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The Effects of Two Cooperative Learning Strategies on the Teaching and Learning of the Topics of Chemical Kinetics

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ABSTRACT

The aim of this study was to determine the effect of group investigation and jigsaw techniques on students' academic achievement in the chemical kinetics unit of a general chemistry course. This study included a total of 106 students studying chemistry in three different classes during the 2008-2009 academic year. One of these classes served as the investigation group, using group investigation, while the second served as the jigsaw group, using the jigsaw technique, and the third served as the control group, using the traditional teaching method. The main instruments for obtaining data were the Chemical Kinetics Achievement Test (ckAT) and Graphics Skills Test (GST), which were applied to the treatments groups. The questions in the ckAT are related to the rate of a chemical reaction, measuring reaction rates, the effect factors on rates of reaction, the order of reactions, and reaction mechanisms. The GST is designed to evaluate the reading and understanding of graphics in chemistry. This is an instrument requiring the students to make drawings and give explanations. Based on the results of this research, it was concluded that the teaching of chemical kinetics via the jigsaw and group investigation techniques was more effective in increasing academic achievement compared to the traditional teaching method.

Key Words: Cooperative Learning, Chemical Kinetic, Group Investigation, Jigsaw Technique.

INTRODUCTION

Chemical kinetics, the branch of chemistry concerned with the study of the rate of chemical reactions, was chosen as the scientific theme for the following reasons. The main objectives of chemical kinetics are to describe and explain the observed relationships between the reaction rate and the variables that exert an influence on it. Moreover, it must provide critical support for the mechanism proposed for any chemical reaction (Justi & Gilbert, 1999). It can thus provide a basis for the comprehension of important chemical processes, which is essential for the education of thinking citizens. The science education literature suggests the teaching and learning of much physical chemistry – including chemical kinetics – is teacher-dominated in approach at both the secondary school and tertiary levels (Choi & Wong, 2004;Chairam, Somsook & Coll, 2009) In general, At the university level, as might be

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expected, the kinetic concepts taught are more complex than at the secondary school level. Chemical kinetics is reported to be difficult for university students to comprehend; mostly because at this level it generally involves more complex mathematics as well as qualitative explanations for both rate equations and variables that affect the rate of a reaction (Chairam et al., 2009).

Science educators have been responding to the call for more emphasis on the process of "doing science" as an effective way for students to learn, retain, and use scientific information (Chiappetta & Russell, 1982; Ertepınar & Geban, 1996; Heppner, 1996; Eilks, 2005; Yip, 2005; Lin, 2006; Wenzel, 2007; Doymuş, 2008a; Doymuş, Şimşek & Karaçöp, 2009; Seifert, Fenster, Dilts & Temple, 2009). Learning occurs best when students are actively involved in the construction of their knowledge (Mestre & Cocking, 2002). The practice of science using investigative, discovery-based, open-ended processes, with opportunities for designing experiments built on previous observations represents an educational tool that effectively demonstrates to students how the scientific process works in the professional world (Davidson & Worsham, 1992; Sharan & Sharan, 1994; Switzer & Shriner, 2000). Frequently, such investigative experiences occur in cooperative learning situations, teaching methods that encourage students to work together to achieve a common goal, and that result in greater student achievement than traditional didactic methodology (Johnson & Johnson 1999; Doymuş et al., 2009a). In addition to greater student achievement, engaging in cooperative learning leads to the development of higher level thinking skills, greater intrinsic motivation, improved interpersonal skills, positive attitudes toward learning, and heightened self-esteem (Dornyei, 1997; Slavin, 2000; Hanze & Berger, 2007).

Cooperative learning is a possible instructional innovation that could be related to the affective aspects of reading. In fact, cooperative learning has been established as a promising instructional innovation that may improve the cognitive, social, and affective outcomes of schooling (Slavin, 2000). At present, there are many cooperative learning techniques and structures available. These methods and structures can be categorized into the following models: a) Student Teams and Achievement Divisions (STADs), b) Teams-Games-Tournaments (TGTs), c) Learning Together (LT) d) Jigsaw Technique (JT) e) Group Investigation (GI) f) Team Accelerated Instruction (TAI) and g) Cooperative Integrated Reading and Composition (CIRC) (Slavin, Leavey, & Madden, 1986; Aronson & Shelley, 1997; Towns, 1998; Slavin, 2000; Seetharaman & Musier-Farsyth, 2003; Eilks, 2005; Oh & Shin, 2005; Doymuş, 2008a). To summarize, the question of whether cooperative learning is effective in accelerating student achievement has generally been answered in the positive. However, researchers need to focus on which cooperative methods are more effective and the factors which contribute to or detract from the success of these methods. In this study investigated the issue by examining three approaches to jigsaw technique, group investigation and traditional method.

a) Jigsaw Technique

Different techniques, designed with various aims, are used in the cooperative learning method. Jigsaw, one of these techniques (Aronson, Stephen, Sikes, Blaney, & Snapp, 1978; Sharan, 1998), is preferred by researchers since it can be used in the classroom and makes it easy for students to understand the subject. There are currently six types of jigsaw techniques available for teachers to use in the classroom: a) Jigsaw, developed by Aronson and Shelley (1997); b) Jigsaw II, developed by Slavin (2000); c) Jigsaw III, developed by Stahl (1994); d) Jigsaw IV, developed by Holliday (2000); e) Reverse Jigsaw, developed by Hedeen (2003); and f) Subject Jigsaw, developed by Doymuş (2007). The basic parts of the techniques are the same. In this research, we used the subject jigsaw, which differs from the other jigsaws in that both course topics and students groups are divided (Doymuş, Simsek, Karacop, & Ada, 2009)

In the subject jigsaw technique, first the subjects dealt with the unit are divided into subtopics. Later, students taking the same subject topics are placed into home groups. To learn as an 'expert' of a portion of the material, each student in the home groups prepares a part of the assignment out of class. On returning to the class, students in the home groups teach the information they have learned to each other. The home groups then break apart, like pieces of a jigsaw puzzle, and the students move into jigsaw groups, which consist of members from the other home groups who have been assigned the different subtopics. While in the jigsaw groups, the students discuss their particular material to ensure that they understand it. Students then return to their home groups, where they teach their material to the rest of their group (Doymuş, 2007).

b) Group Investigation

In the group investigation technique, students form interest groups within which to plan and implement an investigation, and synthesize the findings into a group presentation for the class (Tan, Sharan, & Lee, 2006). The teacher's general role is to make the students aware of resources that may be helpful while carrying out the investigation. Group investigation includes four important components ("the four I's"): investigation, interaction, interpretation, and intrinsic motivation. Investigation refers to the fact that groups focus on the process of inquiring about a chosen topic. Interaction is a hallmark of all cooperative learning techniques, required for students to explore ideas and help one another learn. Interpretation occurs when the group synthesizes and elaborates on the findings of each member in order to enhance understanding and clarity of ideas. Finally, intrinsic motivation is kindled in students by granting them autonomy in the investigative process (Sharan & Sharan, 1989).

Group investigation is a cooperative learning method and has as its hallmark students working in small groups, actively constructing their knowledge, with the outcome of the enhancement of student learning and of student satisfaction (Marlowe & Page, 2005). The group investigation method has four elements that function simultaneously to distinguish it from other types of cooperative learning. These elements are investigation, interaction, interpretation, and intrinsic motivation (Seifert et al., 2009). The group investigation also helps students to develop their cognitive abilities since the method involves higher-level thinking tasks such as identifying information relevant to their research topics, applying knowledge to new problems, using inferences to formulate answers, and evaluating the inquiry performances of others (Sharan & Sharan, 1994). Research has reported, with a high degree of consistency, the effectiveness of the group investigation in achieving positive learning outcomes in several domains (Oh & Yager, 2004). Oh and Shin (2005) used group investigation combined with a peer tutoring strategy in high school biology classrooms and found that students from the group investigation settings were superior to those taught by whole-class methods in terms of academic achievement, process skills, perceptions of learning environment, and self-esteem (Doymuş et al., 2009b). Shachar and Sharan's (1994) study also revealed that the group investigation was more effective than the whole-class presentation–recitation method in producing active verbal and social interactions among students as well as larger gains on achievement tests. Oh and Yager (2004) found that the degree of positive student attitudes toward science learning increased as the students learned science using the group investigation on more occasions. Students as well as teachers may consider inquiry-based approaches such as the group investigation inappropriate for them because they feel pressure to cover everything included in the curriculum and because they may have seldom learned science by investigative methods (Doymuş et al., 2009b). Therefore, it is important to gain insights into how students perceive their learning activities with the group investigation in order to understand the ways the cooperative inquiry affects student learning and to find implications for better educational practices in science classrooms. However, few studies have examined students' ideas about their experiences with the cooperative learning method in schools (Gillies, 2004).

The aim of this study was to determine the effects of group investigation, the jigsaw technique, and traditional teaching on students' academic achievement in the chemical kinetics unit of a general chemistry course.

METHODOLOGY

a) Sample

The sample of this study consisted of a total of 106 undergraduates from three different classes enrolled in the general chemistry course for the 2008–2009 academic years. One of the classes was selected randomly as the Investigation Group (IG) (*n*=30), in which the group investigation was applied, the second was selected as the Jigsaw Group (JG) (*n*=40), in which the jigsaw technique was applied, and the third was selected as the Control Group (CG) (*n=36*), in which the traditional teaching method was applied. Pre-service science teachers are admitted to this department only after they have successfully passed a university entrance exam. The mean age of the participants was 19.44 (SD=1.32). Neither age nor gender differed significantly among the groups. Ages ranged from 18 to 23 years. Volunteers were given background information regarding the study prior to consent. During the training period, instruction for the treatment groups was delivered by the researchers. Before the beginning of the treatment, the teacher gave information about learning objectives, the instruction process, and rules of working in a cooperative group, roles, and assessment strategies.

b) Instruments

In this research, the Chemical Kinetics Achievement Test (ckAT) and Graphics Skills Test (GST) were used.

The ckAT consists of 44 multiple-choice questions, with each question worth five points. This test was created by the researchers. The questions in the test were related to the rate of a chemical reaction, measuring reaction rates, the effect factors on rates of reaction, the order of reactions, and reaction mechanisms. This test was given to students who were not involved in the study but had previously taken the course in which the chemical kinetics topics mentioned above had been taught. With respect to reliability, ckAT was administered to a group of 42 students who had taken the General Chemistry-II course the year before. The KR20 was used to determine the reliability of ckAT and the reliability coefficient was found (α= 0.68). Moreover, to check the validity of the ckAT developed, the opinions of chemistry lecturers and researchers on the subject were taken into consideration. Researchers pointed out that the gains achieved with ckAT related to the subjects of chemical kinetics have been high in terms of measurement.

The GST consists of 24 multiple-choice questions, with each question worth one point. The GST was designed to assess the reading and understanding of graphics used in chemistry. Also, GST was carried out in treatment groups for the purpose of checking pre knowledge of students. The GST was created by the researchers. The questions in the test were related to the reading and understanding of graphics in chemistry courses. The validity of the test was checked by a professor and two other chemistry teachers. With respect to reliability, the GST was administered to a group of 42 students who were not involved in the study but had previously taken the course in which the general chemistry courses mentioned above had been taught. The KR20 was used for determining the reliability of GST, which was found to be α= 0.67.

c) Procedure

In the treatment groups, this study was conducted over a four-week period during which the chemical kinetics unit was taught as part of the regular curriculum in the general chemistry course. Classroom instruction for the treatment groups consisted of four class hours per week. The classes were defined as the IG, JG, and CG. To determine students' graphical skills in chemistry, GST, related to the reading, drawing, and understanding of graphics in chemistry courses, was administered to the groups before the instruction. Next, the chemical kinetics unit was studied in three groups. Two different instructors were involved in the teaching. While one of the teachers actually taught the course, the first teacher, an expert (the second author) in cooperative learning, observed the teaching process in the groups.

i)Forming and Re-Forming Jigsaw Groups

The jigsaw group students were randomly divided into two subgroups (20 students + 20 students). Figure 1 represents one of these subgroups (20 students). The other subgroup was organized in the same way as the first. These students were divided into five "home groups" since the chemical kinetics topic is divided into five subtopics [1) An Introduction to Chemical Kinetics, 2) measuring reaction rates 3) the factors influencing reaction rates, 4) the order of reactions 5) reaction mechanisms]. In this instance, each home group contained four students, taking the same subtopics; however, the number of home groups in a class can be increased or decreased so that every student in the class can participate in the jigsaw method.

These groups are as follows:

Home Group A (HGA), representing an introduction to chemical kinetics. The students in HGA prepared the subjects 'main concepts in chemical kinetics', 'definition of chemical kinetics', 'definition of terms relating to chemical kinetics', 'chemical kinetics in our daily life', and 'the importance of chemical kinetics', and presented these subjects to the class.

Home Group B (HGB), representing measuring reaction rates. The students in HGB prepared and presented the subjects 'the rate of a reaction in terms of changes in the concentration of a reactant or a product per time', 'instantaneous rates of reaction and the rate law for a reaction', 'different ways of expressing the rate of reaction', 'the rate law versus the stoichiometry of a reaction', and 'the rate law constant and unit of reaction constant'.

Home Group C (HGC), representing factors influencing reaction rates. The students in HGC prepared and presented the following subjects to the class: 'the nature of the reactants', 'temperature', 'how temperature affects the rate law constant for a reaction', 'concentration and pressure' and 'catalysts and the theory of how a catalyst works'.

Home Group D (HGD), representing the order of reactions. The students in HGD prepared and presented the following subjects to the class: 'zero-order reactions', 'first-order reactions', and 'second-order reactions'.

Home Group E (HGE), representing reaction mechanisms. The students in HGE prepared and presented the following subjects to the class: 'elementary processes', 'a mechanism with a slow step', and 'a mechanism with a fast, reversible first step'.

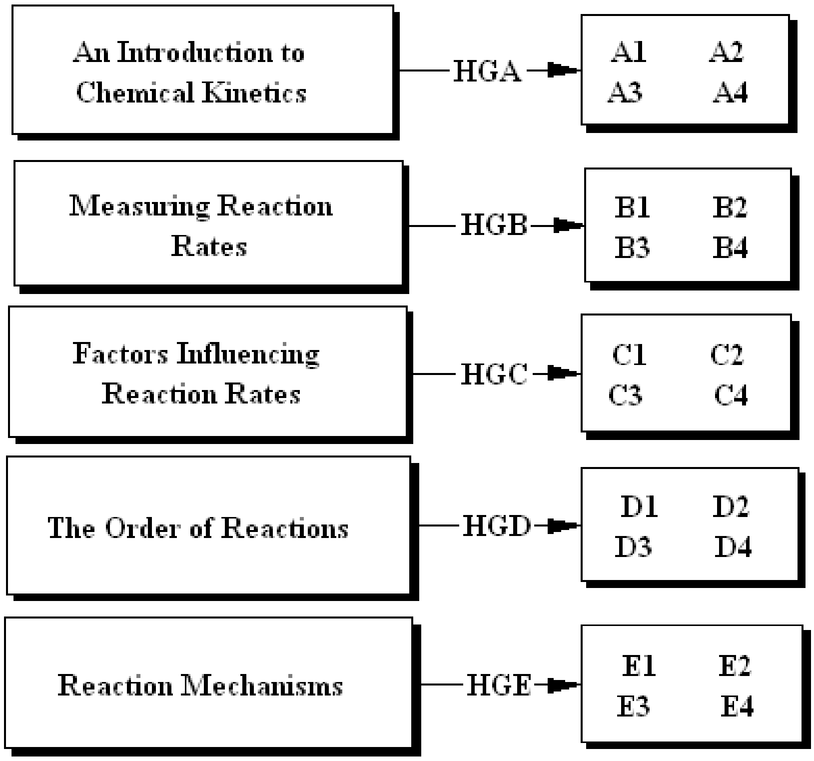

Figure 1. *Subtopics of the Chemical Kinetic Unit and Home Groups Representing (A1, A2, A3 etc. Stand for an Individual Student from a Group)*

Each home group studied their subjects on their own out of class. Then each group was given 30 min to present their work to the class and 20 min for discussion with the class. During this discussion, the home group answered the questions asked by the class. The home groups then broke apart, like pieces of a jigsaw puzzle (Mattingly & Van Sickle, 1991; Doymuş, 2008b), and the students moved into jigsaw groups consisting of members from the other home groups who were assigned the same portion of the material. Then the students in the home groups, following the presentation of all subtopics in chemical kinetics, formed jigsaw groups containing JG1, JG2, JG3, and JG4, with one student from each of the home groups (see Fig. 2). In these jigsaw groups, the teacher asked them to familiarize themselves with their subtopic. They prepared summary reports and then each jigsaw group prepared a teaching strategy for its members to use to explain their subtopic to the rest of the class. Each jigsaw group presented their own topic to the class for 30 min, and then discussed the related topics for 20 min. The students then went back to the home groups. These home groups then consisted of one student from each jigsaw group, and these students were called "expert students." The experts were then in charge of teaching their specific subtopic to the rest of the students in their learning group.

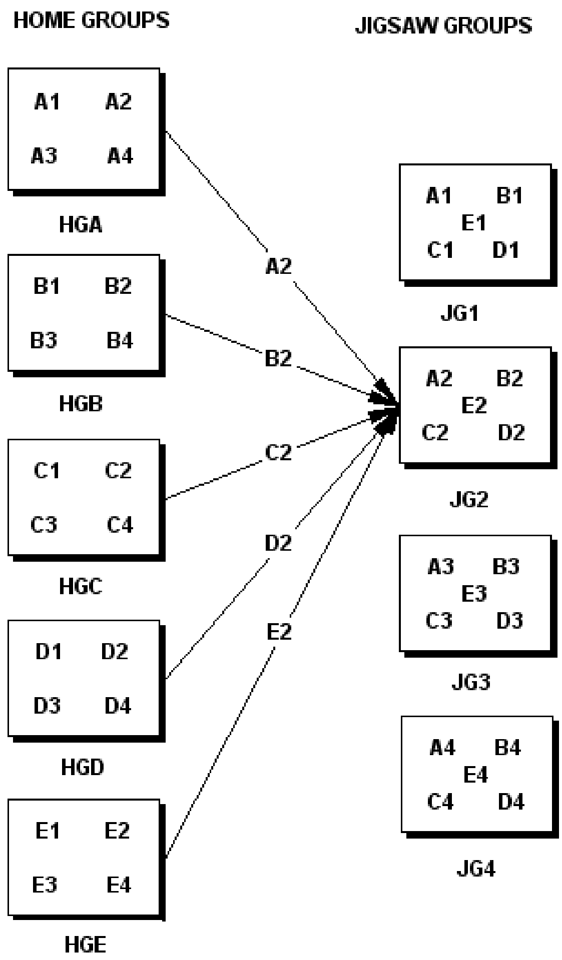

Figure 2. *Forming of Jigsaw Groups from Home Groups*

ii) The Group Investigation Implemented

The IG students were randomly divided into two parts (Part I=15 students + Part II=15 students). The students in these parts were divided into three "home groups" as shown in Figure 3. In this instance, each home group contained five students; however, the number of home groups in a class can be increased or decreased so that every student in the class can participate in the IG. The group investigation was employed over four weeks to research the chemical kinetics unit. The overarching goal of the action research was to create constructivist classroom environments in which students could practice scientific inquiry as they worked together to pursue their own learning goals. The main features of the modified group investigation are presented in three phases (Oh & Shin, 2005), namely 1) in-class discussion, 2) out-of-class investigation, and 3) in-class presentation.

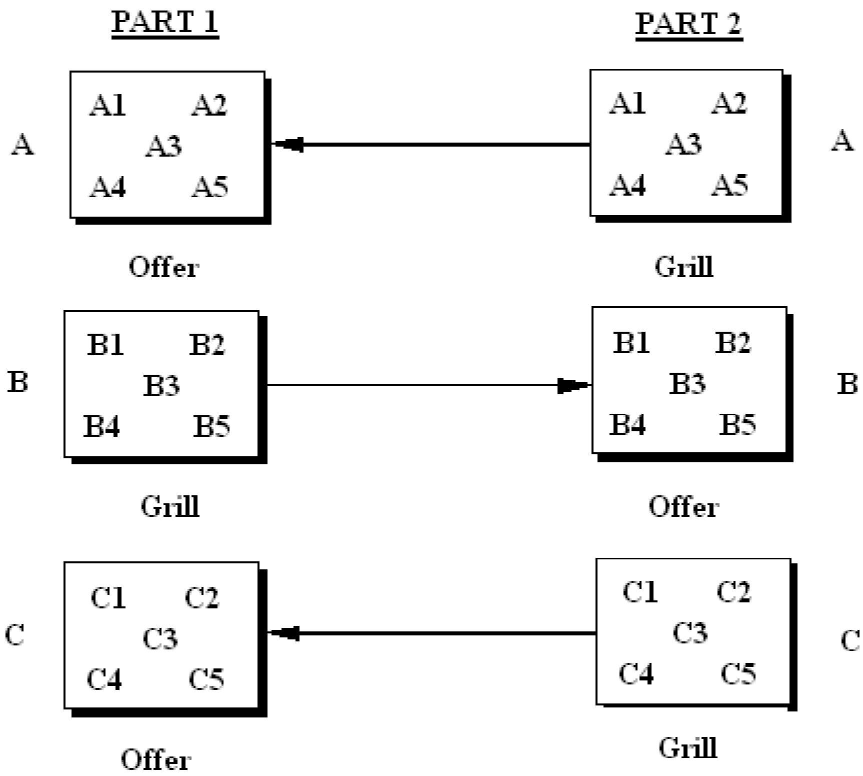

Figure 3. *Forming of grill and offer groups from parts I and II.*

In-class discussion: 'students are organized into research groups', 'students get together in their groups for discussion', 'each group sets an inquiry topic within a given unit and makes a plan for investigation', 'during the discussion, group members use their science books to identify their own problems, questions, or issues and select a topic to study', and 'the teacher participates in the group discussion and the teacher's roles include encouraging students to select authentic topics that can be addressed in multiple ways'.

In out-of-class investigation: 'each student group carries out its investigation', 'the teacher helps students with their investigations', 'the teacher's roles include presenting sources of information, providing instruments for experiments, and assisting students with difficulties', and 'each research group prepares an in-class presentation'.

In-class presentation: Week II: group A in part 1 was the presentation (offer) group while group A in part 2 was the inquiry (grill) group. While group A in part 1 presented the chemical kinetics unit, group A in part 2 questioned the group about their presentation and determined their weaknesses. Other students in the classroom also participated in the discussion. Week III: group B in part 2 was the offer group while group B in part 1 was the grill group. While group B in part 2 presented the chemical kinetics unit, group B in part 1 questioned the group about their presentation and determined their weaknesses. Other students in the classroom also took part in the discussion. Week IV: group C in part 1 was the offer group while group C in part 2 was the grill group.

In the control group, the subjects were taught using the traditional teaching method. The researcher planned the presentation activities of the subjects that would be taught during the lesson in a report not by a classical teaching presentation but by giving assignments to students on the subjects of chemical kinetics, and by providing internet addresses and workbooks for constructing the information to be presented to them. The same content was taught in the cooperative groups and the learning objectives were the same. In contrast with the IG and JG, students in the control group were required to use their textbooks; students were passive participants and rarely asked questions. In the traditional learning method, generally the teacher wrote the concepts on the board and then explained them; students listened and took notes as the teacher lectured on the content. In this process, student's performances were observed and the studies were directed according to the feedback obtained from them. Chemical kinetics topics were taught by the authors to the treatment groups four hours per week for four weeks. Measurement tools were applied to the treatment groups at the end of the study.

d) Data Analysis

One-way analyses of covariance (ANCOVA) tests were used to analyze differences among the IG, JG, and CG with GST as a covariant. ANCOVA tests were formed for the ckAT. Post-hoc tests were used to determine how the groups differed. Furthermore, descriptive statistics related to total mean scores of GST and ckAT were analyzed for the groups.

FINDINGS and RESULTS

Descriptive statistics related to the total mean scores of GST and ckAT in the treatment groups are presented in Table 1. Mean scores of the groups range from 10.94 to 14.75, and from 113.47 to 156.00 for GST and ckAT, respectively.

Table 1. *Descriptive statistics for GST and ckAT*

Groups	Tests	N	Mean	Sd
JG	GST	40	14.75	3.036
	ckAT	40	156.00	20.293
IG	GST	30	11.00	3.363
	ckAT	30	149.33	20.709
CG	GST	36	10.94	3.162
	ckAT	36	113.47	24.078

Maximum scores for GST and ckAT were 24 and 220, respectively

Table 1 shows that the IG and JG students scored significantly higher in both GST and ckAT. One-way analyses of variance (ANOVA) tests were used to analyze differences among the JG, IG, and CG in terms of graphics skills. Data obtained from GST are given in Table 2.

Table 2. *ANOVA results for GST scores*

	Sum of Squares	df	Mean Square	F	p
Between Groups	355.970	2	177.985	17.672	.001
Within Groups	1037.389	103	10.072		
Total	1393.358	105			

The results of ANOVA analysis in Table 2 show statistically significant differences between the GST scores of the students in JG, IG, and CG [$F_{(2,103)}$= 17.672; $p <.05$)]. This finding supports the assumption that the groups should be considered nonequivalent. The GST results showed differences among the treatment groups in this study (Table 2).

Students' academic achievement in chemical kinetics topics was measured by ckAT. This test was performed after the completion of the chemical kinetics topics. To investigate the effect of the jigsaw technique, group investigation, and traditional teaching method on students' achievements, analysis of covariance (ANCOVA) of ckAT scores was performed. Before choosing the covariate variables for ckAT, we investigated the relationships among the students' GST and ckAT scores using Pearson correlations. Because of a statistically significant correlation between GST and ckAT scores ($r = 0.46$, $p < 0.01$), the GST scores were chosen as the covariant for ckAT score analysis. The analysis of covariance of ckAT is presented in Table 3.

Table 3. *ANCOVA result for ckAT scores with GST scores as covariate*

Source	Sum of Squares	df	Mean Square	F	Sig.
GST scores	6426.170	1	6426.170	15.473	.001
Groups	26052.754	2	13026.377	31.366	.001
Error	42361.469	102	415.309		
Total	2154775.000	106			

a R Squared = .513 (Adjusted R Squared = .499)

According to the data given in Table 3, the ANCOVA results show significant differences in the ckAT score with treatment even when the effects of the GST score are removed [$F_{(2,\ 102)}$= 31.366; p <.05)]. Multivariate analysis (post-hoc test) was used to determine where differences existed. The Bonferroni post-hoc test was chosen because it is robust to unequal cell sizes.

According to the multiple comparisons with the Bonferroni test, CG had ckAT scores significantly different from those of JG and IG. The scores of the two experimental groups (JG and IG) did not differ significantly. However, adjusted mean scores of the IG were higher than those of JG (Figure 4). R squared refers to the multiple correlation coefficient, squared and adjusted for number of independent variables, N, and effect size, and indicates how much variance or variability in the dependent variable can be predicted. An R squared of .10, .36, and .51 denotes small, medium, and large effect sizes, respectively (Cohen, 1988; Leech, Barrett, & Morgan, 2005). The effect size was large (R squared = .513). Students' chemical kinetics achievement on the ckAT was related to the type of group (CG or JG and IG) . One possible explanation might be that, with the simple students' chemical kinetics achievement that was depicted in this study, the maximum effect was achieved with both the jigsaw technique and the group investigation technique (Figure 4).

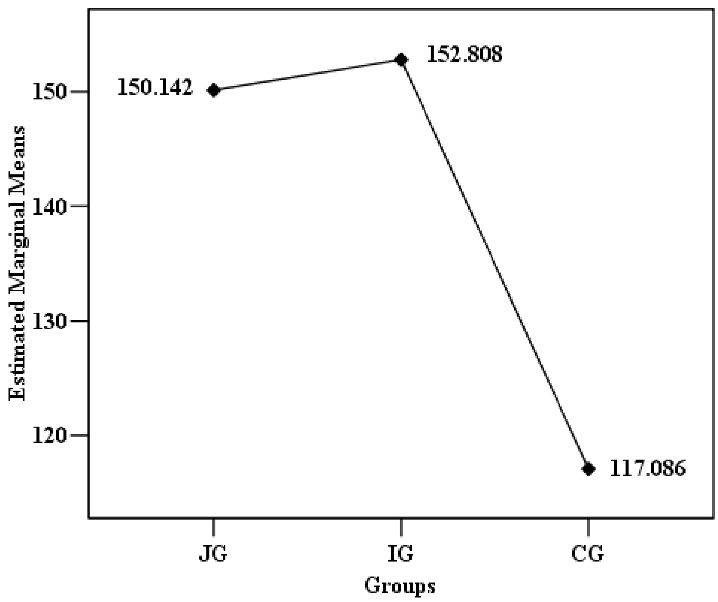

Figure 4. *Estimated marginal means of ckAT scores*

CONCLUSIONS and DISCUSSION

When the results obtained from the GST are analyzed, it is seen that JG students are more successful in reading and interpreting graphs than IG and CG students. It is seen that JG, which is successful in GST, has the same academic achievement in chemical kinetics as well (Table 1). To help students to be successful in the topics of chemical kinetics, they should be supplied with the skills of reading and interpreting graphs before they are taught the chemistry subjects. When the GST scores were co-variated, the results of the covariance analysis of ckAT scores showed that the impact of the teaching techniques on academic achievement was significant (Table 3).

Based on these results, it was concluded that, compared to the traditional teaching method, group investigation and jigsaw technique were more effective in increasing academic achievement (Table 1). In the study, the reason that the group investigation and jigsaw techniques were more effective than the traditional teaching method can be attributed to differences in the application processes of these techniques and to the fact that students are directed and encouraged to express their ideas in a warm atmosphere, to convey their ideas, and to cooperate with their friends.

In this study, the findings that group investigation has stronger effects on academic achievement than the traditional learning method are in line with the results of the studies by Zingaro (2008), Abordo and Gaikwad (2005), and Shackar and Fischer (2004). The results obtained from the groups with which another teaching method, the jigsaw method, was applied are in parallel with those reported by Doymuş (2007), Doymuş (2008a), Lai and Wu (2006), Gillies (2006), Hennessy and Evans (2006), and Eilks (2005).

Finally, the following points should be taken into consideration when teaching the units of chemical kinetics: 1) Student-centered teaching should be implemented in the presence of an expert, 2) Before the topics are taught, the students' ability to read and interpret graphs should be sufficient.

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