ISSN 1303-0485 • **eISSN** 2148-7561
DOI 10.12738/estp.2015.4.2522

Educational Sciences: Theory & Practice • 2015 August • 15(4) • 1087-1101

Received | April 15, 2014
Accepted | April 17, 2015
OnlineFirst | August 7, 2015

The Place of Learning Quantum Theory in Physics Teacher Education: Motivational Elements Arising From the Context

Nilüfer Didiş Körhasan[a]
Bülent Ecevit University

Abstract
Quantum theory is one of the most successful theories in physics. Because of its abstract, mathematical, and counter-intuitive nature, many students have problems learning the theory, just as teachers experience difficulty in teaching it. Pedagogical research on quantum theory has mainly focused on cognitive issues. However, affective issues about student learning are just as important as cognitive issues. The purpose of this study was to investigate pre-service physics teachers' motivation towards learning quantum theory by examining motivational constructs such as expectancies, values, ability beliefs, and goals. The participants (n = 6) of this case study were fourth-year pre-service physics teachers at a state university in Turkey. Through semi-structured interviews, the participants were asked seventeen questions that focused on motivational constructs. Analysis of the qualitative data indicated that the instructor, nature of the content, and previous performance were three motivational elements that originated in the context of the quantum mechanics course. Furthermore, these context-dependent elements interacted with the other elements of motivational constructs in both direct and indirect ways. Because unsuccessful learning situations are explained by low motivation, context-dependent affective elements and their interactions should be considered in the teaching and learning of quantum theory.

Keywords: Physics education • Teacher education • Motivation • Quantum theory • Pre-service physics teachers

a **Correspondence**
Assist. Prof. Nilüfer Didiş Körhasan (PhD), Ereğli Faculty of Education, Bülent Ecevit University, Zonguldak Turkey
Research area: Physics education
Email: niluferdidis@gmail.com

It is acknowledged that motivation is one of the most important affective elements that have an impact on learning, and it is "a polymorphous concept containing attitudes, goals, and strategies" (Donald, 1999, p. 27). Schunk (1990) defines motivation as "the process whereby goal directed behavior is instigated and sustained." It is necessary for individuals to direct their own energy. When individuals are motivated to learn, they learn constantly because they are directing their energy through attention, concentration, and imagination (Wlodkowski, 1999, p. 8). Motivation has a positive impact on students' social and academic functioning (Paulsen & Feldman, 1999, p. 17; Wentzel & Wigfield, 2007), and it is also affected by some social factors such as teacher-student interaction (Fan, 2011), parenting (Fulton & Turner, 2008), culture (Salili, 1996), personal motives, thoughts, expectancies, and goals (Wlodkowski, 1999, p. 8).

Motivation has been widely studied in educational settings from the perspectives of both students and teachers at different levels. In particular, teacher motivation is a growing research area in recent years because previous research has revealed that teacher motivation plays an important role in student learning (Atkinson, 2000). The recent research on teacher motivation focuses on the career choices of pre-service teachers. For example, teacher candidates' motivations for pursuing a teaching career were investigated in different countries such as Croatia (Jugovic, Marusic, Ivanec, & Vidovic, 2012), Germany (König & Rothland, 2012), Australia (Watt & Richardson, 2007, 2008), and Hong Kong (Lam, 2012), as well as across cultures, such as in Oman and Canada (Klassen, Al-Dhafri, Hannok, & Betts, 2011). Some research has used Factors Influencing Teaching Choices (FIT-Choice) as the framework for examination of teacher motivation (Gokce, 2010; Jugovic et al., 2012; König & Rothland, 2012; Watt & Richardson, 2007, 2008). FIT-Choice is a project examining novice teachers' motivations for selecting teaching as a career (FIT-Choice, 2007; Watt & Richardson, 2007, 2008, 2012a, 2012b). With this project, teacher motivation was investigated across countries and the results were compared (Watt & Richardson, 2012a, 2012b) according to a scale that was developed based on the Expectancy-Value theory (Watt & Richardson, 2012a, 2012b). This theory is also used as the theoretical framework in the current study, which focuses on the investigation of specific motivational constructs emerging in the context of a quantum mechanics course. In addition, it aims to identify how these constructs influence each other and how pre-service physics teachers' motivation is shaped by them. Therefore, in order to investigate the influence of these factors, the researcher asked the following research questions based on the Expectancy-Value theory about motivation in the context of a physics course:

i. What are the motivational elements influencing pre-service physics teachers' motivation towards learning quantum theory?
ii. How do the motivational constructs indicating pre-service physics teachers' motivation towards learning quantum theory relate to each other?

The current study is significant in many aspects. First, most of the domain-specific studies about motivation have been conducted on elementary school children and adolescents (Wigfield, 1994). Second, a great majority of teacher motivation research lacks a clear theoretical framework (Jugovic et al., 2012). In addition, quantitative approaches to teacher motivation research have had some limitations, such as restrictions in defining teacher motivation and the risk of unexamined assumptions about teacher motivation (Klassen et al., 2011). Last, several physics educators have investigated how students understand the concepts of quantum theory (Bao, 1999; Çataloğlu & Robinett, 2002; Didiş, Eryılmaz, & Erkoç, 2010, 2014; Gardner, 2002; Ireson, 2000; Ke, Monk, & Duschl, 2005; Mashhadi & Woolnough, 1999; Müller & Wiesner, 1999, 2002; Olsen, 2002; Özcan, Didiş, & Taşar, 2009; Sadaghiani, 2005; Singh, 2001; Singh, Belloni, & Christian, 2006; Styer, 1996; Wattanakasiwich, 2005). However, to the knowledge of the researcher, research examining students' motivation towards learning quantum theory has been very limited. Deci and Ryan (2000) emphasize that contextual factors play important roles in one's motivation because contexts influence individuals' choices about performing the tasks during the learning process. By considering all these reasons, the examination of pre-service teachers' motivation towards the specific domain -quantum physics- by means of Expectancy-Value theory is of great importance in developing an understanding of the qualitative relations among context-specific affective elements and content knowledge in physics teacher education.

Theoretical Framework: Expectancy-Value Theory

Achievement motivation, as defined by Atkinson, is one of the theories on motivation for academic success. Expectancy-Value theory is one of the most important views about achievement motivation, developed for understanding early adolescence as well as adolescent performance and choice in the domain of mathematics achievement (Wigfield, 1994). This theory considers student engagement in academic tasks as being successful with the task (Paulsen & Feldman, 1999). Eccles et al. (1983, p. 81) stated that expectancy and value influence a whole range of achievement-related behaviors such as choice of activity, intensity of the effort spent, and the actual performance. The researchers elaborated on the topic as follows:

> "…achievement expectancies play a significant role in students' academic choices, it is important to identify the factors shaping these expectancies. We propose that expectancies are influenced most directly by self-concept of ability and by the student's estimate of task difficulty. Historical events, past experiences of success and failure, and cultural factors are proposed to have indirect effects that are mediated through the individual's interpretations of these past events, perceptions of the expectancies of others, and identification with the goals and values of existing cultural role structures." (p. 82)

Expectancy for success is defined by Atkinson as "the individual's expected probability for success on a specific task" (as cited in Eccles et al., 1983; Pintrich & Schunk, 2002, p. 60; Wigfield, Tonks, & Eccles, 2004). It is followed by either success or failure (Wigfield, 1994). Individuals' expectations of success and the values for succeeding are important determinants of their motivation for choosing future behaviors (Pintrich & Schunk, 2002, p. 53) and performing different achievement tasks (Wigfield, 1994).

The characteristics of the task and the needs, goals, and values of the person determine the value of a task (Eccles et al., 1983, p. 89). Atkinson defines *value* as "the relative attractiveness of succeeding or failing on a task" (as cited in Wigfield, 1994). Four types of values are defined in the theory as attainment, intrinsic (interest), utility, and cost. The value of *attainment (or importance)* is defined as "the importance of doing well on the task" (Eccles et al., 1983; Wigfield, 1994; Wigfield & Eccles, 2000; Wigfield et al., 2004). The attainment value is determined by the perceived qualities of the task through their interaction with an individual's needs and self-perceptions (Eccles et al., 1983, p. 89). "The inherent, immediate enjoyment one gets from engaging in an activity" is called *intrinsic (or interest)* value (Eccles et al., 1983, p. 89). Hidi and Harackiewicz (2000) examined the factors that affect the interest of students. They mention that personal interest, which is a relatively stable characteristic of an individual, and situational interest, which is more transitory and elicited by environmental conditions, are different from each other. For some future goals, the value of *utility* is determined by the importance of the task (Eccles et al., 1983, p. 89; Wigfield, 1994; Wigfield et al., 2004). In other words, it is the consideration of future needs capturing the extrinsic reasons for engaging in a task; rather than doing the task for the sake of doing it, the incentive is to reach some desired end-state (Wigfield & Eccles, 2000). *Cost*, the last element of the value construct, is defined as "what the individual has to give up to do a task" (Wigfield, 1994; Wigfield & Eccles, 2000; Wigfield et al., 2004). Cost value has two basic dimensions: effort and worth (Wigfield, 1994; Wigfield & Eccles, 2000; Wigfield et al., 2004).

Ability beliefs and *goals* are also important for achievement motivation. Ability beliefs are "individuals' evaluations of their competence in different areas" and they are important in several theoretical models of achievement (Wigfield, 1994; Wigfield & Eccles, 2000). In the Expectancy-Value theory of motivation, ability beliefs are created by broad beliefs about competence in a given domain. However, ability beliefs are in contrast to expectations of success with upcoming tasks, since expectancies are seen as more specific beliefs. In addition, ability beliefs focus on present ability whereas expectancies focus on the future (Wigfield & Eccles, 2000). Schunk (1990) defines goal as "what a student wants to accomplish" (as cited in Zimmerman & Risemberg, 1997). Goals are one of the task-specific beliefs that have an effect on expectancies and values (Wigfield et al., 2004). Considering the definitions of these terms and the studies conducted on achievement motivation, the current study adopted the following methodology for the context of a quantum mechanics course.

Pedagogical Research on Quantum Theory

Since the 1990's, educational research on student understanding of quantum mechanical concepts has increased. A great proportion of this research has been conducted in the cognitive domain, and research in the affective domain has only recently been conducted by focusing on achievement motivation (Didiş & Özcan, 2007; Didiş & Redish, 2010, 2012). The pedagogical research on quantum theory examines the understanding of both upper-level high school and university-level physics students, and provides new methodologies about quantum mechanics instruction (Bao, 1999; Budde, Niedderer, Scott, & Leach, 2002a, 2002b; Cuppari, Rinaudo, Robutti, & Violino, 1997; Çataloğlu & Robinett, 2002; Didiş, 2015; Didiş et al., 2010; 2014; Dobson, Lawrence, & Britton, 2000; Escalada, 1997; Frederick, 1978; Gardner, 2002; Hadzidaki, Kalkanis, & Stavrou, 2000; Ireson, 2000; Kalkanis, Hadzidaki, & Stavrou, 2003; Ke et al., 2005; Kwiat & Hardy, 2000; Mannila, Koponen, & Niskanen, 2002; Michelini, Ragazzon, Santi, & Stefanel, 2000; Morgan, 2006; Müller & Wiesner, 1999, 2002; Olsen, 2002; Özcan et al., 2009; Sadaghiani, 2005; Shadmi, 1978; Singh, 2001; Singh et al., 2006; Strnad, 1981; Styer, 1996; Vandegrift, 2002; Wattanakasiwich, 2005).

The research examining student understanding of quantum theory can be classified into four categories. First, it is the examination of the conceptual understanding and difficulties of students and identification of the misconceptions about the quantum theory. One of the reasons for student misconceptions is the difficulty of abstract concepts in quantum physics (Singh et al., 2006; Styer, 1996). Misconceptions are individuals' stable, unscientific concepts. It is difficult to understand abstract concepts by reading their definitions, so misconceptions are unavoidable in understanding quantum physics. Misconceptions in quantum mechanics are not considered to be preconceptions because students have almost no chance to gain experience about quantum theory in their daily lives. For this reason, unscientific, coherent, and robust explanations of concepts that might be gained from the textbooks, teachers, or the language in lessons were identified as misconceptions. Styer (1996) listed some misconceptions in quantum mechanics based on his observation of students, colleagues, and so forth. He emphasized conceptual difficulties and suggested these misconceptions should be taken into consideration in order to combat them. After identification of the general misconceptions of students, Müller and Wiesner (1999; 2002) investigated German pre-service physics teachers' conceptualizations of atomic systems, and they explained that the most of the students whose major was not physics never had a chance to learn concepts in quantum mechanics conceptually. The study of Müller and Wiesner (1999) can be accepted as the first study on pre-service physics teachers, so it is valuable for both its design and results. Ireson's (2000) study with pre-university students in England showed that students could not interpret the quantum theory by confusing some basic ideas of the theory with each other and attributing conflicting mechanistic properties to them. Gardner (2002) identified that undergraduate students had conceptual difficulties with waves, harmonic oscillators, angular momentum, Hamiltonian systems, energy levels and transitions, wave particle duality, and uncertainty. He concluded the reasons for these difficulties were due to the difficulty with physical concepts. Sadaghiani (2005) identified that students did not have a functional understanding of probability and related concepts, and they had problems with terminology, confusing some terms such as expectation value with probability density and probability density with probability amplitude. Bao (1999) studied university physics students' mental models about the concept of probability for classical and quantum mechanics. He identified that students' mental models were both strong classical-mechanical models (hybrid models) which included correct information about quantum mechanical concepts by using classical mechanical reasoning, and mixed models which included both quantum mechanical and classical mechanical models at the same time. Wattanakasiwich (2005) also examined university physics students' conceptions on probability. She accounted for student difficulties in conceptual understanding as having a lack of physics knowledge. Singh (2001) examined advanced undergraduate students' difficulties in some quantum mechanical concepts such as measurement and time development. The results indicated that although students had different backgrounds, teaching styles, and textbooks, most of them presented the same difficulties, such as doubt about their responses, difficulty in discriminating between concepts, and conflicting justifications. In addition, students had some misconceptions about operators, expectation values, eigenstates, and time evolution. Didiş et al. (2010) examined pre-service physics teachers' understanding of some quantum concepts such as operators, observables, eigenvalues, and interrelated concepts. The researchers identified the following: students had insufficient conceptions that influence their descriptions and discriminations, student comprehension contains correct and wrong ideas simultaneously, their indefinite comprehension influences the use of different concepts interchangeably, they make explanations and discriminations through intuitive reasoning, and some of student conceptions were totally unscientific.

Second, the researchers focused on student problems with the mathematics of quantum theory because mathematical formalism is one of the prominent characteristics of the theory. While Pospiech (2000) explained that mathematical formalism often hides the philosophical issues, Ireson (2000) claimed that the mathematical formalism of quantum mechanics is not the problem, but that its interpretation is. Gardner (2002) supported this idea by indicating that student problems were not related to the calculation of mathematical problems but were related to a lack of mathematical skills and calculus background, lack of transfer of mathematical knowledge to the quantum mechanics course, and difficulty in notations and mathematical ideas. Strnad (1981) and Sadaghiani (2005) also explained that students' unsatisfactory mathematics backgrounds play a role in their difficulty learning quantum theory, and they recommended that instructors should emphasize that quantum mechanics is a mathematical theory (Sadaghiani, 2005).

Third, there is the pedagogical research on quantum theory focusing on student understanding of visual representations and problems with these representations. Eddington's (Eddington, 1928, p. xvii as cited in Mashhadi & Woolnough, 1999, p. 511) statement that "When I think of an electron there rises to my mind a hard, red, tiny ball" is a good example showing us that not being able to experience the quantum mechanical concepts at micro-level brings different visuals to our mind about them. The researchers examined the imaginings about electrons and photons of upper secondary-school students in England and Wales. The results showed that the majority of students made abstract concepts concrete by imagining unscientific visual images. Çataloğlu and Robinett (2002) indicated that students could connect their mathematical and conceptual knowledge with visual representations in quantum mechanics and students could use their knowledge of quantum mechanics by manipulating the information given in visual representations.

The last issue was the examination of student discriminations of classical and quantum phenomena. The study of Mannila et al. (2002) with students whose majors were physics and physics education stressed that the main difficulty of students was constructing a new ontology for a conceptual shift. Bao (1999) explained that students could interpret the situations in quantum mechanics if there were traces from classical mechanics; otherwise they could not make any physical interpretation and quantum mechanics became merely a composition of mathematical equations. In contrast, it was recommended in many studies that classical mechanical concepts should be avoided in quantum mechanics courses. Sadaghiani (2005) investigated students' use of classical mechanical models to interpret quantum mechanical events. Olsen (2002) indicated that some students clearly demonstrated misconceptions due to their classical physics background. Pospiech (2000) claimed that the reasons for difficulty in understanding quantum mechanics started with classical mechanics. A similar study by Budde et al. (2002a; 2002b) added the reasons for difficulty in learning atomic models were attributable to the differences between the views in quantum physics and classical physics. Müller and Wiesner (1999, 2002) explained that students confused classical and quantum notions because of traditional instruction and the counter intuitiveness of quantum mechanics, so it is not surprising that misconceptions occurred.

All this pedagogical research on the quantum theory showed how students understand the theory. In the light of the previous research about cognitive domain of learning, this study examines whether there are some context specific motivational elements (affective variables) influencing student learning of the quantum theory.

Method

The objectives of the study are to investigate specific motivational constructs emerging in a quantum mechanics course context and to identify how these constructs influence each other and pre-service physics teachers' motivation toward learning the quantum theory.

Data Collection

Case Study: In order to answer the research questions aimed at investigating pre-service physics teachers' motivation towards learning quantum theory through examination of some motivational constructs (such as expectancies, values, ability beliefs, and goals), the researcher adopted qualitative approaches to data collection. Marshall and Rossman (1999, p.159) state that the power of case studies lies in focusing on specific instances of the phenomenon in depth and in detail. In this study, the group of pre-service physics teachers learning quantum theory was considered to be a case in order to examine achievement motivation.

Selection and Description of the Participants: Six pre-service physics teachers participated in the study. All participants were fourth-year students who had already completed a quantum physics course and were taking the quantum mechanics course the following semester. Participants were selected purposively by considering the teacher candidates' cumulative grade point averages (CGPA's). All participants were moderate level students whose CGPA's varied between 2.30 and 2.90 out of 4.00. Five participants (P1, P2, P4, P5, and P6) were female and one participant, P3, was a male.

Selection and Description of the Course: Physics teacher candidates take all the physics courses required for their subject matter knowledge from the department of physics. They are educated in the same classes with physics students. Quantum Physics (PHYS 300) and Quantum Mechanics (PHYS 431), which focus on teaching quantum theory, are two fundamental courses for the subject-matter knowledge of physics teacher candidates. The quantum physics course is the first and fundamental step in teaching quantum theory. It is a three-credit compulsory course for all physics and physics education students offered in the third year of the program. In this course, the topics such as "historical experiments and theories; the postulates of quantum mechanics; function spaces and Hermitian operators; superposition and computable observables; time development; conservation theorems and parity; one-dimensional problems; bound and unbound states" (Department of Physics, 2015a) are taught. After the introduction of quantum theory, students take the subsequent compulsory course, Quantum Mechanics (PHYS 431), in their fourth year.

Quantum mechanics is a theoretical framework that describes, correlates, and predicts the behavior of atomic systems (Merzbacher, 1998, p. 1). Quantum mechanics is one of the fundamental theories of physics, since it represents an absolutely new paradigm in physics. It provides mathematical tools for explaining quantum theory and requires both conceptual knowledge and deeper mathematical calculations. This course covers the "postulates of quantum mechanics; Dirac delta function and Dirac notation; the Schrödinger equation in three-dimensions; angular momentum; the radial equation; the hydrogen atom; interaction of electrons with electro-magnetic field; operators, matrices, and spin; the addition of angular momenta; time-independent perturbation theory" (Department of Physics, 2015b).

Instrument and Procedure: This study confines itself to semi-structured interviews. Most of the questions were prepared from the sample items of Wigfield (1994) and Wigfield and Eccles (2000). The questions were examined by an external researcher (a physics educator with a Ph.D degree) in terms of their appropriateness to the aim of the study. Finally, the 17 questions presented in Table 1 were determined and used in the study.

Table 1
Interview Questions

Motivational Constructs		Questions
Expectancies for success		1. How well do you think you are doing in quantum physics this semester? 2. How well do you expect to do in quantum mechanics next semester? 3. Compared to other students, how well do you expect to do in quantum mechanics next semester?
Task values	*Attainment*	4. How important is it for you to be good at quantum mechanics?
	Interest	5. How much do you like quantum physics and quantum mechanics? 6. Would you take the quantum mechanics course if it were an elective course? 7. Are you interested in quantum mechanical concepts (do you read books, do research etc.)? 8. Do you like the concepts of quantum mechanics?
	Utility	9. Compared to your other courses, how useful is what you have learned in quantum mechanics? 10. Do you need to learn quantum mechanics?
	Cost	11. What did you give up to learn introductory quantum mechanics in the quantum physics course? 12. Is learning quantum mechanics worth giving up something? 13. Do you make an effort to succeed in the quantum physics course?
Ability beliefs		14. How good are you at quantum physics? 15. Compared to the other students, how do you measure your success in quantum physics?
Goals		16. What are your goals about quantum mechanics? 17. What makes you to succeed quantum physics?

First, before the main interviews, pilot interviews were conducted with the participants in order to control the probable threats about communication and stress regarding being recorded by a video camera. Then, the main interviews with these six participants were conducted in Turkish, their native language. Follow-up questions were asked to clarify participants' answers and get more details. Member checks were done at the end of each interview. Each interview took almost one hour, and all interviews were video recorded by the researcher.

Data Analysis

First, the video recorded interviews were transcribed verbatim by the researcher. During the development of the code list, mutual exclusiveness and inclusiveness were considered. The same external researcher examined the developed and revised code list. After the conversion of verbal data to written data and just before the coding, the transcriptions were read by the researcher several times. In this way, precautions were taken to prevent probable threats to the data analysis caused by the researcher (for example, fatigue, feelings, and so forth). The researcher started coding by using the code list, which emerged from the literature and data. In data analysis, the unit of analysis was the group of sentences indicating a motivational construct, meaning that each meaningful chunk was coded once by considering the mutual exclusiveness of the codes. Sample data belonging to a participant were given to the same external researcher for analysis. The inter-rater coefficient was found to be .78, and disagreements were resolved by discussing each code.

Reliability, Validity, and Ethical Issues

Ethics was the first issue considered in this research. Three issues regarding ethics that were discussed by Fraenkel and Wallen (2000, p. 43) were considered in this study. All the purposively selected participants accepted to participate in this study after they were informed about the study. They were presented with the informed consent form introducing the ethical issues in detail, and confidentiality of the data was also explained to the participants. Harmful (physical and psychological) factors for the participants were not included in the study.

Internal reliability (dependability) of the data analysis was provided by examining the sample data using a peer coder (external researcher). 78% agreement was obtained at first, and then full agreement was obtained after discussing the points of disagreement. For the internal validity (credibility) of the research, peer debriefing and member checking were used. The external researcher was included for the development of the interview questions and code list, and during the coding some precautions were taken to maintain credibility. Peer debriefing was used to eliminate the effects of bias, if any. Having the interviewee check the explanations was important for increasing credibility and removing ambiguity. In addition, thick description and purposive sampling were the precautions taken for external validity (transferability) of the results into different settings. The last issue, external reliability, which corresponds to confirmability or objectivity of the research, was provided using some precautions as explained by LeCompte and Goetz (1982) and Yıldırım and Şimşek (2005, pp. 260-262). More specifically, in order to aid in the replication of this study by other researchers, the researcher's role, selection and description of the participants and social environment (the quantum mechanics course), and the data collection and analysis techniques were described in detail.

Results

This section is composed of two parts explaining pre-service physics teachers' motivations towards learning quantum theory. Each motivational construct was examined separately at first. Then, the superposition map indicating the relationships was presented.

Motivational Constructs and Context Dependent Motivational Elements

Pre-service Physics Teachers' Expectancies: To examine expectancy, the first three questions of the interview protocol were analyzed holistically. Teacher candidates' future-oriented short-term expectancies were categorized hierarchically in Table 2.

Table 2

Pre-service Physics Teachers' Expectancies

Pre-service physics teachers	Expectancies
P1, P2, P5, P6	To be able *to pass the course* by *understanding the content* and *getting a good grade*
P4	To be able *to pass the course* by *understanding the content*
P3	To be able *to pass the course*

As shown in Table 2, pre-service physics teachers presented three different types of expectancies in terms of complexity. In the first one, the simplest expectancy is *to be able to pass the course*. Since quantum mechanics is a compulsory course for pre-service physics teachers, all of the teacher candidates firstly expect to be able to pass the course. Excluding P3, passing the course was the basic expectancy for all participants. Four of them added other expectancies such as *understanding the concepts* and *getting good grades* in the quantum mechanics course.

The examination of pre-service physics teachers' explanations in the interviews about their expectancies revealed that their expectancies were influenced by some factors: the instructor, their previous performance, and the nature of the content of quantum mechanics. A sample excerpt from the interview of one teacher candidate, P5, indicates the elements that shape her expectancies:

> *Interviewer*: You got a BA grade in the quantum physics course. How well do you expect to do in quantum mechanics next semester?
>
> *P5*: Umm... Actually, it depends on the lecturer of the quantum mechanics course. For this reason, my best friends and I will take the quantum mechanics course from the other instructor. I think I will then be successful in the quantum mechanics course and get the minimum grade of BA.

Although this teacher candidate mainly expects to pass the course by understanding the course content and getting a good grade, this excerpt indicates that the *instructor* plays a key role in achieving these expectancies. This excerpt also implies that the expectancies for the quantum mechanics course can change. Another pre-service physics teacher, P6, also stated that she expects to be able to pass the course by understanding the content and getting a good grade in quantum mechanics:

> *Interviewer*: How well do you expect to do in quantum mechanics next semester?
>
> *P6*: I got an AA grade in the quantum physics course. I believe that I understood the fundamental concepts of quantum mechanics. From now on, I can add new things to my knowledge. In other words, my course grade will get better.

The quantum physics course is just an introductory course explaining the fundamental ideas of quantum theory. The explanations based on her *performance* in the quantum physics course reflect the participant's confidence about her knowledge. This excerpt is also a context specific element influencing expectancy because the main focus is the same for both courses. P3 indicates another motivational element. An excerpt from his explanations is as follows:

> *Interviewer*: How well do you expect to do in quantum mechanics next semester?
>
> *P3*: Umm... Quantum mechanics is so mathematical. I expect to just pass the course...

In the pedagogical research on quantum mechanics, the abstract, counter-intuitive, and mathematical nature of quantum mechanics was identified as one of the reasons that students have difficulty with quantum mechanics (Sadaghiani, 2005; Wattanakasiwich, 2005). In this study, the reports of pre-service physics teachers indirectly provide information about the influence of the *mathematical nature of quantum theory* on student learning. In other words, the mathematical nature does not directly show how it influences the participants' success, but it explains how this element influences their expectancy so that their motivation is in turn influenced.

When all the other expectancies reported by the teacher candidates are considered, it is found that the expectancy to pass the course is the basic expectancy for all participants. Since the nature of quantum mechanics cannot be manipulated like other elements such as the choice of instructor or an individual's performance, this element seems to shape pre-service physics teachers' expectancy more than other constructs. By considering pre-service physics teachers' previous performances, the explanations indicating their ability beliefs can be classified into two categories. One of them is the perception of their abilities when considering their modern physics or quantum physics grades (P1, P2, P5, P6) and the other is their sense of achievement (P3, P4).

Pre-service Physics Teachers' Task Values: Value and the relations among value elements (attainment, intrinsic or interest, utility, and cost) were investigated by questions four through fourteen in the interview protocol.

The fourth question is about *attainment*. It asks pre-service physics teachers that how important that being good at quantum mechanics while learning a challenging domain of physics. Three types of explanations on the importance of learning quantum theory were investigated in relation to being good at quantum mechanics. Table 3 summarizes their explanations about why they give importance to quantum mechanics.

Table 3
Pre-service Physics Teachers' Attainment Values about Quantum Mechanics

Pre-service physics teachers	Reason of importance	Categories
P3, P4	*Learning*	It is important *to learn* the concepts of the quantum mechanics course
P2, P6	*Grade + Learning*	It is important *to get good grades that indicate learning* of quantum mechanics
P5, P1	*Grade*	It is important *to get good grades* in quantum mechanics

As presented in Table 3, being good at quantum mechanics is of first importance for learning quantum theory. An excerpt from one of the teacher candidates stating the importance of *learning* as follows:

Interviewer: How important is it for you to be good at quantum mechanics?

P3: Umm... It is important to learn... Umm... I am not interested in the grades. It is important to learn it. I do not concern myself about other things such as getting a good grade... I think... Umm... If I do not learn it as a physicist, as a physics teacher, I will regret not learning it. To be able to explain... Umm... To know how to explain something about quantum theory is what motivates me.

P3 gives some clues about how his motivation is intrinsically derived. He thinks that being good at quantum mechanics is important for learning the quantum theory. Another explanation is given by P2, who considers both learning and *getting good grades* at the same time:

Interviewer: How important is it for you to be good at quantum mechanics?

P2: Umm... I especially want to get good grades from physics courses. I like physics very much and I want to understand everything in physics courses. But... Umm... Getting a good grade shows what you understand, so it is important to get good grades and understand it.

This explanation shows how the teacher candidate considers success in quantum physics because she perceives getting good grades as an indicator of learning, so she gives importance to both of them at the same time. Another point considered as an attainment value is that to be good at quantum mechanics means getting a good grade. One of the teacher candidates, P5, explains how and why it is important:

Interviewer: How important is it for you to be good at quantum mechanics?

P5: Umm... (Smiling)... For example, it might be good to have good grades on my transcripts because we cannot predict what happens in the future.

This explanation shows the role of external elements in a pre-service teacher's motivation. She gives importance to being good at quantum mechanics because it will result in good grades, and she also places importance on being able to demonstrate high grades when necessary.

Questions five through eight in the analysis describe the *interest* value. Interest is also an element interacting with other motivational elements that appear in the context as well as with other constructs of Expectancy-Value theory. *Nature of content* and *instructor* are again motivational elements that appear in this context. P3, P4, and P6 think that the *philosophical*, *highly mathematical*, and *abstract nature of quantum mechanics* content respectively affect their interests.

Interviewer: Would you take the quantum mechanics course if it were an elective course?

P3: Umm... It depends on what would be taught.

Interviewer: Can you elaborate on this?

P3: Umm... If it were a lecture including the philosophical foundations of quantum mechanics, I would take the course. I am really interested in the philosophical foundations of quantum mechanics.

Similar to the previous section explaining the attainment element for motivation, P3 still thinks that the nature of context intrinsically influences his motivation. He mentions his interest in learning quantum mechanics because he likes learning. At this point, he focuses on how the nature of quantum theory influences his interest. P4, another teacher candidate who gives importance to learning quantum mechanics, describes how its mathematical nature influences her motivation.

Interviewer: Would you take the quantum mechanics course if it were an elective course?

P4: I know quantum mechanics uses more mathematical calculations. Umm... Maybe I would not take this course if it were an elective course. I don't like focusing on mathematics in physics. Everybody can handle mathematics, but understanding the physical idea behind the concepts is more important than overcoming its mathematics. I am interested in the physical meanings of the concepts in quantum mechanics more than their mathematics.

As the mathematical nature of quantum mechanics was explained to be an element influencing student understanding (Gardner, 2002; Sadaghiani, 2005; Strnad, 1981; Wattanakasiwich, 2005), it is also a context-specific element that influences pre-service physics teachers' motivation. P6 stresses the other characteristics of quantum theory. She indicates how the abstract nature of quantum mechanics shapes her motivation.

Interviewer: Would you take the quantum mechanics course if it were an elective course?

P6: No, I would not... Umm... It is because of the abstract nature of the course. I will not use these abstract concepts in the future, so if I do not use them, why would I take this course?

Another motivational element influencing pre-service physics teachers' interest is *instructor*. P1 describes the influence of the instructor as follows:

Interviewer: Would you take the quantum mechanics course if it were an elective course?

P1: Umm... If I were really interested in quantum mechanics and I wanted to learn it, who the instructor would be is important to me. I mean, if the instructor were to teach me it at an advanced level, I would not want to take the course from that instructor.

As seen in the examples above, the nature of the concepts of quantum mechanics and the instructor are two motivational elements stated by the pre-service physics teachers. They reported that these elements influence their expectancy and interest in the context of learning the quantum theory.

The *utility* of learning quantum mechanics was examined using the ninth and tenth questions. Pre-service physics teachers' utility values can be classified basically into two categories. A group of teacher candidates (P1, P2, P3, P4) think that quantum mechanics is useful for physics teachers, physicists, and all other individuals. On the other hand, the second group (P5, P6) thinks that it is not useful for physics teachers. Table 4 presents pre-service physics teachers' utility values about learning quantum mechanics.

P5 and P6 think that learning quantum mechanics is not useful for physics teachers. They justify themselves using the abstractness of quantum mechanics and the incompatibility between what they learn in quantum mechanics and what they will teach in high school physics classes. However, other teacher candidates, P1, P2, P3, and P4, think that learning quantum mechanics is useful for physics teachers for many reasons. They indicate the usefulness of subject matter knowledge and pedagogical content knowledge of a physics teacher while teaching physics. The teacher candidates (P1 and P2) also recognize the utility of quantum mechanics for scientists. They state its importance mainly in the development of technology. Finally, they (P1, P3, and P4) consider its utility for every individual in terms of intellectual development.

Wigfield et al. (2004) mention that *cost* value has not been stated much in the literature. What pre-service physics teachers give up to succeed in quantum physics is considered as cost. In the current study, the cost value was examined using questions eleven through thirteen. Common answers to the question "What did you give up to learn introductory quantum mechanics in the quantum physics course?" were giving up some physical needs such as sleep or summer holidays, and psychological needs such as those afforded by family and friends. The two explanations given by P4 and P6 indicate what they had to give up learning quantum mechanics:

Interviewer: What did you give up to learn introductory quantum mechanics in the quantum physics course?

Table 4
Pre-service Physics Teachers' Utility Values

	Pre-service physics teachers' explanations about usefulness	
	Not Useful	Useful
For Physics Teachers	P5- Abstractness of quantum mechanics will not be used in physics teaching. P6- What we learn in the quantum physics course and what we teach in a high school physics class are incompatible.	P1- Quantum mechanics is very popular among high school students. They are very curious about it. As future teachers, we can provide meaningful explanations to them... A physics teacher should have more information about physics than other people. Knowing quantum mechanics provides us with this opportunity. P4- A physics teacher should be knowledgeable about all branches of physics... It is expected that a physics teacher should be able to answer students' questions about quantum mechanics, so we should learn it. P3- We may lead students' interest into physics by explaining some ideas of quantum theory. P2- We can explain concepts of atomic level by knowing quantum mechanics.
For Physicists	-	P2- Being able to understand the atomic nature of matter is useful... Nanotechnology is developed based on knowledge of quantum mechanics. P1- It is useful for the development of technology that we see in our daily lives, such as cell phones and plasma TV's.
For everyone	-	P3- Each individual should know physics; it is not bad to know the physics of atoms. P1- Learning quantum mechanics improves an individual's way of thinking. P4- It affects people's stance in life.

> *P4*: Umm... I had a part-time job, I could not go to work… I did not chat with my friends while they were chatting… Sometimes I did not sleep because I had to study the concepts of quantum theory.
>
> ***
>
> *Interviewer*: What did you give up to learn introductory quantum mechanics in the quantum physics course?
>
> *P6*: I took the quantum physics course in summer school. I am from Antalya, so I had to stay here, I gave up my summer holiday, my family…

In addition, pre-service physics teachers were asked "Is learning quantum mechanics worth giving up something?" Some of them stated that they were not too happy when they had to give up certain needs learning quantum mechanics. However, P1 said "Being appreciated by the quantum physics instructor is worth all the effort I spent learning quantum mechanics." This explanation also indicates how an instructor shapes pre-service physics teachers' motivation.

Interrelations among the Motivational Elements

The interviews with pre-service physics teachers also revealed some qualitative relationships among the motivational elements for learning quantum mechanics. Figure 1, the superposition map, presents the qualitative relationships among these elements.

The superposition map also indicates the roles of context specific elements on each pre-service physics teacher's motivation. For example, P1 stresses the influence of *effort* in her expectancy as follows:

> *P1*: Umm... I expect to get a minimum grade of BB in the quantum mechanics course because I think I understand the concepts of quantum theory in the quantum physics course. But... Umm... My expectancy about quantum mechanics may change depending on how much I study for it during the semester.

This explanation indicates that expectancy can be manipulated by personal effort in achievement tasks. P1 also states how a context specific

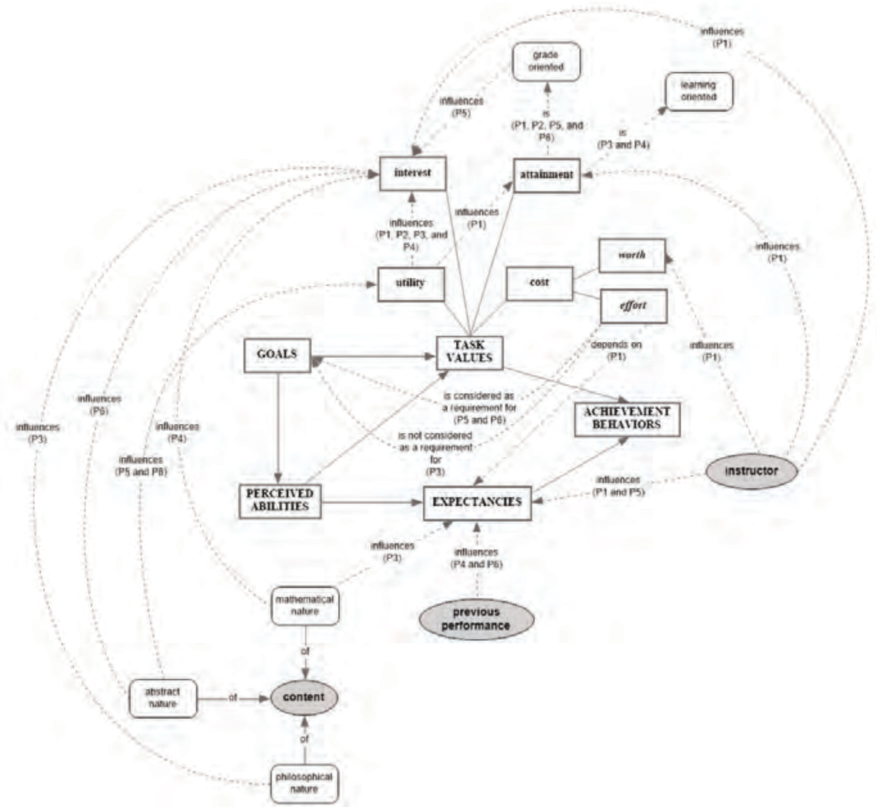

Figure 1: Relations among the *motivational constructs* and *pre-service physics teachers' motivation*: Rectangular shapes represent the theoretical elements and the other ones represent the contextual elements.

motivational element, *instructor*, influences her interest in learning quantum mechanics.

> *Interviewer*: Can you clarify what you mean by stating the most important factor that affects your interest?
>
> *P1*: The course name will be shown on my transcripts, so taking this course will provide me with an advantage in the future. In addition, it is a mysterious, popular, and excellent topic, so it can be taken as an elective course.

It was observed that some extrinsic orientations (grades) shaped the interest of teacher candidates. P5 is a grade-oriented student. Like her expectancy, her interest is also shaped by grades. She said "If taking the quantum mechanics course influences my CGPA positively, I will take this course as an elective course."

In the questions "Are you interested in quantum mechanical concepts (do you read books, do research etc.)?" and "Do you like the concepts of quantum mechanics?" pre-service physics teachers related their interests to how much of an effort they made. All teacher candidates stated that they were interested in learning quantum mechanics for different reasons. However, their explanations about effort varied, as shown in Table 5.

Table 5
Interest-Effort Uncertainty

Pre-service physics teachers	Interest- effort
P1, P3	I am interested in quantum mechanical concepts and I do research in addition to the lecture requirements. I read books, do research on the internet, etc.
P2, P4	I am interested in quantum mechanical concepts and I discuss them with the lecturers in addition to the lecture requirements. I read books, do research on the internet, etc.
P5, P6	I am interested in quantum mechanical concepts; however, I do nothing in addition to the lecture requirements.

For all pre-service teachers, effort means "to do the minimum requirements of the course, such as attending the course, studying for exams, taking quizzes, and so forth." The intrinsically-oriented pre-service physics teacher, P3, implied that he does not make any effort to learn quantum mechanics, although he stated researching on the internet and reading books. On the other hand, P5 and P6 mentioned that they make great effort to learn by only fulfilling the requirements of the course. This discrepancy indicates how pre-service physics teachers' perceptions of effort change by level of interest. In other words, intrinsically-oriented teacher candidates do not think that they work too much to learn. However, extrinsically-oriented teacher candidates who focus on getting a good grade perceive that they make too much effort; although they do not do work outside of what is required. In this study, effort is also identified as the only element related to goals.

Conclusion and Discussion

Atkinson and Feather (1966) remarked that expectations about the actions and incentive values of the actions are important for motivation (p. 5) because expectancies and values are the determinants of the future behavior (Pintrich & Schunk, 2002, p. 53). By examining six pre-service teachers' motivation for learning quantum theory, this study identified the instructor, previous performance in the quantum physics course, and the nature of quantum mechanics content as elements that influence pre-service teachers' expectancy and value constructs, and hence, their motivation.

Many students think that quantum mechanics is a difficult course since it has an abstract, counter-intuitive, and highly mathematical nature (Wattanakasiwich, 2005). So they consider this course only as a compulsory course in the curriculum to be completed. In addition, Sadaghiani (2005) has shown that in addition to students' problems with learning quantum mechanics, the instructors have problems teaching it because of the nature of the quantum concepts. By using conceptual physics questions, previous research (Bao, 1999; Çataloğlu & Robinett, 2002; Didiş et al., 2010, 2014; Dobson et al., 2000; Escalada, 1997; Gardner, 2002; Ke et al., 2005; Kwiat & Hardy, 2000; Morgan, 2006; Müller & Wiesner, 1999, 2002; Olsen, 2002; Özcan et al., 2009; Sadaghiani, 2005; Singh, 2001; Singh et al., 2006; Strnad, 1981; Styer, 1996; Wattanakasiwich, 2005) has shown that students' understanding was shaped by the abstract, counter-intuitive, and mathematical nature of the theory. This study identified the nature of quantum theory was a context-specific motivational element influencing students' motivation, so their learning the theory. Correspondence of the findings in two different ways indicates that students' difficulty in understanding quantum theory might be explained with affective variables as the cognitive explanations. Low motivation was given as the most important reason for unsuccessful situations in schools (Brophy, 1983). In other words, pre-service physics teachers' learning of quantum theory may be improved by motivating them to learn the theory through focus on the context-specific motivational elements.

Wigfield (1994) cited the results of the study by Eccles et al. showing children's conceptions on the importance or usefulness of different tasks may not be very clear in the several years they spend at school. In this study, because all the participants were very close to graduation and obtaining a job as physics teachers, they had clear ideas about the attainment and utility of learning quantum mechanics. Pre-service physics teachers gave importance to learning quantum theory in spite of giving different explanations for its importance (such as just for learning, learning and good grades, or just for good grades). In addition, although two of the pre-service physics teachers thought that learning quantum theory was not useful, four of them explained the benefits of learning quantum theory for physics teachers. This explanation is important because the new curricula for the Turkish high school physics course (Milli Eğitim Bakanlığı, 2013) propose the teaching of introductory quantum theory concepts in 12^{th} grade. For this reason, physics teacher candidates' learning of the theory is important for their subject-matter knowledge. This importance can be explained to teachers in terms of professional development and needs (Deci & Ryan, 2000). Because of its relation and usefulness to them, teachers are more likely to be motivated to make changes that could influence student achievement, as Atkinson (2000) explained that teacher motivation is important for students' learning.

Eccles et al. (1983) proposed that there are clear causal links between individuals' goals, ability beliefs, subjective values, and expectancies for success (p. 81). In this study, both direct and indirect relations with expectancies and value elements have been identified. For example, Wigfield (1994) also implied that ability beliefs might causally precede expectancies. In addition, Eccles et al. (1983) explained that students' ability beliefs and expectations for success should be positively related. This study showed that pre-service physics teachers' success expectancy is shaped by their performance in the quantum physics course. In this sense, the results of the current study are similar to Wigfield's (1994) and Eccles et al.'s (1983) studies indicating previous performance as a context-dependent motivational construct having relation with expectancy. Wigfield and Eccles (2000) stated that interest value is a construct similar to the construct of intrinsic motivation, as defined by Deci, since it concerns doing a task with interest and enjoyment. In this study, it was also revealed that interest was directly shaped by the nature of content, which is abstract, mathematical, and philosophical. The results of this study support that context-dependent motivational elements are in interaction with each other, and motivation towards learning quantum theory is shaped by these interactions.

This qualitative study examined pre-service physics teachers' motivation towards learning quantum theory through Expectancy-Value theory and identified context-dependent motivational elements for a quantum mechanics context. For further research, quantitative relationships among the variables may be tested and the interactions may be modeled. In addition, other affective elements that are motivational constructs, such as expectancies, values, ability beliefs, and goals, related to student learning may be examined.

References

Atkinson, E. S. (2000). An investigation into the relationship between teacher motivation and pupil motivation. *Educational Psychology, 20*(1), 45-57.

Atkinson, J. W., & Feather, N. T. (1966). *A theory of achievement motivation*. New York, NY: John Wiley & Sons.

Bao, L. (1999). *Dynamics of student modeling: A theory, algorithms and application to quantum mechanics* (Doctoral dissertation, University of Maryland). Retrieved from http://www.physics.ohio-state.edu/~lbao/archive/Thesis/Thesis.htm

Brophy, J. (1983). Classroom organization and management. *Elementary School Journal, 83*(4), 265–285.

Budde, M., Niedderer, H., Scott P., & Leach, J. (2002a). Electronium: A quantum atomic teaching model. *Physics Education, 37*(3), 197–203.

Budde, M., Niedderer, H., Scott, P., & Leach, J. (2002b). The quantum atomic model 'Electronium': A successful teaching tool. *Physics Education, 37*(3), 204–210.

Çataloğlu, E., & Robinett, R. W. (2002). Testing the development of student conceptual and visualization understanding in quantum mechanics through the undergraduate career. *American Journal of Physics, 70*(3), 238–251.

Cuppari, A., Rinaudo, G., Robutti, O., & Violino, P. (1997). Gradual introduction of some aspects of quantum mechanics in a high school curriculum. *Physics Education, 32*, 302–308.

Deci, E. L., & Ryan, R. M. (2000). The what and why of goal pursuits: Human needs and the self determination of behavior. *Psychology Inquiry, 11*(4), 227–268.

Department of Physics. (2015a). *Course list* [On-line]. Retrieved from http://www.physics.metu.edu.tr/Education/Courses-P3#C2300300

Department of Physics. (2015b). *Course list* [On-line]. Retrieved from http://www.physics.metu.edu.tr/Education/Courses-P4#C2300431

Didiş, N. (2015). The analysis of analogy use in the teaching of introductory quantum theory. *Chemistry Education: Research and Practice, 16*, 355–376.

Didiş, N., & Özcan, Ö. (2007, November). *Pre-service physics teachers' attributions about successing quantum mechanics.* Paper presented at the meeting of the International Conference on Physics Education (ICPE) - Building Careers with Physics, Marrakech, Morocco.

Didiş, N., & Redish, E. F. (2010, July). *How do students perceive the reasons for their success in a modern physics course?* Paper presented at Physics Education Research Conference, Portland, OR.

Didis, N., & Redish, E. F. (2012, July). *Comparison of Turkish and American students' attributions of success/failure in modern physics.* Paper presented at World Conference on Physics Education, Istanbul, Turkey.

Didiş, N., Eryılmaz, A., & Erkoç, Ş. (2010). Pre-service physics teachers' comprehension of quantum mechanical concepts. *Eurasia Journal of Mathematics, Science & Technology Education, 6*(4), 227–235.

Didiş, N., Eryılmaz, A., & Erkoç, Ş. (2014). Investigating students' mental models about the quantization of light, energy and angular momentum. *Physical Review Special Topics: Physics Education Research, 10*(2), 1–28, 020127.

Dobson, K., Lawrence, I., & Britton, P. (2000). The A to B of quantum physics. *Physics Education, 35*(6), 400–405.

Donald, J. G. (1999). Motivation for higher order learning. In M. Theall (Ed.), *Motivation from within: Approaches for encouraging faculty and students to excel* (pp. 1–16). San Francisco, MA: Jossey-Bass Publishers.

Eccles, J. S., Adler, T. F., Futterman, R., Goff, S. B., Kaczala, C. M., Meece, J., & Midgley, C. (1983). Expectancies, values and academic behaviors. In J. T. Spence (Ed.), *Achievement and achievement motives* (pp. 75–146). San Francisco, MA: W. H. Freeman and Company.

Escalada, L. T. (1997). *Investigating the applicability of activity-based quantum mechanics in a few high school physics classrooms* (Doctoral dissertation, Kansas State University). Retrieved from https://web.phys.ksu.edu/dissertations/escaladaPhD.pdf

Fan, W. (2011). Social influences, school motivation and gender differences: An application of the expectancy-value theory. *Educational Psychology, 31*(2), 157–175.

FIT-Choice Project: Factors Influencing Teaching Choice. (2007). *FIT-Choice Project: Factors influencing teaching* [On-Line]. Retrieved from Choicehttp://www.fitchoice.org/

Fraenkel, J. R., & Wallen, N. E. (2000). *How to design & evaluate research in education.* Boston, MA: McGraw Hill.

Frederick, C. (1978). A mechanical model for teaching quantum mechanics. *American Journal of Physics, 46*(3), 242–243.

Fulton, E., & Turner, L. A. (2008). Students' academic motivation: relations with parental warmth, autonomy granting, and supervision. *Educational Psychology, 28*(5), 521–534.

Gardner, D. E. (2002). *Learning in quantum mechanics* (Doctoral dissertation, Purdue University). Retrieved from ProQuest Dissertations And Theses; Publication Number: AAI3104944.

Gokce, F. (2010). Assessment of teacher motivation. *School Leadership & Management: Formerly School Organization, 30*(5), 487–499.

Hadzidaki, P., Kalkanis, G., & Stavrou, D. (2000). Quantum mechanics: A systemic component of the modern physics paradigm. *Physics Education, 35*(6), 386–392.

Hidi, S., & Harackiewicz, J. M. (2000). Motivating the academically unmotivated: A critical issue for the 21st century. *Review of Educational Research, 70*(2), 151–179.

Ireson, G. (2000). The quantum understanding of pre-university physics students. *Physics Education, 35*(1), 15–21.

Jugovic, I., Marusic, I., Ivanec, T. P., & Vidovic, V. V. (2012). Motivation and personality of preservice teachers in Croatia. *Asia-Pacific Journal of Teacher Education, 40*(3), 271–287.

Kalkanis, G., Hadzidaki, P., & Stavrou, D. (2003). An instructional model for a radical conceptual change towards quantum mechanics concepts. *Science Education, 87*, 257–283.

Ke, J. L., Monk, M., & Duschl, R. (2005). Learning introductory quantum physics: Sensori-motor experiences and mental models. *International Journal of Science Education, 27*(13), 1571–1594.

Klassen, R. M., Al-Dhafri, S., Hannok, W., & Betts, S. M. (2011). Investigating pre-service teacher motivation across cultures using the Teachers' Ten Statements Test. *Teaching and Teacher Education, 27*, 579–588.

König, J., & Rothland, M. (2012). Motivations for choosing teaching as a career: Effects on general pedagogical knowledge during initial teacher education. *Asia-Pacific Journal of Teacher Education, 40*(3), 289–315.

Kwiat, P. G., & Hardy, L. (2000). The mystery of the quantum cakes. *American Journal of Physics, 68*(1), 33–36.

Lam, B. H. (2012). Why do they want to become teachers? A study on prospective teachers' motivation to teach in Hong Kong. *The Asia-Pacific Education Researcher, 21*(2), 307–314.

LeCompte, M. D., & Goetz, J. P. (1982). Problems of reliability and validity in ethnographic research. *Review of Educational Research, 52*(1), 31–60.

Mannila, K., Koponen, I., & Niskanen J. A. (2002). Building a picture of students' conceptions of wave- and particle-like properties of quantum entities. *European Journal of Physics, 23*, 45–53.

Marshall, C., & Rossman, G. B. (1999). *Designing qualitative research.* Thousand Oaks, CA: Sage.

Mashhadi, A., & Woolnough, B. (1999). Insights into students' understanding of quantum physics: Visualizing quantum entities. *European Journal of Physics, 20,* 511–516.

Merzbacher, E. (1998). *Quantum mechanics.* New York, NY: John Wiley & Sons.

Michelini, M., Ragazzon, R., Santi, L., & Stefanel, A. (2000). Proposal for quantum physics in secondary school. *Physics Education, 35*(6), 406–410.

Morgan, J. T. (2006). *Investigating how students think about and learn quantum physics: An example from tunneling* (Doctoral dissertation, The University of Maine). Retrieved from http://www.library.umaine.edu/theses/pdf/morganjt2006.pdf

Müller, R., & Wiesner, H. (1999, March). *Students' conceptions of quantum physics.* Paper presented at the meeting of the National Association for Research in Science Teaching (NARST), Boston, MA.

Müller, R., & Wiesner, H. (2002). Teaching quantum mechanics on an introductory level. *American Journal of Physics, 70*(3), 200–209.

Olsen, R. V. (2002). Introducing quantum mechanics in the upper secondary school: A study in Norway. *International Journal of Science Education, 24*(6), 565–574.

Milli Eğitim Bakanlığı. (2013). *12. Sınıf fizik dersi öğretim programı* (High school physics curriculum for grades 12). Retrieved from http://ttkb.meb.gov.tr/www/ogretim-programlari/icerik/72

Özcan, Ö., Didiş, N., & Taşar, M. F. (2009). Students' conceptual difficulties in quantum mechanics: Potential well problems. *Hacettepe University Journal of Education, 36*, 169–180.

Paulsen, M. B., & Feldman, K. A. (1999). Student motivation and epistemological beliefs. In M. Theall (Ed.), *Motivation from within: Approaches for encouraging faculty and students to excel* (pp. 17-25). San Francisco, CA: Jossey-Bass Publishers.

Pintrich, P. R., & Schunk, D. H. (2002). *Motivation in education: Theory, research and applications.* Upper Saddle River, New Jersey: Merrill, Prentice Hall.

Pospiech, G. (2000). Uncertainty and complementarity: The hearth of quantum physics. *Physics Education, 35*(6), 393–399.

Sadaghiani, H. R. (2005). *Conceptual and mathematical barriers to students learning quantum mechanics* (Doctoral dissertation, The Ohio State University). Retrieved from https://etd.ohiolink.edu/!etd.send_file?accession=osu1123878116&disposition=inline

Salili, F. (1996). Achievement motivation: A cross-cultural comparison of British and Chinese students. *Educational Psychology, 16*(3), 271–279.

Schunk, D. (1990). Introduction to the special section on motivate and efficacy. *Journal of Educational Psychology, 82*(1), 3–6.

Shadmi, Y. (1978). Teaching the exclusion principle with philosophical flavor. *American Journal of Physics, 46*(8), 844–848.

Singh, C. (2001). Student understanding of quantum mechanics. *American Journal of Physics, 69*(8), 885–895.

Singh, C., Belloni, M., & Christian, W. (2006). Improving students' understanding of quantum mechanics. *Physics Today, 59*(8), 43–49.

Strnad, J. (1981). Quantum physics for beginners. *Physics Education, 16,* 88–92.

Styer, D. F. (1996). Common misconceptions regarding quantum mechanics. *American Journal of Physics, 64*(1), 31–34.

Vandegrift, G. (2002). The maze of quantum mechanics. *European Journal of Physics, 23,* 513–522.

Watt, H. M. G., & Richardson, P. W. (2007). Motivation factors influencing teaching as a career choice: Development and validation of the FIT-Choice scale. *Journal of Experimental Education, 75*(3), 167–202.

Watt, H. M. G., & Richardson, P. W. (2008). Motivations, perceptions, and aspirations concerning teaching as a career for different types of beginning teachers. *Learning and Instruction, 18,* 408–428.

Watt, H. M. G., & Richardson, P. W. (2012a). An introduction to teaching motivations in different countries: comparisons using the FIT-Choice scale. *Asia-Pacific Journal of Teacher Education, 40*(3), 185–197.

Watt, H. M. G., & Richardson, P. W. (2012b). Motivations for choosing teaching as a career: An international comparison using the FIT-Choice scale. *Teaching and Teacher Education, 28,* 791–805.

Wattanakasiwich, P. (2005). *Model of understanding of probability in modern physics* (Doctoral dissertation, Oregon State University). Retrieved from http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/28663/WattanakasiwichPornrat2005.pdf?sequence=1

Wentzel, K. R., & Wigfield, A. (2007). Motivational interventions that work: Themes and remaining issues. *Educational Psychologist, 42*(4), 261–271.

Wigfield, A. (1994). Expectancy-value theory of achievement motivation: A developmental perspective. *Educational Psychology Review, 6*(1), 49–78.

Wigfield, A., & Eccles, J. S. (2000). Expectancy-value theory of achievement motivation. *Contemporary Educational Psychology, 25,* 68–81.

Wigfield, A., Tonks, S., & Eccles, J. S. (2004). Expectancy-value theory in cross-cultural perspective. In D. McInerney & S. Van Etten (Eds.), *Research and socio-cultural influences on motivation and learning* (pp. 165–198). Greenwich, CT: Information Age Publishing.

Wlodkowski, R. J. (1999). Motivation and diversity: A framework for teaching. In M. Theall (Ed.), *Motivation from within: Approaches for encouraging faculty and students to excel* (pp. 1–16). San Francisco: Jossey-Bass Publishers.

Yıldırım, A., & Şimşek, H. (2005). *Nitel araştırma yöntemleri.* Ankara: Seçkin.

Zimmerman, B. J., & Risemberg, R. (1997). Self-regulatory dimensions of academic learning and motivation. In G. D. Phye (Ed.), *Handbook of academic learning: Construction of knowledge* (pp. 181–199). New York, NY: Academics Press.