n=3$ and $m_l=-2$?

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