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The Challenge of Quantum Physics Problems with Self-Metacognitive Questioning

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Abstract

Pre-service science teachers learn about metacognitive knowledge theoretically in their pedagogy courses; however, teaching practice in science classes reveals the theory–practice gap in their metacognitive knowledge, which has practical importance for prospective teachers. This paper reports on an experiment conducted to investigate the influence of self-metacognitive questioning for non-routine quantum physics problems on pre-service science teachers' attitudes towards a quantum physics course. Pre-service teacher participants in the experimental and control groups were taught the subjects of quantum physics for 14 weeks, but only those in the experimental group were guided by self-metacognitive questioning during their engagement of non-routine problem-solving as a treatment process. The results indicate that self-metacognitive questioning for non-routine quantum physics problems creates a statistical effect favouring the experimental group students' attitudes towards the quantum physics course. However, the positive change in the control group is explained by the postulates of the Elaboration Likelihood Model (ELM) of persuasion.

Keywords Metacognition · Problem-solving · Attitudes · Teacher education

Introduction

Problem-solving is a major part of training activities, as well as in people's real lives. A problem is a difficulty or challenge that invites the person facing it to find a solution. The solver has no obvious methods or instruments to solve the problem because it is a new situation for them (Mayer and Wittrock 1996). In physics courses, students, as problem-

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solvers, can be expert or novice, and a problem according to its solver can be routine or non-routine. An expert's approach to solving physics problems differs from that of a novice. Moving from novice to expert level as a physics problem-solver requires a greater development of skills and strategies (Docktor et al. 2016; Mayer 1998). The expert solver knows the ways to identify physics problems, organise and interpret data, and formulate solutions (Chi et al. 1981; Eylon and Reif 1984; Larkin 1979; Reif 1981; Sweller 1988). Expert physics problem-solvers are superior to novice physics problem-solvers in terms of their analytical skills (Robbins 2011; Williams 2018), which include ordering, comparing, contrasting, evaluating and selecting correct strategies. These analytical skills provide a logical framework for problem-solving helping the solver to select the best alternative from the available range of possibilities. Creative thinking skills (Mumford et al. 2012) are also important for both experts and novices in solving physics problems. These skills include the imagination to create a large range of ideas for the solution of non-routine physics problems. Students who become effective problem-solvers during their physics courses are able to balance a mixture of analytical and creative thinking.

Our previous experiences have revealed that the solutions to physics problems are occasionally learned by rote. This process is as follows: the instructor teaches the concepts and principles or laws of a physics subject, then solves a few problems related to this subject as a model. Thus, students can only resolve certain types of problems which have been solved in class by the instructor but the students do not have the strategies to solve different types of physics problems. Engaging in this process results in students learning solutions by rote, which allows them only to solve similar problems (Selcuk et al. 2007; Sin 2014) but they will find it very difficult to solve non-routine physics problems (Anzai and Yokoyama 1984; Stewart and Rudolph 2001). There are two main disadvantages of the rote learning process for students. First, they sometimes struggle to memorise the required number of solutions, and they also need to develop less strategies. The second disadvantage is that students are unable to solve non-routine problems.

Undoubtedly, it is easier for students to learn how to use several strategies in metacognitive awareness than memorising a large number of solutions (Akben 2018; Hollingworth and McLoughlin 2001). In the work of Schoenfeld (1992), Lester (1994) and Mevarech (1999), the issue underlined was the role of metacognitive awareness in problem-solving, where metacognitive awareness is essential to understand, monitor and regulate students' own thought process during their engagement in problem-solving. Students with metacognitive awareness know how, when, and why to use cognitive strategies through problem-solving. Metacognitive instruction leads students to adopt self-questioning as appropriate strategies for solving a problem.

Extensive research on metacognition in science education (for example in the Avargil et al. 2018; best review works of Hattie 2009; Moshman 2018; Schraw and Moshman 1995; Thomas 2012; Zohara and Barzilai 2013) showed that the application of metacognitive instruction improved students' conceptual understanding of science (Abd-El-Khalick and Akerson 2009; Colthorpe et al. 2018; Dianovsky and Wink 2012; Georghiades 2004, 2006; Schraw et al. 2006; Leopold and Leutner 2015; White and Gunstone 1989), higher-order thinking skills (Ghanizadeh 2018; Kramarski and Mevarech 2003; Seraphin et al. 2012; Zohar 1999, 2004) and problem-solving skills (Akben 2018; Efklides 2001; King 1991; Meijer et al. 2006; Swanson 1990).

However, studies on metacognition training for problem-solving have mostly referred to mathematics problems (Cardelle-Elawar 1995; Chan et al. 2017; Hargrove and Nietfeld 2015;

Kramarski et al. 2001; Mevarech 1999; Schoenfeld 1987; Schoenfeld 1992; Rosenzweig et al. 2011), with less research being undertaken to investigate the effect of metacognition on physics problem-solving (Taasoobshirazi and Farley 2013; Thomas 2013).

The reviewed works of Thomas (2012) and Zohara and Barzilai (2013), and the work of Soodla et al. (2017) reveal that there is a research gap in the literature concerning teachers' knowledge and professional development regarding metacognition. Pre-service science teachers learn metacognitive knowledge theoretically in pedagogy courses; however, there is a need for the practical implementation in science lessons during teaching practice to reduce the theory-practice gap of metacognitive knowledge (Georghiades 2004; Hutner and Markman 2016; Thomas 2012; Zohara and Barzilai 2013). Pre-service science teachers need to be presented with metacognitive tasks in science courses (i.e. physics, chemistry and biology), which allows the students to gain experience and develop metacognitive skills (Veenman and Spaans 2005; Veenman 2011). Based on the literature summarised above, research on metacognitive practices in pre- and in-service science teacher education are serious issues, and the present research contributes to literature with the following research question which guided the study: What is the impact of self-metacognitive questioning for non-routine quantum physics problems on pre-service science teachers' attitude towards quantum physics course?

Theoretical Framework

Cognition is a mental process (Hutner and Markman 2016), in which knowledge is obtained and made known in a person's brain, including the skills necessary to encode, memorise and recall information (Anderson 1990; Schraw et al. 2006). In other words, if something is known in a persons' brain, it is encoded and memorised, and can be recalled or used whenever necessary. Knowledge is objective when it is unknown and it becomes subjective in the human brain after it is acquired by cognitive learning. The *meta* prefix refers to the more abstract aspect of cognition. According to Flavell (1976), who provided the first definition of metacognition, "In any kind of cognitive transaction with the human or non-human environment, a variety of information processing activities may go on. Metacognition refers, among other things, to the active monitoring and consequent regulation and orchestration of these processes in relation to the cognitive objects or data on which they bear, usually in service of some concrete goal or objective" (p. 232). The definitions of metacognition, such as *cognition about cognition* or *knowing about knowing* (Metcalfe and Shimamura 1994) refer to higher-order cognitions that supervise a person's thoughts, knowledge and actions (Weinert 1987).

Metacognition has often been conceptualised as consisting of two components (Brown 1987; Flavell 1979; Schraw et al. 2006; Schraw and Moshman 1995): the knowledge of cognition and the processes involving the monitoring, control and regulation of cognition, constituting the basic distinction between metacognitive knowledge and metacognitive control or self-regulatory processes (Pintrich 2002).

The first component refers to a person's awareness of "How does one make any knowledge known in his or her brain?" The answers to this question obviously depend on the person's individual differences which affect their performance as a learner in relation to well-known strategies and how they use these strategies appropriately in accordance with the task (Brown 1978). For example, two students of the same age and gender memorise 30 foreign words

using the same strategies in the same way. One of them can complete the task in 2 days but the other student takes 5 days. What effect can cause this difference?

The second component comprises metacognitive control and self-regulatory processes that learners use to monitor, control and regulate their cognition and learning (Pintrich 2002; Schraw et al. 2006; Schraw and Moshman 1995). They are represented in tasks, such as checking, planning and generating with the first categories referring only to knowledge of cognitive strategies, not the actual use of those strategies (Pintrich 2002).

Learners who have metacognitive awareness use metacognitive skills that involve thinking about a learning process, planning, monitoring and evaluating learning effectively. They are aware of what they should learn to achieve their goal, what prior knowledge they possess to construct new knowledge, which strategy/ies they will use to learn, the resources they need, how they will use the strategies, and how they will understand whether they have learned the necessary knowledge reached their goal (Lewis et al. 2015). In cognitive psychology, learning strategies are divided into two main groups: cognitive and metacognitive. Vaidya (1999) describes these strategies as follows: "Cognitive strategies help a person process and manipulate information; examples include taking notes, asking questions, or filling out a chart. Cognitive strategies tend to be very task specific, implying that certain cognitive strategies are useful only when learning or performing certain tasks. Metacognitive strategies are executive in nature. They are the strategies a student uses when planning, monitoring, and evaluating learning or strategy performance" (p. 186).

Early research on metacognition was conducted by developmental psychologists (Brown 1975, 1978, 1987; Flavell 1976, 1979, 1982), and many ideas developed since then have been accepted into the conventional wisdom of metacognition. Following this early research, numerous articles, chapters and edited books have been published about the role of metacognition in learning and instruction. In the work of Osman and Hannafin (1992), metacognition was analysed and classified in relation to its functions (meta-memory, meta-comprehension, self-regulation, schema training and transfer). Moreover, the authors classified metacognitive strategies according to the training approach presented in the existing literature. Subsequent research designed for instructional methods are generally based on the effect of metacognitive process on cognitive functions, such as reading context (e.g. Cross and Paris 1988; Koch 2001; Salomon et al. 1989), memorisation (e.g. Schnitzspahn et al. 2011), conceptual understanding (e.g. Abd-El-Khalick and Akerson 2009), critical thinking (e.g. Ku and Ho 2010) and problem-solving (e.g. King 1991; Kramarski et al. 2002; Swanson 1990).

Metacognition can be especially important during problem-solving in the stage of definition of goals, mental visualisation of the problem, selecting the strategy, activating prior knowledge, planning, monitoring and the evaluation of possible solutions (Güss and Wiley 2007; Taasoobshirazi and Farley 2013; Taasoobshirazi et al. 2015). Many of the problem-solving strategies developed for mathematics (e.g. Hammouri 2003), physics (Anzai and Yokoyama 1984) and chemistry (e.g. Sutherland 2002) are part of metacognitive knowledge generally based upon in order of the mental process of recognising a problem, representing the problem in the memory, and considering relevant information (Morse and Morse 1995). For example, in physics classes, students can apply their knowledge to solve problems in a practical way as expert physics problem-solvers who use their monitoring, assessing and decision-making skills in metacognitive awareness more effectively than novice problem-solvers (Schoenfeld 1985), and these are essential elements that determine a person's success or failure in physics problem-solving.

There is a need for students to receive professional training to monitor their cognitive processes during physics problem-solving (Teong 2003). Without this training, students are less likely to proceed to the end of the problem and/or find an elegant mathematical solution (Yimer and Ellerton 2006). The importance of "monitoring" as a metacognitive skill (checking once again the veracity of their thought, concepts, calculations, equations, plans, diagrams or anything) in solving physics problems is indicated by using the "think aloud" method within the qualitative research design (Ali et al. 2016). Taasoobshirazi and Farley (2013) and Taasoobshirazi et al. (2015) developed a physics metacognition inventory to assess students' metacognition for physics problem-solving using the following six components of their metacognition; knowledge of cognition, planning, monitoring, evaluation, debugging and information management.

The literature discussed above shows that metacognition has positive effects on students' conceptual understanding of science and high-order mental skills within the cognitive domain of learning. An important issue that should be researched is the metacognitive effects on the affective (attitude) domain of learning. In the main psychology literature, attitude is considered to comprise affective, cognitive and behavioural components (Eagly and Chaiken 1993). The affective component refers to a persons' emotional response and feelings about the ideas, events, objects or people. A student's feeling in physics course, such as "I am bored in the physics class" is an example of the affective component of attitude. A student sleeping during most of the physics class is an example of the behavioural component of attitude. The cognitive component involves the knowledge or belief about the ideas, events, objects or people. The student who is bored in the physics class believes that physics is very difficult and they cannot understand anything.

The psychological processes of persuasion responsible for attitude change are based on a complex and dynamic structure in social psychology. The Elaboration Likelihood Model (ELM) is one of the contemporary theories of persuasion (Petty and Cacioppo 1986). According to this theory, changing people's attitudes depends on persuasion, which is related to communication. The effectiveness of the communication variables, namely the source of the message, message itself and the recipient of the message, is important in the process of persuading people (Petty and Cacioppo 1979). Early research on attitude changing generally focused on one effect of a given variable and one process by which that effect occurred (Petty and Cacioppo 1981); however, ELM analysed the approach of multiple persuasion processes for changing attitude into two ways; central and peripheral (Petty 1994).

The receiver is persuaded to do something by the central route to persuasion when the receiver has the motivation and the ability to think about the message (Petty 1994). Sometimes the receiver can be persuaded to do something by the peripheral route to persuasion by way of peripheral cues even if the receiver lacks the ability or motivation to think about the argument or content of message individually (Petty 1994). For example, when a student has both the motivation and ability to learn physics in the classroom, he/she is easily persuaded to learn physics topics. However, a student having no motivation or ability to learn physics can also be persuaded to learn because of a good-looking and well-spoken teacher, and the use of attractive teaching material or teaching method and techniques in the classroom. This reasoning led to our research hypothesis that pre-service science teachers receiving training in self-metacognitive questioning for non-routine quantum physics problems will develop positive attitudes towards the quantum physics course.

Method

The design of the study was based on pre-test-post-test, a comparison group and quasi-experiments. The participants were prospective science teachers attending Gazi University Turkey enrolled in the second year of the "Introduction to Quantum Physics Course (IQPC)" taught by the same instructor (the first author). The participants were divided into an experimental group and a control group. Two sections of IQPC were taught to the participants of both groups for 2 h a week over 14 weeks, but only the members of the experimental group were guided by self-metacognitive questioning during their engagement in non-routine problem-solving.

The Participants

Of the 57 participants, 27 (93% female) were allocated to the control group and 30 (90% female) to the experimental group. Their ages ranged from 20 to 24, and all students were taking this course for the first time. All the participants had previously taken the courses of Physics I, II and III, consisting of mechanics, electric and magnetism and thermodynamics and optics, respectively.

Instrument

The Attitude Scale of Quantum Physics Course (ASQPC) used in this study as a pre-test and post-test was developed by Kocakulah and Kırtak (2010) to measure college students' attitudes towards a quantum physics course. It has a Cronbach's Alpha reliability coefficient of .96 and comprises 32, five-point Likert-type statements, where "1" corresponds to "strongly disagree" and "5" to "strongly agree", and the total score of the scale ranges from 32 to 160. The five factors of ASQPC having a theoretical connection (Eagly and Chaiken 1993) are: Factor 1 (being successful in the course, 13 items) is a cognitive component of attitude related to course success, Factor 2 (having qualifications from the course, 8 items) is an affective component of attitude, Factor 3 (importance of the course in daily life, 4 items) is a cognitive component of attitude related to the importance of the course in everyday life, Factor 4 (activities in the course, 4 items) is a behavioural component of attitude and Factor 5 (difficulty of the course, 3 items) is a cognitive component of attitude related to the difficulty of the course. Kocakulah and Kırtak (2010) performed the scale analyses using the SPSS programme within the Explicit Factor Analysis (EFA) process.

Treatment for Teaching Theoretical Part

The aim of IQPC was for the students to learn the basic concepts and principles of quantum physics theoretically and solve related problems. The topics in this course are special relativity (relativity in time distance and mass), introduction to quantum physics (the concept of quantum, radiation of a black body, photoelectric and Compton effects), quantum mechanics (duality of wave and particle, de Broglie waves, Haisenberg uncertainty principle) and the atomic structure (atomic models, atomic energy levels, atomic spectrums).

The participants in both groups undertook ASQPC as a pre-test in the first course. The theoretical part of the subjects was taught to all the participants using the same teaching techniques and materials (i.e. textbook, web and computer environment relevant to the subject

Table 1 Procedures for treatment implementation

Steps	EG	Time in EG (hour)	CG	Time in CG (hour)
1. Administration of ASQPC as a pre-test and introduction of lesson		2		2
2. Teaching treatment				
Teaching theoretical part of special relativity	X	2	X	2
Non-routine problems related relativity in time, distance and mass	Three problems with SMQS	2	Three problems	1
Teaching theoretical part of the radiation of black body	X	1	X	1
Non-routine problem related the radiation of black body	One problem with SMQS	1	One problem	0.5
Teaching theoretical part of the photoelectric effects	X	2	X	2
Non-routine problems related photoelectric effects	Three problems with SMQS	2	Three problems	1
Teaching theoretical part of the Compton effects	X	1	X	1
Non-routine problems related Compton effects	Two problems with SMQS	1	Two problems	0,5
Teaching theoretical part of the duality of wave-particle and de Broglie waves	X	2	X	2
Non-routine problems related duality of wave-particle and de Broglie waves	Three problems with SMQS	2	Three problems	1
Teaching theoretical part of the Heisenberg uncertainty principle	X	1	X	1
Non-routine problems related Heisenberg uncertainty principle	Two problems with SMQS	1	Two problems	0,5
Teaching theoretical part of the Hydrogen atomic model	X	1	X	1
Non-routine problems related Hydrogen atomic model	One problem with SMQS	1	One problem	0.5
Teaching theoretical part of modern atomic theory	X	2	X	2
Non-routine problems related modern atomic theory	Two problems with SMQS	2	Two problems	1
3. Review and administration of ASQPC as a post-test and Introduction of lesson		2		2

X shows that the theoretical parts of teaching are in the same conditions in both groups of EG and CG

EG experimental group, *CG* control group, *SMQS* Self-Metacognitive Questioning Sheet

and concept maps). In this teaching process, the teacher/researcher encouraged the students to learn about quantum physics. For example, at the beginning of the first lesson (Special Relativity Theory), the teacher drew the attention of the students by presenting this motivating introduction to the topic:

> Teaching Example-1 (TE-1): You may not fully understand some abstract concepts in this subject, but you will comprehend by carefully considering the concepts and you will learn them with the help of mathematics. Quantum physics pertains to entities and events in the micro-cosmos, which are different from our universe in which classical physics laws are valid. Who/How are entities of the micro-cosmos? Let's engage in a mental journey into the micro-cosmos. If we had a pure copper dust in our hands which had a mass of about 10^{-3} grams, how many copper atoms would be there in this dust? Let's calculate the number of atoms. If there are 6.02×10^{23} atoms in 63 grams of copper, how many are there in 10^{-3} grams? Based on the calculation of simple proportions, the amount should be about 10^{19} atoms. The copper dust has about 10000000000000000000 atoms. This is a micro-cosmos. While entities in micro-cosmos have four dimensions, in our universe, we can perceive only three dimension. What does this mean? Can we perceive that the time is the fourth dimension? Maybe not, but we can comprehend why we can't perceive it. For example, if we were two-dimensional entities like a picture on the wall and another creature from the third dimension shed light on us with a flashlight, what would we do? Or what would we feel? Maybe we would think that it was a miracle. Just as a two-dimensional entity cannot perceive the third dimension, a three-dimensional entity cannot perceive the fourth dimension.

Students were also encouraged to learn about some micro-events using analogy. For example, why the experimental results of photoelectric effect cannot be explained with the classical laws of physics but they can be explained by quantum physics concepts. Mostly, this is a difficult subject for students to understand; thus, to help them, the researcher presented the following example analogy:

> Teaching Example-2 (TE-2): You can cause an orange on a tree to fall by throwing another orange or a ball at it. The ball collides with the orange and causes it to fall to the ground. Well, could you make an orange fall from a tree by shining a flashlight on it? This does not seem possible but Einstein found that light was composed of particles called photons and according to the experimental results of the photoelectric effect, light waves can eject electrons from metals.

After the participants did some homework to develop conceptual understanding and received positive feedback, they worked on the same set of problems for each subject. Table 1 shows the teaching process for both groups.

As shown in Table 1, equal time was spent on both groups in teaching the theoretical part of the subjects. However, the students in the experimental group were given more time for the problem-solving part. Since the students faced these problems for the first time, for them, the problems for each subject were non-routine. Different approaches were adopted in the experimental and control groups for problem-solving. The students in the experimental group were asked to use certain self-metacognitive questioning and to respond to these questions individually during their engagement in problem-solving as given in the Self-Metacognitive Questioning Sheet (SMQS).

SMQS

Internal discussion of how I can turn the physical quantities into more meaningful concepts

Please ask yourself!

(1) Do I understand the meaning of the physical quantities in this problem? (If I don't know the meaning of physical quantities in this problem, I can't understand the problem)
(2) Do I know the units of physical quantities related to problem? (Knowing the units helps to organize the problem)

Connection between physical principle and problem statement.

(3) Which physical principle regarding the problem do I need? Do I know it?
Am I sure that I understand the problem thoroughly?

Don't forget Einstein's metacognitive awareness! "If I had one hour to save the world I would spend fifty-five minutes defining the problem and only five minutes finding the solution."

Monitoring and planning

(4) How can I use my knowledge to solve the problem? In the first instance, what should I do? Which steps should follow? Do I need mathematical knowledge for the calculation the problem?

Evaluating

(5) Do I need to check my solution?

Treatment for Problem-Solving Aspect

The development of the five-stage self-metacognitive questioning in SMQS was inspired by Mayer (1987), Cardelle-Elawar (1995), and Kramarski and Gutman (2006). To ensure that the questions were more appropriate for quantum physics problems, SMQS consists of the some instructions in the textbox above.

The students in the experimental group were allowed to use their lecture notes and textbooks during their engagement in the problems for the time specified in Table 1. Initially, the researcher talked to the students to support them in the correct use of SMQS. All the students in experimental group were guided by the researchers one-to-one to use self-metacognitive questioning. The students' engagement with the problems listed in Table 1 ensured that their development was iterative (Lewis et al. 2015).

In the control group, the researcher gave the students time to think about the problems and then she showed them how to solve problems. The duration of the lessons for problem-solving in the experimental group took longer than the control group, and for the latter, during the remaining time, the students worked individually.

At the end of the 14 week-course, all the participants completed a post-test ASQPC and the implementation was completed.

Results

In the following sections, "E" and "C" refer to the experimental and control groups, respectively. The quantitative data was analysed using SPSS version 21, and significance level was accepted as 0.05.

Table 2 presents independent sample t test results of the experimental and control group participants' pre- and post-test mean scores of ASQPC. According to Table 2, there were no statically significant differences between the experimental and control groups according to the pre-test ASQPC scores, $t(55) = 1.31$; $p > .05$,$\eta^2 = 0.03$.

The pre-test results also showed that there was no significant difference between the participants in the control and experimental groups according to each factor of ASQPC. The mean and standard deviation scores, which students obtained in the post-tests in experimental and control groups, were presented descriptively. The data was analysed by an independent sample t test to compare the attitudes of the participants towards the quantum physics course before and after the 14-week course. A paired sample t test was implemented separately to determine the development of positive attitudes in both groups. A significant difference was found between the control and experimental group participants in favour of the latter, concerning the total attitudes towards the quantum physics course [$t(55) = 2.49$; $p < .05$, $\eta^2 = 0.1$] and having qualifications from the course (Factor 2) [$t(55) = 3.22$; $p < .05$, $\eta^2 = 0.16$]. However, for Factor 1 (being successful in the course) [$t(55) = 1.42$; $p > .05$, $\eta^2 = 0.03$], Factor 3 (importance of the course in daily life) [$t(55) = 1.29$; $p > .05$, $\eta^2 = 0.03$], Factor 4 (activities in the course) [$t(55) = 1.29$; $p > .05$, $\eta^2 = 0.03$] and Factor 5 (difficulty of the course) [$t(55) = 0.69$; $p > .05$, $\eta^2 = 0.00$], there was no significant difference between the control and experimental group participants.

Table 3 presents the experimental group participants' pre-test and post-test mean scores of ASQPC, which shows a significant difference between the participants' total attitudes in the experimental group before and after the treatment [$t(29) = 6.63$; $p < .05$, $\eta^2 = 0.58$]. Also, the control group participants' pre-test and post-test mean scores of ASQPC reveals a significant difference between the participants' total attitudes before and after the course [$t(26) = 2.78$; $p < .05$, $\eta^2 = 0.22$] (Table 3).

According to the results of the paired sample t test, the participants in the experimental group showed a development of the positive attitudes for four factors; being successful in the course [$t(29) = 6.7$; $p < .05$, $\eta^2 = 0.6$], having qualifications from the course [$t(29) = 3.21$; $p < .05$, $\eta^2 = 0.26$], activities in the course [$t(29) = 3.8$; $p < .05$, $\eta^2 = 0.33$], and difficulty of the course [$t(29) = 3.25$; $p < .05$, $\eta^2 = 0.266$]. There was no significant difference between the

Table 2 ASQPC independent sample t test results for the experimental and control groups

		Pre-test					Post-test				
ASQPC	Groups	M	SD	t	p	η^2	M	SD	t	p	η^2
Factor 1	E	37.67	2.88	0.9	0.37	0.01	45.3	6.65	1.42	0.15	0.03
	C	36.96	2.94				42.48	8.24			
Factor 2	E	23.8	2.84	0.84	0.4	0.01	26.87	4.07	3.22	.00	0.16
	C	23.22	2.25				22.96	5.06			
Factor 3	E	12.37	1.45	1.15	0.25	0.02	12.5	2.48	1.29	0.19	0.03
	C	11.93	1.43				11.67	2.33			
Factor 4	E	17.1	2.77	1.16	0.11	0.02	19.13	2.83	1.29	0.2	0.03
	C	16	2.37				18.07	3.32			
Factor 5	E	8.67	1.34	1.27	0.2	0.02	9.93	2.31	0.69	0.49	0.00
	C	9.04	0.7				9.52	2.19			
Total ASQPC	E	99.6	7.75	1.31	0.18	0.03	113.73	11.93	2.49	.01	0.1
	C	97.1	5.81				104.7	15.28			

Table 3 ASQPC paired sample *t* test results for the experimental and control groups

		Experimental group					Control group				
ASQPC	Groups	M	SD	t	p	η^2	M	SD	t	p	η^2
Factor 1	Pre-test	37.67	2.88	6.7	.00	0.6	36.96	2.94	3.74	.00	0.34
	Post-test	45.30	6.65				42.27	8.33			
Factor 2	Pre-test	23.8	2.84	3.21	.00	0.26	23.22	2.25	0.26	.79	0.00
	Post-test	26.87	4.07				22.96	5.06			
Factor 3	Pre-test	12.37	1.45	0.3	.75	0.003	11.93	1.43	0.55	.58	0.01
	Post-test	12.5	2.48				11.67	2.33			
Factor 4	Pre-test	17.1	2.77	3.8	.00	0.332	16	2.37	3.21	.00	0.27
	Post-test	19.13	2.83				18.07	3.32			
Factor 5	Pre-test	8.67	1.34	3.25	.00	0.266	9.04	0.7	1.16	.25	0.04
	Post-test	9.93	2.31				9.52	2.19			
Total ASQPC	Pre-test	99.6	7.75	6.33	.00	0.58	97.15	5.81	2.78	.01	0.22
	Post-test	113.73	11.93				104.65	15.5			

participants' attitude related to the importance of the course in daily life [$t(29) = 0.3$; $p > .05$, $\eta^2 = 0.00$] in the experimental group before and after the treatment.

According to the results of the paired sample *t* test, the participants in the control group showed improvement of the positive attitudes for two factors; being successful in the course [$t(26) = 3.74$; $p < .05$, $\eta^2 = 0.34$] and activities in the course [$t(26) = 3.21$; $p < .05$, $\eta^2 = 0.27$]. However, there was no significant difference between the participants' attitudes related to having qualifications from the course [$t(26) = 0.26$; $p > .05$, $\eta^2 = 0.00$], importance of the course in daily life [$t(26) = 0.55$; $p > .05$, $\eta^2 = 0.01$] and difficulty of the course [$t(26) = 1.16$; $p > .05$, $\eta^2 = 0.04$] in the control group prior to or following the 14-week course.

Discussion

The present study investigated the effects of self-metacognitive questioning through physics problem-solving on students' attitude towards quantum physics course. The findings revealed two results shown in Figs. 1 and 2.

The first finding was that the students' attitude towards the quantum physics course changed positively in both the control and experimental groups due to their cognitive response. The cognitive response approach is related to various models of persuasion. One such model is ELM, in which persuasion is employed to foster people's motivation and their ability to engage in issue-relevant thinking (Petty and Cacioppo 1986). This situation is closely related to the communication variables (source, message and recipient), which affect the persuasion. Therefore, the first finding of present study can account for the multiple effects of the communication variables as follows:

The recipients (students), consisting of the control and experimental groups attending the quantum physics course, held almost the same attitude towards the quantum physics course at the beginning of the course. The cognitive response for the attitude change stemmed from the changes of beliefs, judgement/prejudice and thoughts of quantum physics which had first formed from cognitive information gained from sources such as previous experiences, friends and the media (McGuire 1969). For example, some students generally come to the course with the preconceived idea about the difficulty of

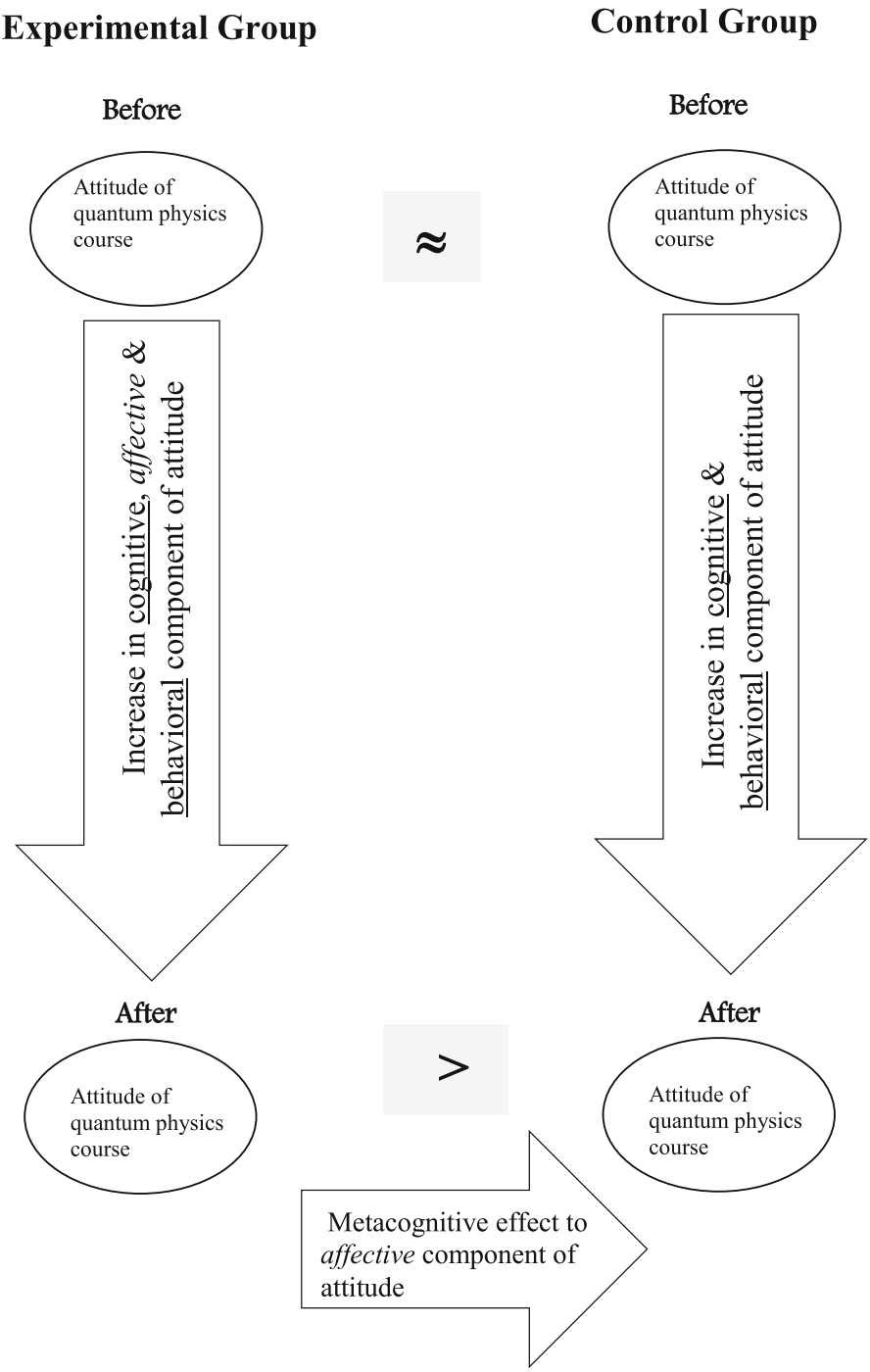

Fig. 1 Representation of attitude change

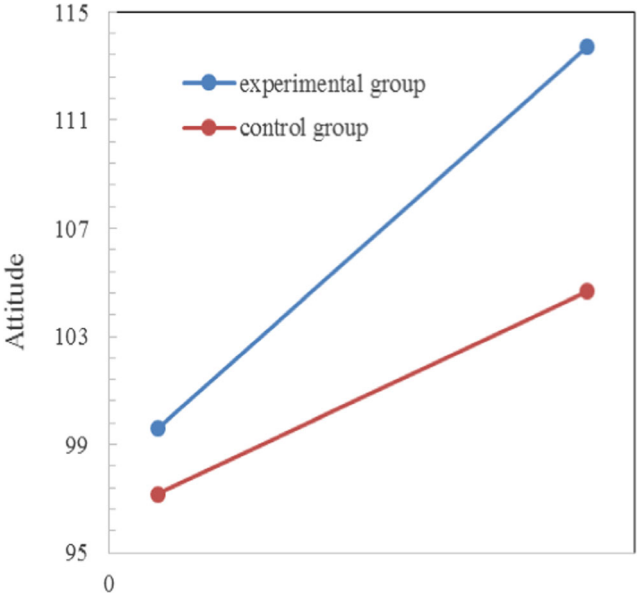

Fig. 2 Attitude change in experimental and control group before and after treatment

physics. They thought they would not be successful in the course because other students had to take the course a second, third or fourth time.

The message referred to some arguments of learning quantum physics hidden in the teaching process. Teaching the theoretical parts of quantum physics in both the control and experimental classes under the same conditions had the messages and the cognitive response to these messages was the positive change of attitude. This feature of the teaching process leading to the receipt of message in this study is discussed with their possible effects on persuasion as follows:

Conciseness The teaching process made the subject of quantum physics simple and clear in accordance with the academic level of students (e.g. TE-1 in treatment in both control and experimental groups). This served to persuade the students that they could learn and succeed in understanding the extraordinary difficult subjects of quantum physics (Petty and Cacioppo 1979).

Concreteness An analogy or videos in a web and computer environment were used to simplify and make some difficult subjects concrete in the theoretical part of the course. This allowed the students to easily learn how micro-events can be understood (e.g. TE-2).

Motivation of Thinking Teaching in the theoretical parts of subjects could affect how the students could be motivated to think. The meta-physics connection with quantum physics in the teaching process enhanced the relevance of the learning for the students leading them to think more about quantum physics (Tormala and Petty 2002; Sin 2014). For example, after learning about the special relativity theory (time expansion), the researcher discussed "reaching the speed of light" and "exceeding the speed of light" with the students in both groups and posed various questions including "Could death be the passing of the human soul

to another dimension at light speed?" and "Could there be a universe where time is endless?". These types of discussions are thought to make the topic more relevant to the students and lead to increase their motivation to think and learn, and ultimately to engage in a positive change of attitude towards the quantum physics course.

The source, the researcher in this study, is an expert in physics with 25 years of physics teaching experience and taught the theoretical parts of the subjects in both groups by taking into consideration cognitive factors which affect the amount of the students' thinking particularly related to the meta-physics connection with quantum physics. The 14-week teaching application in this study may be led to effective influence persuading the students to absorb the content of the message.

The second finding of this study was that self-metacognitive questioning created a statistical effect favouring the experimental group students' positive attitudes towards the quantum physics course due to the effects of the meta-cognitive treatment. Persuasion stemming from the meta-cognitive process was also taken into consideration to account for this result. In addition to influencing the amount of thinking, the meta-cognitive treatment also could be an impact on the attitude towards the quantum physics course by affecting what the experimental group students felt about their thought process (Baumeister and Finkel 2010; Tormala and Petty 2004). The metacognitive treatment with the five-stage self-metacognitive questioning through problem-solving in the experimental group may have affected the students' problem-solving performance for the following reasons (Petty and Cacioppo 1986; Tormala and Petty 2004):

1. They identified the structure of the problem.
2. They created a connection between their knowledge related to physical principles and the problem structure.
3. They used mathematical strategies.
4. They used a strategy or developed a strategy.
5. They became more aware of how they could promote their own thinking process successfully.
6. They self-regulated their learning appropriately to solve the problem instead of being an unthinking follower.
7. They applied reasoning to quantum physics problems.
8. They increased their confidence in physics problem-solving.

According to the results, the students in the control group received an effective message from the teacher in the theoretical parts of the subjects, which positively changed their attitude towards the quantum physics course in such factors as "being successful in the course" and "activities in the course" (as shown in Table 3) as the cognitive (related to course success) and behavioural components of attitude, respectively.

The students in the experimental group also were influenced positively by the learning part of the course and the problem-solving with self-metacognitive questioning to change their attitude in the following factors; "being successful in the course", "difficulty of the course", "having qualifications from the course" and "activities in the course" (as shown in Table 3), which refer to the cognitive (related to both the success and difficulty of the course), affective and behavioural components of the attitude, respectively.

For both groups, there was no change in the cognitive component of attitude related to importance of the quantum physics course in everyday life, which reveals that all efforts were insufficient to create a positive change in this component.

The positive attitude change for the students in the control group resulted from the cognitive and behavioural component of attitude whereas the positive attitude change for the students in the experimental group was due to the cognitive, behavioural and affective components. The significant difference in favour of the experimental group was seen in the affective component of attitude (Factor 2; having qualifications from the course). These results lead to the important conclusion that self-metacognitive training positively influences the affective component of attitude.

In conclusion, our findings suggest that metacognitive treatments positively affect students' attitude towards courses, and thus have considerable importance in teacher education.

Limitation

One particular concern in this study was that the researcher was also the instructor of the control and experimental groups; thus, she might have affected the teaching application by manipulating students to accept her preconceived expectations. However, having a single instructor offered the advantage of eliminating the peripheral variables on students' attitudes towards the quantum physics course. The researcher as instructor was able to maintain all conditions as constant in both the control and experimental groups during the course with the exception of the metacognitive treatment in the experimental group.

Another limitation of this study was that the groups were relatively small considering the traditional quantitative standards. Further research can be conducted with a greater number of participants and possibly consider more than a single experimental and control group.

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