Peer instruction in chemistry education: Assessment of students' learning strategies, conceptual learning and problem solving

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Abstract

The aim of this research was to investigate the effects of peer instruction on learning strategies, problem solving performance, and conceptual understanding of college students in a general chemistry course. The research was performed students enrolled in experimental and control groups of a chemistry course were selected. Students in the experimental group instructed with peer instruction, while students in the control group instructed by conventional instruction. The research data were collected with chemistry achievement test, learning strategy survey, an examination, and student evaluation questionnaire. The results revealed that the students' conceptual understanding, learning strategies, and problem solving performance in the experimental group improved significantly relative to the students in the control group. The students also changed their perspective on comprehending a concept and solving a problem and enhanced their learning strategies (cognitive/metacognitive strategies and resource management strategies) with peer instruction in the experimental group.

Keywords: chemistry education; conceptual learning; learning strategies; peer instruction; problem solving

Introduction

Chemistry courses are required for many different STEM (science, technology, engineering, and mathematics) disciplines. Chemistry educators in these fields have realized that most students are not able to learn sufficient chemistry through conventional instruction and complete courses with similar misconceptions and preconceptions because the students do not generally make links between different concepts (e.g., acids and bases, chemical bonding, enthalpy and enthalpy change, energy and its change, heat and temperature, heat and work, etc.) (Burrows & Mooring, 2015; Cartrette & Mayo, 2011; Nagel & Lindsey, 2015; Nilsson & Niedderer, 2014).

Students also have great difficulty in finding correct results for quantitative/qualitative chemistry problems (Avramiotis & Tsaparlis, 2013; Broman & Parchamnn, 2014). Therefore student-centered instructional approaches are needed to overcome this drawback of conventional instruction and to provide a better comprehension in chemistry (Gosser, Kampmeier, & Varma-Nelson, 2010; Lewis & Lewis, 2005; Liaw, Chiu, & Chou, 2014). One of the instructional approaches used is peer instruction.

Mazur and Watkins (2010) defined peer instruction as "an interactive teaching technique that promotes classroom interaction to engage students and address difficult aspects of the material" (p. 39). Peer instruction (PI) is mainly based on the constructivist approach, which is an active process based on student-centered learning in which learners construct their own meaning of knowledge instead of knowledge transfer from instructors (Kwan & Wong, 2015). Peer instruction was originally used to teach fundamental physics concepts using multiple-choice test items in a large-enrollment introductory undergraduate physics course (Mazur, 1997). PI consists of three stages, which are the set up stage, the response stage and the solution/discussion stage of the concept tests/problems (Turpen & Finkelstein, 2009).

Peer instruction provides many advantages for both students and instructors. Some of these benefits are as follows: (a) PI enhances the engagement and comprehension of the students regardless of their background knowledge (Crouch & Mazur, 2001; Lasry, Mazur, & Watkins, 2008); (b) PI increases peers interaction, allows peers to challenge each other with debates, and provides a process of reasoning during class discussions (Nicol & Boyle, 2003; Perez et al., 2010; Smith et al., 2009); (c) PI improves students' ability to solve problems and gain new insights as a consequence of the thinking process (Gok, 2015); (d) PI reduces students' number who drops out of the course (Gok, 2012a) and (e) PI diminishes the gender gap in students' conceptual learning (Gok, 2014, Lorenzo, Crouch, & Mazur, 2006; Miller, et al., 2014).

The literature does not include sufficient studies on peer instruction in chemistry classroom apart from the research of Cavalli, Hamerton, & Lygo-Baker, (2015); McCreary, Golde, & Koeske (2006); Parkinson (2009) and Schell & Mazur (2015). The purpose of this research was to investigate whether peer instruction affected students' conceptual learning, problem solving performance, and learning strategies. The research questions examined were:

1. Is peer instruction effective on students' conceptual learning?
2. Is peer instruction effective on students' learning strategies?
3. Is peer instruction effective on students' problem solving performance?
4. Does peer instruction change students' affective and cognitive ideas regarding the course?

Methodology of Research

A two-group, pretest and posttest, quasi experimental design was conducted in this research (Fraenkel & Wallen, 2009). Pretest and posttest evaluation before and after the implementation were conducted on the experimental group (EG) and the control group (CG). The research design is presented in Table 1. The details of implementation were explained in the instructional approaches and data collection section, respectively.

Table 1. *The Research Design*

Groups	Pretest	Implementation	Posttest
EG	CAT, LSS	PI	CAT, LSS
CG	CAT, LSS	CI	CAT, LSS

Note: CAT: Chemistry Achievement Test; LSS: Learning Strategy Survey; PI: Peer Instruction; CI: Conventional Instruction

Participants

The research was conducted at Dokuz Eylul University, Izmir, Turkey. The age of students was between 18 and 22. The research sample consisted of 47 freshman students from two different chemistry classes. The EG composed of 22 students and the CG consisted of 25 students. The students' academic background in both groups was investigated and it was found that the difference was not statistically significant.

Instructional Approaches

The experimental group students were instructed with peer instruction (PI), which is based on constructivist approach, and the control group students were instructed with conventional instruction (CI). Two groups were taught by the same instructor. Some possible limitations of the research were listed as follows; the sample size of the research was small and the research only was applied to chemistry course. Primary objectives of the course were to accustom the students to describing and explaining the fundamental principles and concepts of chemistry. The details of peer instruction and conventional instruction were given respectively.

a) The instructor gives the recitation section. The sample course procedure of peer instruction was presented in Table 2.

b) Time is given to the students to consider the concept test.
c) They indicate their responses individually.

Colored flashcards (A-red, B-yellow, C-green, and D-blue) are used to indicate the students' answers during the voting process. Low technology (flashcards) instead of high technology (classroom response systems) was used due to limited financial resources.

d) They debate their responses with their peers.

If the percentage of correct answers is between 30% and 70%, then the instructor starts the discussion. If the percentage of correct answers is lower than 30%, the concept test(s)/problem(s) is reexamined.

e) They revise their responses.
f) General feedback on the revised answers is provided by the instructor.

Identical concepts were presented to the EG and the CG. The control group students are monitored in the following procedure. The instructor gives a brief explanation. The students are given time to examine the concept tests. They show their individual responses. The students use the flashcards during the voting process. Finally, general feedback to the students by examining the correct responses is provided by the instructor.

Concept tests designed by the authors were edited to be multiple-choice test questions. Some concept tests were chosen from the literature (Brown, LeMay, & Bursten, 1997). The concept tests mirrored the course goals. Students were given four or five concept tests (easy, medium, and difficult) which they answered in a 75 minute block-class.

It should be noted that similar concept tests were answered and discussed in the class and in the chemistry achievement test to prevent pseudo-enhancement in the research results. The difficulty levels of the concept tests were adjusted to equal the protocol presented by Reay, et al., (2005) and Smith, et al., (2009). Designed concept tests were prepared from lower to higher order thinking skills (Cook, Kennedy, & McGuire, 2013). Easy concept tests were based on remembering or understanding. Medium concept tests were based on applying or analyzing. Difficult concept tests were based on evaluating or creating. An isomorphic question (Porter, et al., 2011) as an alternative to the medium or difficult concept test with the same difficulty level was also prepared.

Table 2. Sample Course Procedure of PI

Time	The Process of PI	Activities
0-20 min	The instructor gives the recitation section.	Recitation -20 min-
21 min	The instructor gives the first concept test to the class.	First Concept (Easy) Test - 6 min-
23 min	Time is given to students to consider the concept test.	
24 min	The students indicate their responses individually.	
26 min	If the percentage of their correct answers exceeds 70%, then the instructor explains the concept in detail.	
27 min	The instructor gives the second concept test to the class.	Second Concept (Medium) Test -9 min-
29 min	Time is given to students to consider the concept test.	
30 min	The students indicate their responses individually.	
32 min	If the percentage of their correct answer falls between 30% and 70% the instructor initiates a peer discussion section. The students debate their responses with their peers.	
33 min	Students declare their revised responses.	
35 min	If the percentage of revised answers exceeds 70%, then the instructor explains the concept test.	
35-50 min	The instructor continues the recitation section.	Recitation -15 min-
51 min	The instructor gives the third concept test to the class.	Third Concept (Difficult) Test -15 min-
53 min	Time is given to Sstudents to consider the concept test.	
54 min	The students indicate their responses individually.	
56 min	If the percentage of their correct answer is lower than 30% the instructor informs about the concept test.	
57 min	The instructor gives the concept test to the class again.	
59 min	Time is given to students to consider the concept test.	
60 min	The students indicate their responses individually.	
62 min	If the percentage of their correct answer falls between 30% and 70% the instructor initiates the peer discussion section. The students debate their responses with their peers.	

63 min	Students declare their revised responses.	
65 min	If the percentage of revised answers is higher than 70% the instructor explains the concept test.	
66 min	The instructor gives the isomorphic concept test.	Isomorphic Concept Test -6 min-
68 min	Time is given to students to consider the concept test.	
69 min	The students indicate their responses individually.	
71 min	If the percentage of their correct answer is higher than 70%, the instructor explains the concept in detail.	
75 min	The instructor finally summarizes the subject.	Summary -4 min-

Data collection & analysis

Data Collection

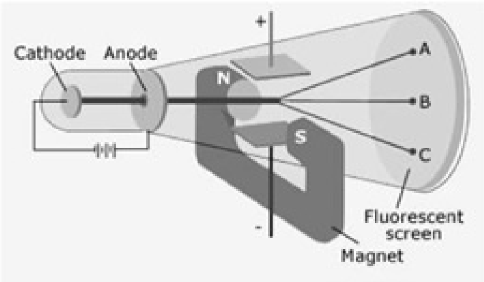
The data for the research were collected using four tools. The first one was Chemistry Achievement Test developed by the authors, two of them were surveys (Learning Strategies Survey developed by Pintrich, et al., (1991) and Student Evaluation Questionnaire 'SEQ' improved by the authors) and the last one was an examination that included quantitative problems which were selected from the textbook (Brown, LeMay, & Bursten, 2000). CAT and LSS were applied to the EG and the CG before and after the implementation. SEQ only was applied to the EG after the implementation. Finally quantitative problems were performed to both groups at the end of the implementation. The details of them are explained as follows:

Chemistry Achievement Test (CAT)

CAT is multiple-choice test assessing students' knowledge of fundamental chemistry concepts (classifications of matter, properties of matter, the atomic theory of matter, the discovery of atomic structure, the modern view of atomic structure, and the periodic table) contained 25 questions. The sample questions are presented in Figure 1.

Figure 1. Sample questions in the test

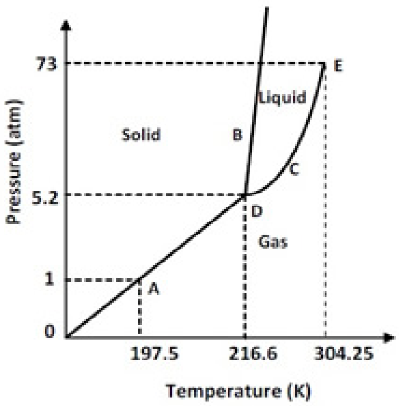
Question 1



The diagram above shows a cathode ray passing through the region between two oppositely charged parallel plates and a magnet. Which path will the cathode ray travel?

a) A
b) *B*
c) C
d) A-B
e) B-C

Question 2



The triple phase diagram of carbon dioxide is given below. Which of the following statements is *definitely* incorrect?

a) It is solid at 197.5 °K and 1 atm.
b) It sublimates above 304.25 °K.
c) Triple is at 216.6 °K and 5.2 atm.
d) It is liquefied by increasing pressure at 230 °K.
e) Point E is the critical point.

The validity and reliability of the CAT were tested by using classical test theory. Three professors reviewed the face and content validity. Corrections were conducted on the basis of their suggestions. The items were tested on 250 randomly selected students not involved in the present research. Corrections were made based on these students' recommendation concerning the difficulties in answering the questions. The reliability coefficient of the pilot test was calculated as 0.82 using the Kuder-Richardson 21-formula. The reliability coefficient is acceptable for an instrument of this type (Fraenkel & Wallen, 2009).

The discrimination and difficulty indices of each multiple choice test question were analyzed. The difficulty indices of the questions ranged from 0.25 to 0.87. The difficulty index value is accepted between less than 30% (difficult) and greater than 80% (easy) (Mitra, et al., 2007). The discrimination indices (D) ranged from 0.30 to 0.81. Ebel (1972) categorized items based on classical test theory as follows. An item with a negative discrimination index must be discarded. D should be revised as poor between 0.0 and 0.19. D should be accepted as normal between 0.20 and 0.29. D should be accepted as good between 0.30 and 0.39. D should be accepted as excellent greater than 0.40. These index values were reasonably accepted without changing for further modification of the test items (Black, 1999).

Learning Strategies Survey (LSS)

Pintrich, et al. (1991) developed Motivated Strategies for Learning Questionnaire to evaluate learners' motivations and their learning strategies. The survey comprises two sections (motivation survey with 31 items and learning strategies survey with 50 items) in the English version. The learning strategies survey was used in this research. The learning strategies survey consists of "cognitive/metacognitive strategies" (rehearsal, organization, elaboration, critical thinking, and metacognitive self-regulation) and "resource management strategies" (help seeking, peer learning, effort regulation, and time and study environment). LSS was modified and translated into Turkish by Buyukozturk, et al., (2004). The detail statistical findings of their research can be found from their research paper.

Quantitative Problem Solving

Problem-solving performance of the students in the groups was evaluated with an examination having four quantitative problems. The problems were analyzed according to problem solving strategy steps which are identifying the fundamental principle (IFP), solving (SLV), and checking (CHK) (Gok, 2013, 2015). A handout on problem solving strategy steps (Gok, 2015) was delivered to the students at the beginning of the research. A sample problem from the handout is presented in Appendix A. The problems in the handout were chosen from the literature (Brown, et al., 2000).

Student Evaluation Questionnaire

A questionnaire comprising 12 statements was used to evaluate peer instruction. The statements were derived from the literature (Cortright, Collins, & DiCarlo, 2005; Giuliodori, Lujan, & DiCarlo, 2006; Nicol & Boyle, 2003) and usually expressed affective ideas and cognitive ideas of the students concerning peer instruction. The students in the experimental group anonymously completed an evaluation questionnaire on a Likert type scale with 5 choices (1= strongly disagree, 2= disagree, 3= neither agree nor disagree, 4= agree, 5= strongly agree) at the end of the research. The findings were analyzed using descriptive statistics.

Data Analysis

The students' responses were analyzed using IBM SPSS Statistics 22. Descriptive statistics were calculated means and standard deviations. The fractional gains (g) of the groups developed by Hake (1998) were calculated. He recommended specific ranges based on the fractional gain formula as follows: *high gain* is higher than 0.7, *medium gain* is between 0.7 and 0.3, and *low gain* is lower than 0.3.

$$\text{Fractional Gain} < g > = \frac{(\text{posttest\%} - \text{pretest\%})}{(100\% - \text{pretest\%})}$$

ANOVA (Analysis of variance) was applied to test the implementation main effect on the posttest means of the experimental group and the control group, after identifying that the difference between the experimental group and the control group pretest means was not significant ($p>0.05$). Values of skewness and kurtosis were also calculated between -2 and +2. These values indicated the normal distribution (George & Mallery, 2010).

Results of Research

Results of CAT

The descriptive statistics (Table 3) at the beginning of the research indicate the similarity between the EG and the CG.

Table 3. CAT Results of the Students in the Groups

Group	*N*	Pretest		Posttest		Fractional Gain
		M	*SD*	*M*	*SD*	*g*
EG	22	5.13	1.24	19.36	1.09	0.71
CG	25	5.16	1.62	11.28	1.10	0.30

ANOVA shows that the difference between the experimental group students' CAT pretest results and the control group students' CAT pretest results was not significant ($p>0.001$) while the difference between the experimental group students' CAT posttest results and the control group students' CAT posttest results was significant with $F(1,45) = 635.69$, $p<0.001$. It was also found that the fractional gain of the experimental group ($g=0.71$) was high while the fraction gain of the control group ($g=0.30$) was medium. These findings indicated that peer instruction was more effective for improving the experimental group students' learning performance.

Results of LSS

Table 4 indicates the descriptive statistics of the LSS components for the pretest and posttest results. When the pretest and posttest results of the groups were evaluated, the pretest results for both groups appeared to be similar while the EG posttest result was higher than the CG posttest results.

ANOVA shows that the difference between the experimental group students' LSS pretest results and the control group students' LSS pretest results was not significant ($p>0.001$) while the difference between the experimental group students' LSS posttest results and the control group students' LSS posttest results was significant with $F(1,45) = 1137.97$, $p<0.001$. A series of ANOVAs was applied to test the main effects on the component results (rehearsal [R], organization [O], elaboration [E], critical thinking [CT], help seeking [HS], peer learning [PL], metacognitve self-regulation [MSR], effort regulation [ER], time and study environment [TSE]) between the experimental and control groups. The results indicate that the difference between the experimental group students' LSS pretest component results and the control group students' LSS pretest component results was not significant ($p>0.001$) while the difference between the experimental group students' LSS posttest component results and the control group students' LSS posttest component results was significant ($p<0.001$).

Table 4. *LSS Results of the Students in the Groups*

	EG-Pretest		**CG-Pretest**		**Statistical Value**		**EG-Posttest**		**CG-Posttest**		**Statistical Value**	
Components	*M*	*SD*	*M*	*SD*	*F(1,45)*	*p*	*M*	*SD*	*M*	*SD*	*F(1,45)*	*p*
R	18.81	2.34	18.72	1.94	0.02	0.876	36.95	4.79	19.36	1.49	303.73	$p<0.001$
O	18.54	1.50	18.72	1.98	0.11	0.739	38.13	3.96	19.40	1.70	461.47	$p<0.001$
E	8.27	2.79	8.96	1.36	1.18	0.281	23.68	1.21	9.40	1.60	1157.77	$p<0.001$
CT	10.63	1.78	11.52	2.69	1.70	0.198	24.36	2.42	11.84	1.49	468.07	$p<0.001$
HS	14.36	3.15	13.80	2.29	0.49	0.483	30.90	2.34	14.08	1.75	786.37	$p<0.001$
PL	8.09	1.90	8.32	1.51	0.21	0.649	19.22	1.34	8.56	0.65	1247.75	$p<0.001$
MSR	8.95	1.93	8.96	1.13	0.00	0.991	19.18	1.50	9.20	0.76	856.30	$p<0.001$
ER	5.90	1.06	5.72	1.83	1.80	0.674	18.40	1.84	5.96	0.61	1016.61	$p<0.001$
TSE	5.27	1.45	5.72	1.83	0.84	0.364	12.50	1.76	5.96	0.61	302.48	$p<0.001$

Problem Solving Performance Results

The students included in the groups were asked four quantitative problems to evaluate their problem solving performance at the end of the research. Problems asked in the examination were the similar to the handout problems and solved problems in terms of difficulty level. When the students' problem solving performance as presented in Table 5 was evaluated according to problem solving strategy steps (identifying the fundamental principles-IFP, solving-SLV, and checking-CHK) by percentage, the students' problem solving performance in the experimental group was higher than the students' problem solving performance in the control group.

Table 5. *Problem Solving Performance Results of the Students in the Groups*

Problems	**Group**	**IFP**	**SLV**	**CHK**
1. Problem (Properties of Matter)	EG	91% (20/22)	82% (18/22)	64% (14/22)
	CG	56% (14/25)	40% (10/25)	40% (10/25)

2. Problem (Atomic Structure)	EG	86% (19/22)	86% (19/22)	64% (14/22)
	CG	52% (13/25)	44% (11/25)	36% (9/25)
3. Problem (Atomic Structure)	EG	91% 20/22	82% (18/22)	59% (13/22)
	CG	56% (14/25)	36% (9/25)	32% (8/25)
4. Problem (Periodic Table)	EG	91% (20/22)	77% (17/22)	68% (15/22)
	CG	56%(14/25)	48% (12/25)	36% (9/25)

When the students' problem solving strategy steps were generally evaluated, it was observed that approximately 90% of the experimental group students identified the fundamental principles/concepts in asked problems regarding to the properties of matter, atomic structure and periodic table. The rate (55%) for the control group students was lower. Roughly 80% of the experimental group students solved the quantitative problems while 42% of the control group students solved them. After the fundamental principles were determined, the experimental group students easily solved the problems. The control group students only focused on problem solving without understanding the problems. It could be said that the students had difficulty in comprehension.

Finally, almost 65% of the experimental group students checked the problem solution ways (unit, sign, magnitude, etc.), but this rate (36%) for the control group students was lower. Peer instruction provided to the students to monitor problem solving procedures logically. Besides the students could evaluate themselves while problem solving with the help of peer instruction. The students in the control group did not watch out checking of the problem solution ways.

Results of the Student Evaluation Questionnaire

The questionnaire data in Table 6 indicates that peer instruction had a significant effect on the students' affective and cognitive ideas. With respect to affective ideas, most of the students included in the experimental group reported that peer instruction was understandable and easy to follow, allowed them to express their ideas during peer discussion, enhanced interaction between the students and instructor, and encouraged them to attend in class. Furthermore, the students enjoyed peer instruction. With respect to cognitive ideas, the students reported that peer instruction helped them understand the course materials, stimulated them to think about the questions and answers, helped them to evaluate themselves, and provided an interactive learning environment.

Table 6. *Opinions of the Students in the Experimental Group*

Questionnaire Items		**Responses**
Affective Ideas		
1.	I enjoyed this learning method.	4.8 ± 0.08
2.	I was attentive in class.	4.5 ± 0.10
3.	I interacted with classmates and instructor.	4.7 ± 0.09
4.	I liked to express my ideas during peer discussion.	4.8 ± 0.09
5.	The method was understandable and easy to follow.	4.7 ± 0.08
6.	It was good to use the flashcards anonymously.	4.6 ± 0.11
Cognitive Ideas		
7.	The method helped me to comprehend the subjects.	4.8 ± 0.08
8.	The immediate feedback provided by the instructor was impressive.	4.7 ± 0.09
9.	The method provided an interactive learning environment during the course.	4.7 ± 0.08
10.	The method helped me to evaluate myself through the questions and answers.	4.6 ± 0.08
11.	The method encouraged me to think about the questions and answers carefully.	4.5 ± 0.10
12.	It was essential to answer and report the questions individually before peer discussion.	4.6 ± 0.09

Discussion

The results of this research revealed that teaching with peer instruction had more positive effects on the students' conceptual learning, learning strategies, and problem solving performance than teaching with conventional instruction.

With reference to the first research question (Is peer instruction effective on students' conceptual learning?), the effect of peer instruction on conceptual learning of students in the experimental group was found to be statistically significant. The results in the literature (Crouch & Mazur, 2001; Gok, 2012a, 2015; Lasry et al., 2008, Smith, et al., 2009) supported the findings of the research. On the other hand, the students in the control group had difficulty in conceptual learning. They generally focused on quantitative problem solving without understanding the fundamental concepts. They were generally focused the correct response on the multiple choice test questions without any concern for meaningful conceptual learning. Eventually, many students did not want to examine and interpret the fundamental concept(s)/principle(s).

With reference to the second research question (Is peer instruction effective on students' learning strategies?), the effect of peer instruction on learning strategies (metacognitive and management strategies) of students in the experimental group was found to be statistically significant. The result in the literature (Gok, 2012b; Miller-Young, 2013) supported the findings of the research. Peer instruction influenced metacognitive strategies such as recalling, deeper understanding, critical thinking, planning, monitoring and evaluation of knowledge. The students made internal connections using the information and enhanced the encoding process by discussing a specific topic with their peers in the class. Thus, the students in the experimental group did not memorize keywords or concepts as described in the items covering rehearsal strategy. Peer instruction encouraged students to express their thoughts to peers by listing concepts or making simple charts/diagrams with the help of organization strategy. Peer instruction induced the students to think aloud and brainstorm. The students by means of critical thinking strategy questioned, interpreted, evaluated and found alternative options. Peer instruction provided self-regulation by searching for an answer to the concept test or problems.

The students realized what they knew/understood and tried to find an assistant to clarify the questions in their mind as investigated in help-seeking and peer-learning strategies. Peer instruction developed the level of collaboration with their peers and instructors gaining a better understanding of the fundamental concept(s) and the course materials. The effort regulation strategy addressed whether the students continue to research despite difficulties or distractions. The discussion with peers made the course environment more enjoyable and easier to adapt. This also supplied regular attendance to each course. The time and study environment strategy covered the items related to management of study time. Peer instruction gave students a brief period of quiet time to discuss and think about the concept questions. The students became accustomed to using their limited time effectively by concentrating on the concept questions with their peers.

With reference to the third research question (Is peer instruction effective on students' problem solving performance?), the students' problem solving performance in the experimental group was found higher than the students' problem solving performance in the control group. The result in the literature (Cortright, et al., 2005; Giuliodori et al., 2006; Gok, 2012a, 2013, 2014, 2015; Miller-Young, 2013) supported the findings of the research. Peer instruction helped them to determine the fundamental principles/concepts therefore they focus on solving quantitative and qualitative problems. On the other hand, the control group students only focused on the results of the problems without identifying the fundamental principles. As a result of this finding, the students' problem solving performance was lower according to the students in the experimental group.

With reference to the four research question (Does peer instruction change students' affective and cognitive ideas regarding the course?), the effect of peer instruction on cognitive and affective ideas of students in the experimental group indicated that peer instruction helped them to comprehend the subjects and to evaluate themselves through the questions and answers, provided an interactive learning environment during the course, improved their conceptual learning and problem solving performance, enhanced the interaction between students and instructor by the immediate feedback, to gain the reasoning ability, and allowed them to focus on the course materials during the course. In terms of affective ideas of the students, peer instruction stimulated their interest and encouraged them to actively attend the course. Most of the students liked to express their ideas during peer discussion, to use the flashcards anonymously and they enjoyed peer instruction.

Peer interaction helped students' cognitive and social development with the discussion procedures. Cognitive development fostered the students' conceptual learning, cause-effect reasoning, problem solving, critical and analytical thinking, and understanding of logical relationship during peer discussion. Social development improved the students' interaction and communication power, helps the students' cooperation during learning concept and problem solving and fostered learning the sharing of knowledge.

Conclusion

In the light of the findings of the research, it could be deduced that peer instruction affected positively the students' conceptual learning and problem solving performance. Also, peer instruction (a) created synergy for comprehending a concept test, including fundamental principle(s)/concept(s), (b) forced students to analyze the concept(s), (c) enhanced students' learning strategies, (d) improved analytical and critical thinking skills on the concept tests, (e) promoted deeper and meaningful learning, (f) helped students to solve quantitative problems, and (g) improved students' problem solving performance.

Finally, the findings of peer instruction have supported the practices of active learning. A suggestion to readers and researchers could also be presented. PI might be time-consuming; however, this drawback might be prevented by using classroom response systems (high-technology) instead of colored flashcard (low-technology). These systems can be reduced the feedback procedure for the instructor and increased real-time interaction between peers and instructor during peer discussion. Besides, the research findings should be confirmed through more researches with the same experimental design in different countries.

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Appendix

Appendix A

Sample Handout Problem for the Groups

"Calculate the wavelength of light that corresponds to the transition of the electron from the n=4 to n=2 state of the hydrogen atom. Is the light absorbed or emitted" (Brown et al., 2000)?

(IFP): "What is (are) the fundamental principle(s)/concept(s) of the problem"?

(SLV): "Which equation(s) do you need to solve the problem? What is the correct answer to the problem"?

(CHK): "What are the unit, sign, and magnitude of the asked variables(s)"?

Solution steps

IFP- "*First of all, identifying fundamental principle(s)/concept(s) of the problem is determined by the students. Then the concepts, known, unknown variables, and constants are indicated. If it is necessary, the problem can be visualized with the help of simple diagram/chart*".

Principles- The wave nature of light; quantized energy; Bohr's model of the hydrogen atom

Concepts- Energy level; Rydberg and Planck constants; the principal quantum numbers of the initial and final states of the atom; frequency and wavelength of light.

Constants: R_H=$2.18x10^{-18}J$; h=$6.63x10^{-34}Js^{-1}$; c=$3.00x10^{8}m/s$

Known variables: n_i=4; n_f=2

Unknown variables: ν; λ

SLV- "*Secondly, the problem is solved qualitatively and quantitatively. Qualitative solutions are performed with the help of required equations. A mathematical model is established for finding desired unknown variable. The desired unknown variable is calculated by using the given variables in this section*".

Qualitative Solution

$$\Delta E = E_f - E_i = h\nu \qquad -1-$$

$$\nu = \frac{\Delta E}{h} = \left(\frac{R_H}{h}\right)\left(\frac{1}{ni^2} - \frac{1}{nf^2}\right) \qquad -2-$$

$$\lambda = \frac{c}{\nu} \qquad -3-$$

Quantitative Solution

$$\nu = \frac{(2.18x10^{-18}J)}{(6.63x10^{-34}Js^{-1})}\left(\frac{1}{4^2} - \frac{1}{2^2}\right) \quad \text{-4-}$$

$$\nu = (3.29x10^{15}s^{-1})\left(\frac{1}{16} - \frac{1}{4}\right) \quad \text{-5-}$$

$$\nu = (3.29x10^{15}s^{-1})\left(-\frac{3}{16}\right) \quad \text{-6-}$$

$$\nu = -6.17x10^{14}s^{-1} \quad \text{-7-}$$

The wavelength of the emitted light could be calculated by using equation (-3-):

$$\lambda = \frac{c}{v} = \left(\frac{3.00x10^8 m/s}{6.17x10^{14}s^{-1}}\right) = 4.86x10^{-7}m = 486nm$$

CHK- "*Finally, the unit, sign, and magnitude of the variable are checked in this section*".

The negative sign indicates that light with a frequency of $6.17x10^{14}s^{-1}$ is emitted. 486 nm is the wavelength of the green emission line in the spectrum of hydrogen.