Cilt 8 / Sayı 2, 2020
Eğitimde Nitel Araştırmalar Dergisi - ENAD
Journal of Qualitative Research in Education - JOQRE

The Examination of Prospective Chemistry and Physics Teachers' Cognitive Structure Related to Quantum Numbers

Kimya ve Fizik Öğretmen Adaylarının Kuantum Sayılarına Yönelik Bilişsel Yapılarının İncelenmesi

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To cite this article/ Atıf icin:
Temel, S., & Özcan, Ö. (2020). The examination of prospective chemistry and physics teachers' cognitive structure related to quantum numbers. *Eğitimde Nitel Araştırmalar Dergisi – Journal of Qualitative Research in Education, 8(2)*, 649-664. doi: 10.14689/issn.2148-624.1.8c.2s.10m

Article Info
Received:19 Apr. 2019
Revised: 19 Apr. 2020
Accepted: 25 Apr. 2020

Abstract. This study firstly aimed to analyse prospective chemistry and physics teachers' comprehension levels to quantum numbers. Secondly, the study analysed the changes in both groups of prospective teachers' levels of comprehending quantum numbers. In this context, qualitative research method was used and purposeful sampling method was employed in the selection of the participants in this study. 8 prospective chemistry and 9 prospective physics teachers were included in the study. The prospective teachers' responses to the seven open-ended questions were analysed separately by the two researchers according the classification made by Abraham, Grybowsky, Renner and Marek (1992). First, prospective chemistry and physics teachers' level of understanding quantum numbers was determined. Then, variability in their levels of understanding was examined. In addition to that, prospective teachers' probable misconceptions/alternative concepts/wrong concepts and deficient knowledge was also determined. It was concluded that prospective teachers in general had wrong concepts in addition to partial understanding the subject. It was also found that there were considerable changes in their comprehension levels. In this context, the nature of prospective teachers' understanding of quantum numbers was discussed in details.

Keywords: Comprehensive level, cognitive structure, prospective chemistry and physics teachers, stable knowledge structure, quantum numbers.

Öz. Bu çalışmada ilk olarak kimya ve fizik öğretmen adaylarının kuantum sayılarına yönelik bilişsel yapılarının ortaya konulması amaçlanmaktadır. İkinci olarak, her iki grup öğretmen adaylarının kuantum sayılarına yönelik anlama düzeylerindeki değişim incelenmiştir. Bu bağlamda çalışma nitel araştırma yöntemlerine göre yürütülmüştür ve katılımcılar amaçlı örnekleme yöntemine göre belirlemiştir. 8 kimya ve 9 fizik öğretmen adayının katılımıyla çalışma yürütülmüştür. Öğretmen adaylarının bilişsel yapılarını belirlemek için 7 açık uçlu sorudan oluşan veri toplama aracı kullanılmıştır. Öğretmen adaylarının bu sorulara verdikleri yazılı cevaplar analiz edilerek onların kavram yanılgıları/alternatif kavramları/yanlış kavramları, eksik bilgileri belirlenmiştir. Öğretmen adaylarının açık uçlu sorulara vermiş oldukları yazılı cevaplar her iki araştırmacı tarafından ayrı ayrı Abraham, Gryzybowski, Renner, and Marek in (1992)' sınıflandırmasına göre analiz edilmiştir. İlk olarak kimya ve fizik öğretmen adaylarının kuantum sayıları ile ilgili hangi anlama düzeyinde oldukları tespit edilmiştir. İkinci olarak öğretmen adaylarının anlama düzeylerindeki değişkenlik incelenmiştir. Öğretmen adaylarının genel olarak konu ile ilgili kısmen anlama ile birlikte yanlış kavramlara sahip oldukları belirlenmiştir. Ayrıca öğretmen adaylarının anlama düzeylerinde dalgalanmaların oldukça fazla olduğu tespit edilmiştir. Bu bağlamda, öğretmen adaylarında kuantum sayıları ile ilgili ortaya çıkan bilgi yapılarının doğası detaylı olarak tartışılmıştır.

Anahtar Kelimeler: Anlama düzeyleri, bilişsel yapı, kararlı bilgi yapıları, kimya ve fizik öğretmen adayları, kuantum sayıları.

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Introduction

Cognitive structure is a theoretical structure indicating the relations between concepts in students' long-term memory (Shavelson, 1974). Forming a well-constructed cognitive structure- or a conceptual framework- requires that students prefer meaningful learning instead of rote learning. Meaningful learning occurs with students' setting up conceptual ties between their current knowledge and the newly presented knowledge. When meaningful learning does not occur, students cannot connect the newly learnt knowledge to their previous knowledge (Ausubel, 1968). In consequence, the new material is memorised, it is quickly forgotten and cannot be transferred (Bretz, 2001; Novak & Gowin, 1984).

When there are missing conceptual ties in cognitive structure, it is difficult for students to learn the new material or to blend the new concepts into the existing structure of knowledge (Taber & Coll, 2003). Poor cognitive structures prevent the acquisition of new knowledge meaningfully (Tsai & Huang, 2002). As a result, learning difficulties arise. Learning difficulties- one of the obstacles in front of meaningful learning- are revealed by determining cognitive structure (Snow, 1989). Determining those learning difficulties enables one to prepare the educational environments facilitating learning.

Studies on cognitive structure are compatible with constructivist theory (Anderson, 1992; Bodner, 1986). According to the theory, knowledge is actively configured by students and is stored in memory in simple terms. Thus, students in the same learning environment develop different cognitive structure and even different ways of organising scientific knowledge even though the knowledge presented and the learning conditions are the same (Howard, 1988). Therefore, analysing students' cognitive structures is an important indicator in assessing what students know (Tsai, 2001). Examining students' cognitive structure informs us of mental representations students use in the process of obtaining knowledge and organising it and of the ways they process information in addition to their knowledge structure, prior knowledge and misconceptions. Besides, examining their cognitive structure about a specific subject also provides information on the methods they employ in forming and organising concepts (Ifenthaler, Masduki, & Seel, 2009; Jonassen, 1987; Tsai, 2001). There are many methods of determining the cognitive structures of the students such as; word association test, controlled word association, tree construction, concept map, flow map (Tsai & Huang, 2002), achievement test and questionnaire (Bayram, Sökmen & Savcı, 1997). On the other hand, the cognitive structures of the students could be revealed by examining their understanding level for a specific concept (Temel & Özcan, 2016). In this way, educators can notice the information gaps in students' cognitive structure (Ifenthaler et al., 2009; Jonassen, 1987) and students' misconceptions could be exposed (Tsai, 2001).

Quantum Numbers

The subjects of quantum numbers and electron configuration are the basis for most advanced concepts in chemistry and physics (Pearson, 2014). These topics are closely related to students' understanding of quantum mechanics. A review of the literature shows that a lack of an understanding related to quantum mechanics has caused science teachers and textbook writers to consider orbitals as physically observable objects rather than mathematically described quantities (Niaz & Fernández, 2008). So, most of the students encountered some understanding difficulties such as (a) do orbitals really exist in atoms, (b) whether orbital shapes and orientations, as commonly known in textbook, are experimental observation or theoretical construction, (c) can the magnetic quantum numbers be freely exchanged for each type of p and d orbitals (Sunyonu, Tania, & Saputra, 2016). According to Gillespie, Spencer, and Moog (1996), quantum numbers make chemistry more abstract, more impenetrable and more incomprehensible than it should be. Because the subject requires students to have abstract thinking about concepts related to quantum, it is difficult for educators to teach and for students to learn quantum concepts (Garik et al., 2005). Students' mental models and comprehension levels are also important in physics due to the abstract nature of microscopic world that is composed of sub-atomic particles (, 2013). Due to confusion caused by such terms as shell, sub-shell orbital, energy level and degeneration of orbitals; students have difficulty in learning the subjects of quantum numbers and electron configuration (Taber, 2002). Misconceptions students have also indicated that they do not have detailed knowledge about the subject (Sunyonu et al., 2016). Most students have considerable difficulties in understanding quantum mechanics and as a result of this in understanding quantum numbers and electron configuration (Niaz & Fernández, 2008). As Ardac (2002) also points out, these difficulties also stem from the abstract structure of the subject of quantum numbers. The abstract nature of the subject and the superficial treatment of the subject in textbooks cause students to rely totally on their knowledge of algorithm and on mathematical applications in solving relevant problems. The importance of lesson activities prioritizing visually in teaching such subjects containing abstract concepts should be emphasized here (Coppo, 2016). Understanding quantum numbers well in this context will make it easier for students to understand the abstract nature of the structure of atom as a whole (Kahraman, 2013).

Significance of the Study

A review of literature shows that students have several misconceptions about quantum numbers. Those misconceptions are listed especially in Papaphotis and Tsaparlis (2008). Various studies (Dobson, Lawrence, & Britton, 2000; Hadzidaki, Kalkanis, & Stavrou, 2000; Ireson, 2000; Kalkanis, Hadzidaki, & Stavrou, 2003; Michelini, Ragazzon, Santi, & Stefanel, 2000; Taber, 2005; Tsaparlis, 2001) also report that students have difficulty in understanding the subjects of quantum numbers and electron configuration. Setting out from this finding, this study aims to analyse prospective teachers' cognitive structure about quantum numbers. Yet, the fact that this study analyses the changes in prospective teachers' comprehension levels as different from the literature and that it obtains rich knowledge about their knowledge structure and learning makes this study important. It was found through literature review that the studies available did not analyze comprehension levels and the changes in levels of comprehending while they determined misconceptions and understanding difficulties about quantum numbers. While the changes inform us of students' knowledge structure about the subject, they also inform us about the stability of these structures. This kind of stable knowledge structures is important in the occurrence of meaningful learning. The emergence of meaningful learning about quantum numbers will contribute to the exact understanding of modern atomic theory by the students. On the other hand, the students who are stuck with the classical atomic theory (Bohr's atomic theory) concepts will experience some struggles with the basic concepts of quantum physics and quantum chemistry. Determining these possible students' difficulties towards the quantum numbers, the comprehension levels of the students about these concepts needs to be uncovered.

So, this study firstly aims to analyse prospective chemistry and physics teachers' comprehension levels related to quantum numbers and secondly, to analyse the changes in these levels of comprehension. So the research questions of this study are as follows:

- What are the comprehension levels of prospective chemistry and physics teachers related to quantum numbers according to the classification of Abraham, Gryzybowski, Renner, and Marek (1992)?
- How do prospective chemistry and physics teachers' levels of comprehending quantum numbers variate?

Methodology

Instruments such as interviews, tests or questionnaires can be used in studies to reveal students' structure of knowledge about concepts. What is important here is that the content of the tools to be used in data collection should be interpretable or that the content should contain problems for which reasoning can be made. It is not sufficient for a data collection tool to have these properties to transform research questions into comprehensive findings. Properties of the study group or the nature of the subject of the study also influences the choice of methodology. In this context, both quantitative and qualitative methods can be used to reveal students' structure of knowledge about concepts according to the size of the study group. This study uses basic interpretive qualitative study approach (Merriam, 2009, p.217) to determine prospective physics and chemistry teachers' comprehension levels of quantum numbers. By using this approach, students can be provided to interpret how they make sense of the concepts and their experience with them. In this context, such important parameters as participants' properties, data collection tool, data analysis and determining the levels of understanding were described in detail.

Participants

8 prospective chemistry teachers (4 female, 4 male; coded from PCT1 to PCT8) and 9 prospective physics teachers (3 male, 6 female; coded from PPT1 to PPT9) were included in the study. 8 prospective teachers attended the chemistry education department of a state university while 9 attended the physics education department of the same university. Both groups of prospective teachers were the third year undergraduate students in their program. All of these prospective teachers came from different high schools that applied a common curriculum. Purposeful sampling method was employed in the selection of the participants. This method makes it possible to analyse in depth the situations which have rich information and thus to enlighten better the questions that a study focuses on (Patton 2002). Thus, the study was conducted with participants who had medium and high level of academic achievement according to their cumulative grade point averages (CGPAs). All of the prospective chemistry and physics teachers had taken all the courses containing the subject of quantum numbers. The prospective teachers enrolled in chemistry education department took the courses General Chemistry I and Inorganic Chemistry I-II while those registered in physics education department took the courses Basic Chemistry I and Quantum Physics I-II. Such courses are taught to a group of 25-30

students for each semester and they are compulsory courses for both groups of prospective teachers. All the prospective teachers participated voluntarily in the study and they were informed of the content of the applications, evaluation of the data to be collected and of the fact that their names would be kept confidential. They were also informed that they can leave the study during data collection if they feel uncomfortable.

Data Collection Tool

In accordance with the purpose of this study, a questionnaire was developed with 7 open-ended questions by one of the researchers by using various chemistry and physics textbooks. First, a pool of questions was formed about quantum numbers. A pilot study was conducted with 3 prospective physics teachers and 3 prospective chemistry teachers by using the questions. At the end of the pilot study, it was found that some of the questions were not appropriate to the students' level of knowledge and that some of them were too simple for students. Thus, such questions were removed from the questionnaire. Then the remaining 7 questions were re-evaluated by the researchers and the questionnaire was given its final shape following the arrangements made by the researchers. Considering the learning difficulties and lacking parts found in lesson observations and in studies in relation to quantum numbers, the questions suiting to the purpose were selected. The participants were asked 7 questions about what quantum numbers are, what they meant, what values they could take on, how the quantum numbers of an electron for which information was given was determined, how the electron configuration of an ion or an atom could be written and how the quantum number of final orbit electrons could be determined, and how many electrons could be available in systems for which quantum numbers were given; and they were asked to write down their answers. In this way, efforts were made to determine the misconceptions/alternative concepts and lacking information of the prospective teachers are probable to have. The data collection tool was provided in appendix.

Data Analysis

Prospective teachers' written answers to the open-ended questions were analysed separately by both researchers according to Abraham et al. (1992) classification. The symbols, content and scoring employed in the classification are as in the following:

- No Understanding (NU) (empty answer, correct answers-no explanations, correct answers-no comprehensible explanation), (0 point),
- Incorrect Concept (Specific Alternative Conception) (SM) (scientifically unacceptable answer or explanation), (1 point),
- Partial Understanding but Incorrect Concept (Partial understanding with specific alternative conception) (PUSM) (while the answer is correct, the explanation is incorrect or answer is incorrect but explanation is correct), (2 points),
- Partial Understanding (PU) (correct answer, explanation is not complete), (3 points),
- Sound Understanding (SU) (correct answer, full explanation), (4 points).

For our study, inter-coder reliability coefficient was found to be 0.89 at first and then the full agreement was established after some discussions.

Findings

This section presents the findings in relation to the first and second research questions respectively. In accordance with research question one; prospective chemistry and physics teachers' comprehension levels in relation to quantum numbers were determined on the basis of their answers to the seven open-ended questions. The detailed explanation about those comprehension levels is given below. In relation to research question two, variability in prospective teachers' comprehension levels was analysed. Changes were found in prospective teachers' comprehension levels according to their answers to all seven questions that were closely related to each other.

The Comprehension Levels of Prospective Chemistry and Physics Teachers Related to Quantum Numbers

Prospective teachers' answers they had handed in writing were analysed for each question and were transformed into numerical values. The findings are shown in Table 1. As is clear from Table 1, the prospective teachers' answers to questions 1-7 were in the categories of SU, PU, PUSM, SM and NU. Some of the sample answers in the categories of SU, PU, PUSM, SM and NU are displayed in Table 2.

For the first question, on examining the answers, it was found that the prospective teachers could not exactly explain what the quantum numbers mean conceptually. The participants' answers to question one shows that they had written the numbers but they had not explained what the numbers meant- except for the empty answers. Some of the participants were found not to have made complete explanations and additionally to have incorrect concepts. For example, four prospective chemistry teachers (PCT4, PCT5, PCT6 and PCT7) and three prospective physics teachers (PPT7, PPT8 and PPT9) described spin quantum number in particular as magnitude occurring in consequence of electrons' rotation around a nucleus or around themselves (See Table 1, Total score: PCT: 6, PPT: 10).

For second question, it was found that the prospective teachers had incorrect concepts and also they could not make full explanations in relation to what values quantum numbers could take on. It was found that they faced challenges in determining angular quantum number in relation to what values quantum numbers could take on.

Table 1.

Comprehension Level Points of Prospective Chemistry and Physics Teachers

Questions	Comprehension levels	PCT	PPT
Q1	Sound Understanding (SU)	0	8
	Partial Understanding (PU)	3	0
	Partial Understanding but Incorrect Concept (PUSM)	2	2
	Incorrect Concept (Specific Alternative Conception) (SM)	1	0
	No Understanding (NU)	0	0
Q2	Sound Understanding	8	8
	Partial Understanding	15	0
	Partial Understanding but Incorrect Concept	2	6
	Incorrect Concept (Specific Alternative Conception)	0	2
	No Understanding	0	0
Q3	Sound Understanding	16	0
	Partial Understanding	6	6
	Partial Understanding but Incorrect Concept	0	14
	Incorrect Concept (Specific Alternative Conception)	0	0
	No Understanding	0	0
Q4	Sound Understanding	12	4
	Partial Understanding	12	0
	Partial Understanding but Incorrect Concept	2	8
	Incorrect Concept (Specific Alternative Conception)	0	0
	No Understanding	0	0
Q5	Sound Understanding	4	0
	Partial Understanding	0	3
	Partial Understanding but Incorrect Concept	14	10
	Incorrect Concept (Specific Alternative Conception)	0	0
	No Understanding	0	0
Q6	Sound Understanding	12	8
	Partial Understanding	0	0
	Partial Understanding but Incorrect Concept	4	2
	Incorrect Concept (Specific Alternative Conception)	2	5
	No Understanding	0	0
Q7	Sound Understanding	0	12
	Partial Understanding	0	0
	Partial Understanding but Incorrect Concept	14	2
	Incorrect Concept (Specific Alternative Conception)	1	1
	No Understanding	0	0

PCT: Prospective chemistry teachers, PPT: Prospective physics teachers

While they made incorrect generalization and comments stating that angular quantum number was determined with the formula ℓ = (n-1), they ignored the fact that "ℓ" could take on values ranging between 0 and (n-1). In a similar vein, they (PCT2, PCT5, PPT1, PPT3, PPT4, PPT5, PPT9) used incorrect formulas such as m_l=2n+1, m_s=2n+1 in determining quantum numbers (See Table 1, Total score: PCT: 25, PPT: 16).

On the other hand, for 3rd and 4th questions, it was found that the prospective teachers could not correctly explain the given specific quantum state of an electron in an atom and they could not make full explanations about the values that the quantum numbers of the electrons in the final orbit of Cr atom could take on for 5th question. For example, after examining the answers to question three, it was found that some of the prospective chemistry and physics teachers could

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not determine the types of orbital (PCT2, PCT5, PCT8, PPT3 and PPT6) and that some of them could not give the correct answer for spin value despite determining the orbital types (PCT5, PPT3, PPT6 and PPT9). On the other hand, PPT1, PPT4 and PPT5 determined the type of orbital as $3d^2$ and they stated a spin value for two electrons although they were asked to give orbitals and spin values for one electron. An examination of the answers to question four demonstrated that the four prospective chemistry teachers (PCT1, PCT3, PCT4 and PCT5) had errors saying that an electron having the quantum numbers of n=3 and m_l=0 could only be in orbital d or in orbital s, whereas three prospective physics teachers (PPT3, PPT6 and PPT9) could not give any explanation to this question.

Table 2.

Selected Examples of Prospective Teachers Answers to the Comprehension Levels

Comprehension Levels	Some examples of prospective teachers' answers
Sound Understanding (SU)	• n=principle quantum number describes the size of the orbit, • for n=2, l =0 expresses s orbital; m_s=+1/2,-1/2, • for n=3, l =1; m_l=-1,0,1 expresses p orbital; m_s=+1/2,-1/2, • If n=3, m_l=2, then l =2, if l =2, this electron is in orbital d. when n=3, the number of shells is 3, that is to say, the electron is in orbital d. spin value is either +1/2 or -1/2, • if n=3, m_l=0 for an electron, then the m_s value can be +1/2, -1/2.
Partial Understanding (PU)	• n=principle quantum number, it cannot be smaller than one, • m_s=it takes on the values of +1/2 or -1/2 according to the position of electrons, • Orbital is 3d, because m_s value is not given, we cannot make any comments on spin value, • if n=3, m_l=0 and l =0 for an electron, then m_l=0. In this case, the electron can be in orbital s.
Partial Understanding but Incorrect Concept (PUSM)	• Magnetic quantum numbers yield the number of electrons, • Spin quantum number is the movement of electrons around nucleus, • Magnetic quantum number stems from the nucleus movement of electrons, • Spin quantum number represents the direction electrons rotate around themselves, • for n=3, l =0, 2; l =-2,-1,0,1,2; in half full orbital m_s=+1/2, -1/2; in completely full orbital 0, • l value is the ranging between plus and minus of m_l value, • for electrons in the final orbit; n=4, l =0 because the electrons are in orbital s, • if n=2; l=1 and m_s=-1/2, then there are ($1s^2 2s^2 2p^6$) 10 electrons in the system.
Incorrect Concept (Specific Alternative Conception) (SM)	• Magnetic quantum number shows the place of electrons, • for n=3, l =n-1=2; m_l=2n+1=7; m_s=2n+1=7, • if n=2; ml=0 and ms=+1/2, then there are 2 electrons in the system, • if n=2; l =1 and m_l=-1, then there are 6 electrons in the system, • if n=2; l =0; ml=0 and m_s=+1/2, then there are ($1s^2 2s^1$) 3 electrons in the system, • if n=2; l =1 and m_s=-1/2, then there are ($1s^2 2s^2 2p^6$) 10 electrons in the system.
No Understanding (NU)	• n=Principal quantum number • l =Angular quantum number • m_l=Magnetic quantum number • m_s=Spin quantum number • n=Principle quantum number • l =number of sub-shells • m_l=Orbital string • m_s=…

Moreover, PPT1, PPT2 and PPT4 stated the spin value could be +1/2 because $m_l=0$ (See Table 1, Total score for Q3: PCT: 22, PPT: 20, Total score for Q4: PCT: 26, PPT: 12). The answers to the question five showed that three of the prospective physics teachers (PPT2, PPT3 and PPT6) could not write the electron configuration of Cr atom correctly. Except PCT4, PCT6, PCT7, PPT2 and PPT3, the other prospective teachers could not accurately determine the principal quantum number of electrons in the final orbit despite writing the electron configuration correctly (See Table 1, Total score for Q5: PCT: 18, PPT: 13).

Participants also faced challenges with question six. Firstly, it was found that two of the prospective chemistry teachers (PCT6, PCT7) and six of the prospective physics teachers (PPT1 – PPT6) could not write the electron configuration of $Fe3^{+}$ ion correctly. Secondly, although PCT7 and PPT5 were able to determine the quantum numbers n and l in the final orbit correctly; they still could not write the electron configuration of the $Fe3^{+}$ ion correctly (See Table 1, Total score for Q6: PCT: 18, PPT: 15).

The findings regarding to the question seven shows that the both of the prospective teachers had incorrect concepts about how many electrons could be available in given systems. They wrote the general configuration of electrons for the systems given in this question and they considered the total number of electrons in the configuration. Yet, the given systems represent the quantum numbers describing the address of electrons directly. In other words, quantum numbers given to the prospective teachers describe the electrons that can be found in the system; and not the total number of electrons. Four prospective physics teachers (PPT1, PPT4, PPT5 and PPT8) answered correctly the three given quantum systems in question seven, while none of the prospective chemistry teachers did not answer these questions correctly. The first and third part of the question seven, where the spin quantum numbers were given explicitly, were more correctly answered than the second part of it (See Table 1, Total score for Q7: PCT: 15, PPT: 15).

The Diversity of the Comprehension Levels of Prospective Chemistry and Physics Teachers Related to Quantum Numbers

Figure 1 shows the changes in both groups of prospective teachers' levels of comprehension. On examining Figure 1, changes are remarkable in both groups of prospective teachers' comprehension levels. Changes especially in SU, PU and PUSM comprehension levels for both groups of teachers are very striking.

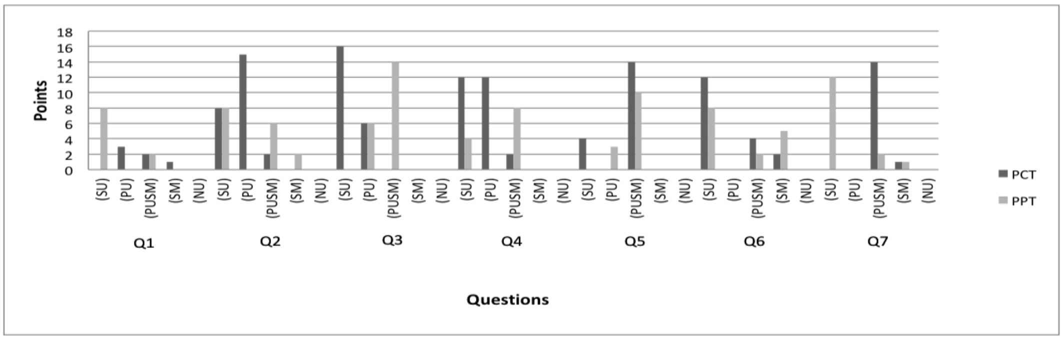

Figure 1. The comprehension level points of prospective chemistry and physics teachers

While, for instance, prospective chemistry teachers' scores for comprehension level in the PUSM category in questions 5 and 7 were higher; prospective physics teachers' scores for comprehension levels were higher in questions 3 and 5. On the other hand, changes in prospective physics teachers' comprehension level (variations in SU, PU and PUSM) were larger in questions 2, 4 and 7. The variations in prospective chemistry teachers' comprehension levels, however, were larger in questions 2, 3, 5 and 6 than in the other questions. Whereas score differences in PU comprehension level were bigger in favour of prospective chemistry teachers in questions 2 and 4, there were not differences in questions 3, 6 and 7. Prospective physics teachers had higher scores in PU only in question 5. Score differences in PU comprehension level between prospective chemistry and physics teachers were quite big in questions 3, 4 and 6. On the other hand, prospective physics teachers had higher scores for SU category of comprehension level in questions 1 and 7, whereas the prospective chemistry teachers had better scores in questions 3, 4 and 6. And finally, scores for SU category of comprehension level were found to be equal for both groups in question 2 (See Table 1).

Discussion and Conclusions

Quantum mechanics/physics differ significantly from classic physics due to the abstract concepts it contains and its different mathematical structure. The differences are mostly contrary to students' intuition. Due to the counterintuitive structure of the theory, the students were confronted with learning difficulties or difficulties in understanding quantum mechanics/physics over time (Ireson, 2000; Özcan, Didiş & Taşar, 2009; Singh, 2001). These challenges in understanding of the theory or misconceptions students encounter can be revealed by analysing of their cognitive structures (Tsai, 2001). A way of analysing cognitive structures is to determine students' comprehension levels (Temel & Özcan, 2016). Thus, meaningful learning will be facilitated thanks to a cognitive structure emerging with scientific knowledge organization (Tsai & Huang, 2002). On examining the findings in this context, it may be said that both prospective physics and chemistry teachers are lacking in knowledge about quantum numbers and in understanding the function of them. Although some of the prospective physics and chemistry teachers used quantum numbers accurately, they had difficulty in explaining what these numbers meant. Table 1 shows some striking findings for the seven questions about quantum numbers. For instance, on considering the questions for which total scores are similar, we see that each level of comprehending has differing contributions to the total score. That is to say, the contributions made by each level of comprehending to the total score gives us important clues about students' learning. An examination of the data shown in Table 1 makes it clear that the total scores for questions 1, 3, 5, 6 and 7 are almost equal; but that the scientific content of the prospective teachers' answers differs. For instance, while the contribution of SU category to the total score of prospective physics teachers was 8 point for question 1, the score received by prospective chemistry teachers was zero in this category. Although the total scores were very similar for question 3 in another example (PCT: 22, PPT: 20), prospective chemistry teachers' scores for the category of SU was 16 point; but prospective physics teachers' score was zero in the same category. Such examples can also be written for questions 5, 6 and 7. It means that new knowledge should be tied to existing knowledge through meaningful learning for a scientifically well-organized cognitive structure. In other words, meaningful learning is possible only through "strong cognitive structure", which is closely related to the scientifically acceptable degree of comprehending levels (Tsai & Huang, 2002). Weak cognitive structures will trigger weak information processing or the mechanisms hindering the effective acquisition of new knowledge. Finally, it will diminish individuals' academic achievement and students' ability to transfer what they have learnt into daily life. This study shows that alternative conceptions and the misconceptions that the prospective teachers had about quantum numbers stem from their weak cognitive structures. The best example for this is seen in prospective teachers' answers about spin quantum numbers and magnetic quantum numbers. That is to say, they had difficulty especially in explaining magnetic quantum numbers and spin quantum number. Especially the concept of spin is very important concept of quantum mechanics/physics that is difficult to learn by the students both of high school and university level because of its the abstract nature. Spin, which is the magnitude originating, totally from sub-atomic particles' intrinsic properties, was evaluated by prospective teachers from a classical perspective (as in classical physics for instance) and was considered as a rotation movement (Özcan, 2013). Charles and Peterson (1989) attributes the contradictory and misleading nature of the concept of spin for students to the way it is presented in general chemistry, organic chemistry and physical chemistry course books. It was found that the prospective teachers had incorrect concepts stating that quantum numbers represented the place of electrons and that electrons originated from the movement of nucleus. The literature also reports that there are similar misconceptions about what quantum numbers represent (Papaphotis & Tsaparlis, 2008).

For example, in question seven, in spite of the total scores of both prospective teachers were the same (PCT: 15, PPT: 15), it could be said that prospective physics teachers have better comprehending level than the prospective chemistry teachers according to the comprehending level scores given in Table 1 (PPT: SU=12, PCT: PUSM=14). According to the Table 1, prospective chemistry teachers might be said to be in the category of PUSM in contrast to prospective physics teachers. This might be because prospective physics teachers study those subjects in more details in their courses of quantum physics and quantum mechanics. One of the reasons for this might be that prospective chemistry teachers made overgeneralizations and wrote all electron numbers in the system instead of writing the electron numbers in the given systems. Another possible reason for this could be that the spin quantum numbers of the electrons were not given explicitly in the second part of the question seven. Ignoring the values that spin quantum numbers can take on or ignoring the probabilistic structure of quantum physics, it is quite difficult for students to answer such questions correctly. In this context, confusions often occur when students associate quantum numbers with these probability regions, electron configurations and energy levels (Garofalo, 1997). In this context, whether or not students learn meaningfully can be checked with such questions appealing to metacognitive levels. That is to say, whether students' conceptual framework is scientific or not can be found. Otherwise, individuals will form alternative concepts by bringing unscientific knowledge fragments together or by using them unconsciously, and it will be inevitable for those individuals to have misconceptions. Because the subjects of quantum numbers and electron configuration form the basis of several advanced concepts in chemistry (Pearson, 2014), determining alternative concepts or misconceptions is more important in this respect.

In line with research problem two, variations in prospective teachers' levels of understanding quantum numbers were evaluated in this study. Accordingly, it was found that changes in both groups of prospective teachers' comprehension levels were remarkable. Thus, there were considerable changes between comprehension levels from one context to another. This result showed that stable knowledge structures had not been formed by prospective teachers in relation to quantum numbers. In this context, it is extremely important to analyse the changes in students' levels of understanding a certain subject or concept. Variations in levels of comprehending a concept in similar contexts offer wealthy information about students' knowledge structures about the concept or about their learning. In other words, changes in understanding levels between contexts also offer us detailed information on their learning history. That is to say, the more changes students have in understanding levels; the lower is the probability for them to learn meaningfully. This instability in their knowledge structure increases their tendency to develop learning difficulties and alternative concepts. Sunyonu *et al.*, (2016) state that the students' misconceptions about quantum numbers demonstrate that they do not have detailed comprehension about the subject. Niaz and Fernández (2008) suggest that most students encounter considerable difficulties in understanding quantum mechanics and consequently quantum numbers and electron configuration. Studies conducted (Ardac, 2002; Dobson *et al.*, 2000; Hadzidaki *et al.*, 2000; Ireson, 2000; Kalkanis *et al.*, 2003; Michelini *et al.*, 2000; Taber, 2005; Tsaparlis, 1997, 2001; Wittman, Steinberg, & Redish, 2002) also concluded that students had difficulty in understanding the fundamental concepts of chemistry such as quantum numbers and the electron configuration of chemical elements.

Implications for Teaching

Enriching in-class activities could be beneficial in raising students' comprehension especially in such abstract subjects as orbitals and quantum numbers and in increasing the permanence of what they learn. Besides, materials enriching the course content can also enable the formation of their stable knowledge structures. At this point, computer software bringing visuals into prominence can be used as materials in teaching abstract concepts (Zollman, Rebello, & Hogg, 2002). Because the concept of atom and relevant concepts are presented visually through such software, learning can be supported in this way. On the other hand, it is necessary to employ alternative teaching materials and strategies to facilitate better learning for students and to eliminate and prevent misconceptions (Choda & Chenprakhon, 2015). The physical model developed by researchers can be used as a learning activity to facilitate students' understanding of electron numbers and of the rules and principles of electron configuration. In this context, concept maps or concept networks asked prior to lessons can give ideas to teachers about developing in-class activities. Teachers can thus be informed of students' prior learning and prepare appropriate content for lessons according to the properties of the groups.

Appendix: Questions about Quantum Numbers

Q1. What do the quantum numbers (n, ℓ, m_l, m_s) mean? What do you think about it? Explain your reasoning?

Q2. For n=3 quantum state, please write down the possible values for the quantum numbers ℓ, m_l, and m_s. Explain your reasoning?

Q3. What could be said 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?

Q4. For an electron with the quantum state n = 3 and m_l = 0, please chose the correct statement(s) below and explain your answer.

	Correct	False	Reasoning
a) m_s should be +1/2			
c) m_l can be 0, 1 or 2			
b) ℓ should be 1			
d) The electron is found in s orbital.			

Q5. Write down the electron configuration of the Cr (Z_{Cr} = 24) atom and specify what values the quantum numbers "n" and "ℓ" can take for the electrons in the last orbit of Cr?

Q6. Write the electron configuration of the $Fe3^{+}$ ion and specify what values the quantum numbers n and ℓ can take for the electrons in the last orbit of $Fe3^{+}$ ion (Z_{Fe} = 26)?

Q7. Considering the electrons in an atom (shell, sub-shell orbitals) how many electrons can be found in the following systems?

a) n=2, l=0, m_l= 0 and m_s=+1/2
b) n=2, l=1, m_l=-1
c) n=2, l=1 ve m_s =-1/2

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