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Development of metacognitive skills: designing problem-based experiment with prospective science teachers in biology laboratory

Huriye DENİŞ ÇELİKER

Mehmet Akif Ersoy University, Education Faculty, Science Education Department, Turkey.

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The purpose of this study is to investigate the effect of designing problem-based experiments (DPBE) on the level of metacognitive skills of prospective science teachers. For this purpose, pre test-post test design, without control group, was used in the research. The research group of the study comprised 113 second-grade prospective science teachers who studied at the Faculty of Education of a state university, which is in the west of Turkey, in 2011-2012 spring semester. DPBE practices were carried out under the course of biology laboratory II. The experimental study was continued for 10 weeks. In the research, Metacognitive Skills Test for Adults which consists of 52 items and 2 factors was used for data collection. Cronbach's alpha coefficient of the test was 0.95. In the analysis of data, related samples T-test and unrelated sample T-test were used via SPSS-21. As a result of analyzing the data, it has been concluded that designing problem-based experiments contributes positively to the development of metacognitive skills and being aware of cognitive features, which are the sub-factors of the scale, of prospective science teachers. Besides, while metacognitive pre-test scores do not show any difference according to gender, post-test scores indicate a significant difference in favor of females.

Key words: Biology laboratory, designing experiment, metacognitive, problem-based learning, prospective science teacher.

INTRODUCTION

Raising individuals who think and who can produce new knowledge and technology is one of the primary goals of education. Considering that knowledge does not exist independent of the knowing and the knowing forms of his learning processes by thinking, the knowledge of individuals regarding their thinking process and strategies and their abilities to monitor and organize these processes become important. This process which is called metacognition requires students to analyze, think and monitor their own thinking and learning. In the process of designing problem based experiments students also need to use their metacognitive skills. Gunstone and Northfield (1994) claimed that metacognitive education needs to be at the center of education of teachers.

E-mail: huriyedenis@mehmetakif.edu.tr. Tel: +90 248 213 40 83.

Many researches stated that metacognition is important in efficient problem solving (Goos and Galbraith, 1996; Wilson, 1999).

Problem solving ability is described as an interaction between cognition and metacognition (Artzt and Thomas, 1992). Metacognitive processes are required to successfully carry out any complex problem solving task. The better the individuals control and monitor the strategies they use the more their problem solving ability improves (Swanson, 1992). Cornoldi (1998) emphasized the role of the faiths of learners in thinking and stated that if students feel safe, they can solve problems and they tend to do better things. Metacognition is described as the knowledge of an individual's cognitive processes and awareness in solving a problem and it involves the processes of planning, monitoring and evaluating the solution of a problem (Flavell, 1992; O'Neil and Abedi, 1996). The use of metacognitive processes helps individuals work through in problem solving and improves their ability to achieve their goals (Fortunato et al., 1991). An individual who has the ability of efficient problem solving focuses his attention to understand the relations between the factors of the problem, checks if the solutions is correct by himself, divides complex problems into simple steps, creates internal and external designs for the problem and asks and answers questions by himself to clarify his thoughts (Descartes, 2008; Gourgey, 1998). Researches have shown that monitoring and controlling the metacognition are important skills for successful problem solving (Artzt and Thomas, 1992). Also, researches have proved that metacognitive skills predict the ability of problem solving (Swanson, 1990).

Metacognitive awareness is, briefly, thinking about thinking (Flavell, 1987). Metacognition is individual's awareness on his own thinking processes and his being able to control these processes (Hacker and Dunlosky, 2003; Jager et al., 2005; Özsoy, 2008). Hacker (1998) described metacognition as the knowledge of individual's knowledge, processes, cognitive and emotional status and as monitoring and organizing these statuses with a goal. Metacognition is the evaluation of individual's knowledge and in this evaluation, it is important to comprehend the learning tasks and what kind of information and skills are required for it. Also, it needs to be integrated with the individual's ability of correctly deducing how he will apply for his strategic knowledge in a given situation and how he will use this strategy in an efficient and safe way (Taylor, 1999). Metacognition is usually related to student's knowledge of learning processes, his awareness and control (Brown, 1987; Garner and Alexander, 1989). A person who has metacognitive skills is thought to be someone who is equipped with the ability of being aware of current opinions, evaluating them and knowing the situations when it is necessary to rearrange them. As metacognition develops with regard to individual's foreknowledge and ability of learning how to learn, it is considered a high level learning skill. The constant change in the rapidly growing technology makes it difficult to comprehend what knowledge will be more important in the future as well as making it impossible to acquire all the knowledge. It is quite significant that individuals are aware of cognitive structure and learning features (Akın, 2006). Metacognition which explains this awareness could be said to describe thinking about thinking, knowing what we know or not know, the awareness of the different aspects of thinking (Namlu, 2004). Metacognition with regards to learning processes involves using and controlling the cognitive functions consciously (Cornoldi and Lucangeli, 1996). According to Bradshaw (2000), metacognition is high level questions that have the ability to activate low level knowledge. Metacognition is a person's realizing his own cognitive processes and taking part in controlling and enhancing these processes rather than the content of cognitive processes (Biggs and Moore, 1993). Metacognition in an overall approach is a structure that involves a person being aware of the events and functions in his own mind and directing mind events and their functions with a goal (Dienes and Perner, 1999).

Researches on metacognition have been conducted in the light of the fact that a functional cognitive system not only learns and acts but also knows how to do it and how to do it better (Lucangeli and Cornoldi, 1997).

In Turkey, when investigated the researches regarding science education and metacognition, it is viewed that scale development and adaptation researches (Aktamış and Uça, 2010; Aydın and Ubuz, 2010; Yıldız et al., 2009), conducted to determine the levels of metacognitive awareness (Evran and Yurdabakan, 2013), researches conducted to find out if metacognitive skill develop by the use of various teaching methods (Aydın and Kaptan, 2014; Tonbuloğlu, Aslan et al., 2013). There have been researches regarding that self and peer assessment activities of cooperative learning method affects the levels of cognitive awareness of students positively (Shamir et al., 2008; Papinczak et al., 2007). Özkan (2007) suggested that there is a positively signicificant relation between teachers' using learning strategies and metacognitive skills while learning and their using strategies that improve metacognitive skills in their classes.

A problem is a situation that subjects an individual to the need of making a decision to choose the method he can use in problem solving. This might be a life problem or a problem in a scientific field. Metacognition is defined as a key concept in the process of problem solving (Hartman, 1998). There is a common idea regarding that metacognitive skills determine an individual's success or failure in problem solving. Cardelle-Elawar (1995) provided metacognitive strategy training for students with low level of achievement and observed the effects of the training on the performance of the students. The researcher reported that students who have low level of achievement but who had the training for monitoring and controlling metacognitive processes are better in problem solving than students who did not have the training. In a research, Swanson (1990) suggested that students with high level of metaconigitive skills show better performance in problem solving than those with low level of metacognitive skills. Thus, he deduced that high performance in problem solving tasks has a closer relationship with metacognitive skills rather than all other skills. In the process, students struggle to define the problem, elaborate the ideas they get from various sources and to evaluate the procedures and all of these are metacognitive activities (McGregor, 2007). Kapa (2001) inferred that learning environments which give metacognitive support in each step of problem solving process are significantly more productive than learning environments which give metacognitive support only at the end of the solving process. According to Schoenfeld (1985), these skills are the basic elements to determine the success or failure of an individual in problem solving and students need to be explicitly trained to monitor their metacognitive processes in problem solving process. When an expert problem solver is asked to categorize science problems, he categorizes them with regard to the scientific law underlying these problems. Likewise, students with high competence categorize science problems with regard to the underlying concept while students with low competence fall into complexity due to superficial features that lead them to wrong solution strategies. Misdescription of the problem inevitably leads to wrong solutions, and cognitive and metacognitive problems occur since both the students are on the wrong track due to incorrect conceptualization of the problem and they fail to comprehend that they are wrong (Silver, 1987). One of the methods that can improve problem solving skills of individuals is problem-based learning.

Problem-based learning might be considered as a small group learning method that combines improving general abilities and acquisition of knowledge (Awang and Ramly, 2008). Problem-based learning uses real life problems as content in order for students to gain the abilities of critical thinking and problem solving (Alper, 2008). In PBL problems which take place in real life are presented to students in intriguing scenarios. A scenario should spark students' interest in a subject (Dahlgren and Öberg, 2001). PBL might be regarded, at least in theory, ideally suitable for the development of the level of metacognition of university students (Downing et al., 2009). PBL process can improve the students' skills such as problem solving, researching and critical thinking, cooperative learning, self learning and lifelong learning (Herron and Major, 2004; Fen-Lin et al., 2010). Teachers should let students take responsibility, encourage them to be free, remain in the back ground (Liceaga et al., 2011).

Considering the studies conducted on PBL in Turkey, there have been researches conducted on the applicability of problem-based learning into science teaching (Şenocak and Taşkesenligil, 2005), researches conducted to determine its effect on the problem solving skills and self-efficacy belief levels of prospective teachers (Altunçekiç et al., 2005; Yaman and Yalçın, 2005), its effect on motivation (Tosun and Taşkesenligil, 2012), its effect on success (İnel and Balım, 2010a; Serin, 2009; Tarhan and Acar, 2007; Şenocak et al., 2007), its effect on perception of self efficacy (Gürlen, 2011) and researches conducted to determine the opinion of students on PBL (İnel and Balım, 2010b).

Examining the researches conducted on the effect of problem-based learning on metacognitive skills; Demirel and Turan (2010) determined that problem-based learning applications in science class increase the metacognitive awareness of sixth graders. In their studies, Downing et al. (2009) deduced that problem-based learning significantly affect the metacognitive skills of university students. Haryani et al. (2012), in their studies found out that problem-based learning applications in analytical chemistry classes improves metacognitive skills of prospective teachers. Tosun and Şenocak (2013) suggested that problem-based learning applications in chemistry classes of prospective teachers with different scientific background increase metacognitive awareness.

The present study

It is considered to be important that prospective teachers who will raise the students of the future are aware of their own thinking processes and they can control these processes. Teachers who are aware of their metacognitive skills are more successful in using strategies that improve the metacognitive skills of the students (İmel, 2002; Özkan, 2007). As prospective teachers' having metacognitive skills provides them to better know and to control their own cognitive skills it will get easy to teach these features to students at schools. When considered from this point of view, it is important that methods and techniques which are directed to improve the metacognitive skills of prospective teachers are used. Therefore, initially, it is necessary to determine the methods that improve metacognitive skills. Thus, the following questions are to be answered:

1. Does designing problem-based experiments in a biology lab course have any effect on metacognitive skills

of prospective science teachers?
2. Do metacognitive pre test-post test scores of prospective science teachers show difference according to gender?

METHODOLOGY

Research design

In the study, pre test-post test design without control group was used. In this design, the effect of the experimental procedure is tested on a single group and the measurements of the subjects regarding the dependent variable are acquired via pre test before the application and post test after the application by using the same subjects and the same assessment instrument. There is no randomness and matching and in this regard, the design can be described as single factorial between-groups or repetitive measuring design. In the design, the significance of the difference between pre test and post test (O1, O2) of the single group (G). (Büyüköztürk et al., 2008).

Study group

The research group of the study comprised 113 second-grade prospective science teachers who studied at the Faculty of Education of a state university, which is in the west of Turkey, in 2011-2012 spring semester. These are prospective teachers who take Biology Lab II course which has 4 classes in daytime education and 2 classes in nighttime education, 6 classes in total. Biology lab is a compulsory subject for science teaching. There is a Biology Lab I (2 credits) in fall semester of second grade and Biology Lab II (2 credits) in spring semester as an applied course. Examining the gender distribution of the prospective teachers, 82(61.7%) of them are females and 31(23.3%) of them are males.

Assessment ınstrument

As part of the research, to determine the metacognitive skills of prospective science teachers, "Metacognitive Skill For Adults" test which Scraw and Dennison (1994) designed for adults was used. Turkish version of "Metacognitive Skill Test For Adults" was adapted by Özcan (2007) and the measurement Cronbach alpha coefficient of the scale was found 0.95. The scale which has two sub-dimensions, one of which is being aware of metacognitive skills sub dimension including 17 questions, and the other which is cognitive skills sub dimension including 35 questions and the test consists of 52 questions in total.

Experimental procedure

The research was conducted with second grade prospective science teachers who take Biology Lab II course in 4 daytime classes and 2 nighttime classes in a faculty of education. Before and after the experimental procedure a Metacognitive Skill Test was done on the experiment group. The experimental study was continued for 10 weeks. Study cards with regard to problem-based learning were used in the groups. In the activity cards, there were 14 real life scenarios that would excite the attention of the students and would arouse their interest and would provide them to research and query. One or two scenarios were given to the prospective teachers as relevant to the subject. Prospective teachers who studied cooperatively in groups of 5-6 people read the scenario they were given beforehand and discussed the questions "What is the problem (or problems) to be addressed in the scenario? What do we know about this subject?" Until the next lesson, they reported their researches regarding the subject and designed experiments that could present the subject of the scenario. During the second week they conducted the experiments they designed and filled out peer and self-assessment forms with regard to the process. After this process, scenarios for the following week were provided and they made discussions again in groups. From the very beginnig of the process, it was aimed to provide them the opportunity to do research on the subject and return with as many resources as possible by telling the prospective teachers the main theme of the next week. Prospective teachers designed experiments with regard to the problems in the scenarios and conducted the experiments they designed for 10 weeks. Herein below one out of 14 scenarios distributed to the prospective teachers are given as example.

Scenario 1: Her father bought fish for Merve and her sister as present. Merve put her fish on the table near the heater in the kitchen while her sister put hers in the balcony. After awhile of observation they saw that their gill movements were different. Although the size of the fishbowl and the amount of the water were the same, they wondered why it happened.

During the applications, no change was made in the weekly lesson schedule of Biology Laboratory II and it was carried out two hours a week.

Data analysis

The data were analyzed via SPSS 21 packet program. To examine the normal distribution range, p value of Kolmogorov-Smirnov test was found as 0.20. Since the values found higher than 0.05 were interpreted as suitable, not showing deviance from normal distribution on this significance level (Büyüköztürk, 2007), related samples T-test and unrelated sample T-test were used in data analysis. In addition, effect sizes were measured to determine how much of the test score variant depends on the independent variable or group variable. Büyüköztürk et al. (2008) suggested that η^2 (et square) value varies between 0, 00 and 100 and 0, 01 is interpreted as small effect size, 0, 06 as middle effect size and 0, 14 as big effect size. He stated that d which is the value of effect size, can take values between +infinite and - infinite, and it is interpreted, regardles of its sign, 0,2 as small effect size, 0,5 as middle effect size and 0,8 as big effect size (Büyüköztürk, 2007; Erika, 2006).

FINDINGS

T-test results conducted on the significance of the difference between pre test and post test average scores of metacognitive skill test are given in Table 1.

As a result of prospective teachers' designing problem-based experiments there has been found significant increase in their metacognitive skills [$t_{(112)}$ =6.00, p<.01]. While the metacognitive skill average of prospective teachers was $\bar{X}$=196, 35 before the application, after the application of designing problem-based experiments it has increased to $\bar{X}$=208, 59. This finding has shown that designing problem-based experiments has an important effect on increasing the metacognitive skills of

Table 1. T-test results of pre test post test for metacognitive skill test total score.

Measurement	N	Mean	S	sd	t	p
Pre test	113	196,35	18,45	112	6,00	.000
Post test	113	208,59	23,39			

prospective teachers. Also, Cohen d value which is calculated to determine effect value has been found 0, 56 and η^2 (et square) value has been found 0, 24. Therefore, it can be said that the difference between the means is 0.56 standard deviation, 24% of the variant that belongs to the metacognitive skill scores show up depending on the pre test post test, namely measurement. Measured effect sizes reflect a wide effect.

T-test results conducted on the significance of the difference between pre test and post test average scores for metacognitive skill test sub dimension of being aware of cognitive features are shown in Table 2.

As a result of prospective teachers' designing problem-based experiments there has been found an increase in the sub dimension of being aware of cognitive features [$t_{(112)}$ =4.74, p<.01]. The mean for being aware of cognitive features of prospective teachers before the application was $\overline{X}$=66, 42, after the application of designing problem-based experiments, it increased to $\overline{X}$=69, 69. This finding can be interpreted as that designing problem-based experiments has a significant effect on the increase of prospective teachers' being aware of cognitive features of their metacognitive skills. Cohen d value which is calculated to determine effect value has been found 0, 45 and η^2 (et square) value is found 0, 16. Therefore, it can be said that the difference between the means is 0,45 standard deviation, 16% of the variant that belongs to the metacognitive skill test sub dimension of being aware of cognitive features scores show up depending on the pre test post test, namely measurement. Measured effect sizes reflect a wide effect.

T-test results conducted on the significance of the difference between pre test and post test average scores for metacognitive skill test sub dimension of organizing cognitive skills are given in Table 3.

As a result of prospective teachers' designing problem-based experiments there has been found an increase in metacognitive skill test sub dimension of organizing cognitive skills [$t_{(112)}$=6,16, p<.01]. The mean for organizing cognitive skills of prospective teachers before the application was $\overline{X}$=129,942, after the application of designing problem-based experiments, it increased to $\overline{X}$=1389. This finding can be interpreted as that designing problem-based experiments has a significant effect on the increase of prospective teachers' organizing cognitive skills. Cohen d value which is calculated to determine effect value has been found 0, 58 and η^2 (et square) value is found 0, 25. Therefore, it can be said that the difference between the means is 0,58 standard deviation, 25% of the variant that belongs to the metacognitive skill test sub dimension of organizing cognitive skills scores show up depending on the pre test post test, namely measurement. Measured effect sizes reflect a wide effect.

Prospective teachers' T-test results of pre test scores for metacognitive skill test according to gender are given in Table 4.

Examining Table 4, prospective teachers' pre test metacognitive score mean hasn't shown significant difference according to gender [$t_{(111)}$ =1, 94, p>.01]. While the metacognitive pre test mean of females was $\overline{X}$=198, 40 males' was $\overline{X}$=190, 93. Cohen d value which is calculated to determine effect value has been found 0,61 and η^2 (et square) value is found 0,071. Therefore, it can be said that the difference between the means is 0,61 standard deviation, 7% of the variant that belongs to the metacognitive skill test scores show up depending on gender. Measured effect sizes reflect a middle effect.

Prospective teachers' T-test results of pre test scores for metacognitive skill test according to gender are given in Table 5.

Prospective teachers' post test metacognitive score mean has shown difference according to gender in favor of females [$t_{(111)}$ =2, 93, p<.01]. While the metacognitive post test mean of females was $\overline{X}$=212, 43 males was $\overline{X}$=198, 41. This finding can be interpreted as that designing problem-based experiments has more effect on the development of metacognitive skills of females prospective teachers than that of males.

In Figure 1 it stands out that the increase in the metacognitive skill scores of females is bigger than that of males.

RESULTS AND DISCUSSION

1. In this research, firstly the effect of designing problem-based experiments (DPBE) on the level of metacognitive skills of prospective science teachers in biology lab course were analyzed.

Examining the findings of this study which aims at determining the effect of designing problem-based experiments in biology lab course on the metacognitive skills of prospective science teachers, at the end of the process of designing problem-based experiments, there has been an significant increase in metacognitive skills of prospective teachers, their metacognitive skill sub dimension of being aware of cognitive features and sub dimension of organizing cognitive skills. Likewise, Haryani et al. (2012) determined that open-ended laboratory applications in analytical chemistry course

Table 2. T-test results of pre test post test for metacognitive skill test sub dimension of being aware of cognitive features.

Measurement	N	Mean	S	sd	t	p
Pre test for Being Aware of Cognitive Features	113	66,42	6,37	112	4,74	.000
Post test for Being Aware of Cognitive Features	113	69,69	7,92			

Table 3. T-test results of pre test post test for metacognitive skill test sub dimension of organizing cognitive skills.

Measurement	N	Mean	S	sd	t	p
Organizing Cognitive Skills Pre test	113	129,92	13,24	112	6,16	.000
Organizing Cognitive Skills Post test	113	138,89	16,18			

Table 4. T-test results of pre test scores for metacognitive skill test according to gender.

Gender	N	Mean	S	sd	t	p
Female	82	198,40	17,90	111	1,94	.055
Male	31	190,93	19,07			

Table 5. T-test results of post test scores for metacognitive skill test according to gender.

Gender	N	Mean	S	sd	t	p
Female	82	212,43	19,85	111	2,93	.004
Male	31	198,41	28,85			

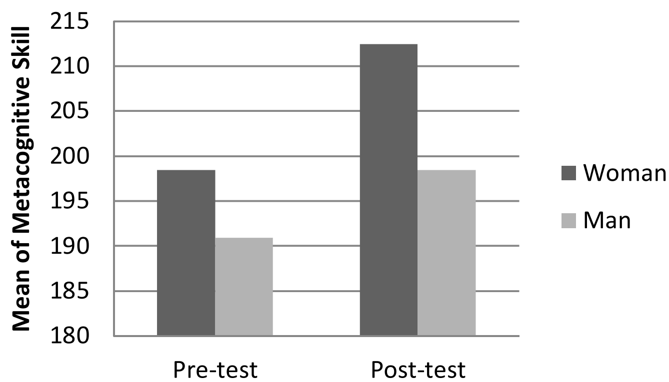

Figure 1. Pre test- post test mean of metacognitive skills according to gender.

improve metacognitive skill of prospective teachers. Downing et al. (2009) deduced in their studies that problem-based learning significantly improves the metacognitive skills of university students.

In the process, while identifying the problems in the scenarios and designing experiments related to the problem prospective teachers had to be aware of their cognitive features and organize their cognitive features. In this process, they researched and inquired, used problem solving procedures and designed experiments related to the status of the problem. Mohamed and Nai (2005) determined that in the process of problem solving students use many cognitive awareness behaviors such as visualizing the problem, deciding how to solve and evaluating the process and thus the process of problem solving provides an increase in being aware of cognitive features. Lucanceli et al. (1997) found out that cognitive awareness of students with low problem solving level is lower than those of with high problem solving level and determined that these students make mistakes in deciding how to use knowledge. In a research conducted on the relationship between problem solving skills and metacognitive skills, students with high metacognitive skills also have high problem solving success (Boekaerts, 1997). Considering the results of the research, it can be said that it has resulted from this relationship between the development of cognitive awareness and problem solving. In different researches it was determined that people who are successful in problem solving exhibit more cognitive awareness behaviors than those with low level of success and cognitive awareness increases problem solving success. (Garduño, 1997; Howard et al., 2000).

Blakey and Spence (1990) determined metacognitive behavioral development strategies as defining what one knows and not knows, thinking by speaking, keeping a diary, planning, organizing and summarizing. Revising all the steps of this strategy it has shown that it is parallel in many ways to the problem-based experiment designing steps which is applied in biology lab course. When viewed from this point aspect, it can be said that problem-based experiment designing processes will be employed in improving metacognitive skills.

2. Secondly, pre test-post test of metacognitive scores of prospective science teachers according to their gender were analyzed.

While pre test metacognitive skill score means of prospective teacher does not differ according to gender, in post tests it differs significantly in favor of females. Thus it can be said that designing problem-based experiments has more effect on improving metacognitive skills of females than males.

SUGGESTIONS

In the light of the results of this study, it has been suggested that it is more productive to create environments where prospective teachers can design open ended experiments using problem solving steps instead of conducting closed ended, prescription type experiments in lab courses (physics, chemistry, biology, science).

As the research was conducted on a formal education program there were certain limitations. In this study conducted with six classrooms, a control group couldn't be selected in order not to cause differences between the classes. The application can be repeated by experimental and control group in different studies.

This study is extremely important as it has been conducted on prospective science teachers who will conduct the experiments related to biology with different techniques in science classes in the future, who will use their metacognitive skills and who will have effect on their students improving these skills. In further researches related to this subject, it can be studied in detail (a) if conducting the laboratory classes with problem-based experiment designing for a long time has an effect on other skills such as cognitive skills(problem solving, creative thinking, inquiry-based learning etc.) (b) if metacognitive skills differ in different groups in which only designing experiments are used and problem-based experiment designing is applied, (c) the effect of designing experiments using different teaching approaches (project-based learning, argumentation-based learning, research-based learning etc.) on metacognitive skills (d) the effect of conducting the lessons of prospective teachers who have laboratory classes in different departments, with problem-based experiment designing and the reasons of differences in gender.

Conflict of Interests

The author has not declared any conflict of interests.

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