Education Tech Research Dev (2010) 58:671–691
DOI 10.1007/s11423-010-9157-2

RESEARCH PAPER

Effects of jigsaw and animation techniques on students' understanding of concepts and subjects in electrochemistry

Kemal Doymus · Ataman Karacop · Umit Simsek

Abstract This study investigated the effect of jigsaw cooperative learning and animation versus traditional teaching methods on students' understanding of electrochemistry in a first-year general chemistry course. This study was carried out in three different classes in the department of primary science education during the 2007–2008 academic year. The first class was randomly assigned as the jigsaw group, the second as the animation group, and the third as the control group. Students participating in the jigsaw group were divided into five "home groups" since the topic electrochemistry is divided into five subtopics. Each of these home groups contained four students. The groups were as follows: (1) Home Group A (HGA), representing the fundamental concepts of electrochemistry, (2) Home Group B (HGB), representing the electrochemical cell and energy source, (3) Home Group C (HGC), representing electrolysis, (4) Home Group D (HGD), representing Faraday's laws, and (5) Home Group E (HGE), representing corrosion. The home groups broke apart, like pieces of a jigsaw puzzle, and the students moved into jigsaw groups consisting of members from the other home groups, who were each assigned a subtopic. For students in the animation group, their lesson focused on explaining the step-by-step process of electrochemistry through a computer-animated presentation. The main data collection tools were the Test of Scientific Reasoning and the Particulate Nature of Matter Evaluation Test. The results indicated that the jigsaw and animation groups achieved better results than the control group.

Keywords Electrochemistry · Jigsaw technique · Animation technique

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An understanding of chemical processes such as melting, evaporating, dissolving, diffusion, electrochemical cells, electron transfer, ion conduction, and intermolecular bonding is fundamental to learning general chemistry (Ebenezer 2001). Electrochemistry has been regarded as one of the most difficult subjects to learn by both students and teachers (Finley et al. 1982). Secondary school students find that electrochemical cells and electrolytic cells are very difficult to understand since these topics involve concepts about electricity and oxidation–reduction, both of which are very challenging (Lin et al. 2002). Chemists use particle models to account for these abstract constructs. However, students find it difficult to visualize chemists' conceptual models (Abraham et al. 1992; Ben-Zvi et al. 1987; Ebenezer and Erickson 1996; Garnett and Treagust 1992; Harrison and Treagust 2002; Lijnse et al. 1990; Novick and Nussbaum 1981; Othman et al. 2008). Dynamic chemistry processes such as gas phase equilibrium, collisions of molecules, and electrochemistry are visually represented in textbooks by static diagrams (Burke et al. 1998). Only a handful of studies report instructional strategies and techniques, or uses of technology that might prove successful in the remediation of misunderstandings of electrochemistry concepts (Sanger 1996). Because students often have difficulty visualizing, understanding, and remembering how dynamic chemical processes occur, the use of computers to display dynamic motion can help students understand complex chemistry concepts (Rotbain et al. 2008; Sanger and Greenbowe 1997; Williamson and Abraham 1995). In order to teach chemistry much more effectively new teaching methods are necessary.

These methods, known as active learning methods, have demonstrated that (compared to teacher-centered lecturing), using a more hands-on approach, animation techniques, jigsaw technique, inquiry-based learning, project-based learning, and problem-based learning increase student's knowledge and conceptual understanding. Recently, among these methods animation and subjects-jigsaw cooperative learning have attracted the attention of teachers, school managers, and educational researchers (Ballantine and Larres 2007; Baumberger-Henry 2005; Doymus 2007; Ebenezer 2001; Siegel 2005; Talib et al. 2005).

Animation is a useful technique for teaching chemistry, general science, physics, and biology concepts or improving conceptual understanding (Ebenezer 2001; Kim et al. 2007; Sanger et al. 2000; Wang et al. 2007).

Large (1996) argues that animations can be a supplement to written information, but cannot replace it. Motion is the special quality of animations that can help promote learning of dynamic processes (Large 1996). Since chemical processes at the molecular level are dynamic, impossible to see, and typically quite hard to imagine, animations could be a powerful tool in chemistry education. Atoms, molecules, and ions are not static, but vibrate, move, collide, and interact with each other. These dynamic processes are better represented in an animation than in static pictures. Molecular-level animations have been proposed as a way to support student understanding in chemistry (Burke et al. 1998). The rationale is that animations make visible otherwise abstract chemical concepts, especially those related to the particulate nature of matter. Chemistry explains many processes from the real world with the abstract concepts of atoms, molecules, and ions. The size of atoms, molecules, and ions is typically several nanometers, and so the world of these particles is sometimes called the nanoscopic world (Schank and Kozma 2002; Vermaat et al. 2003). Other names are the molecular world, submicroscopic world (Ebenezer 2001), and particle world (Bunce and Gabel 2002). The name microscopic world (Sanger and Greenbowe 2000; Wu et al. 2001) suggests that the particles can be seen through a microscope (Greca and Moreira 2000; Kozma and Russell 1997; Seel 2003).

Instructional animations can be constructed so that dynamic visual images communicate abstract ideas, concepts, and processes to students. A conceptual animation should be designed to provide a visualization of a specific chemical process (Appling and Peake 2004; Ardac and Akaygun 2004; Burke et al. 1998). The animation can be at the atomic or molecular level of representation, thereby helping students gain a better understanding of the concept of the particulate nature of matter (Noh and Scharmann 1997; Rotbain et al. 2008; Yezierski and Birk 2006). Representing a chemical event correctly is the first step toward successful problem solving, and representation is an important aspect of conceptual understanding (Burke et al. 1998; Liu 2006).

In addition, consistent with Paivio's dual coding theory of learning from animation, the animations in the present study were best when paired with appropriate verbal support (class discussion) because of the increase in both representational and referential encoding. Therefore, these instructional uses of animation could be described as "learning-by-viewing" approaches (Schank and Kozma 2002). Animation, with accompanying text or narration, offers many opportunities for presenting or elaborating facts, concepts, and principles.

Social constructivist perspectives on student learning point to the critical role of interactions between peers and whole-class discussions in student meaning-making (Wu 2003). Those oral interactions in the classroom not only made students' ideas explicit but also created for them an environment to question and justify their own ideas as well as compare and contrast their ideas to other students' ideas. These interactions eventually allowed students to integrate those ideas into their explanatory framework (Adadan 2006). Peer-to-peer and whole class discussions are utilized to help students discuss and critique their models and understand scientific concepts (Merritt et al. 2007).

Sanger et al. (2000) suggest that the ease of replaying the animations allows students to focus their attention on different aspects of the animation each time it is viewed. Therefore, students were allowed to replay the animations again and again, because some of them were short, lasting just a few seconds. According to the National Science Foundation (NSF) (2001), two factors are important for the effective use of computer animations. One of them is to make the animations interactive and the other is to increase active student involvement in learning. The animations selected were interactive and the students were allowed to replay them. The animations have the options of repetition, pause, and play, which make the comprehension of the phenomenon or the conception that they describe easier.

Animation models are typically simplified, showing only the most important aspects of the phenomenon being modeled while leaving out distracting properties, such as molecular vibrations in solids. Animation models can be viewed by students at the computer terminal, in their own time, and as many times as desired, or in the classroom by projection (Dasdemir et al. 2008; Gilbert 2005; Theall 2003). When learning with molecular level representations, students construct mental models based on their observations that are personal, qualitative, and often incomplete, because they often do not understand the underlying concepts that the model represents (Greca and Moreira 2000; Kelly and Jones 2007). It is probable that students develop a concept from a model that is slightly different from what was intended (Greca and Moreira 2000) because visualization tools, even when presented in two dimensions, must be understood in three dimensions.

Students must learn to navigate model types to solve problems like chemists do (Barnea and Dori 1996). Studies show that students using a combination of model types representing the same concept have a better understanding of molecular level chemistry (Doymus et al. 2009; Wu et al. 2001). Sanger and Badger (2001) found that students who viewed electron plots and animations as a supplement to the traditional wooden molecular model kits and demonstrations to learn about molecular polarity and miscibility responded correctly more often on hourly exams than did students who did not view the electron plots and animations. Furthermore, several chemical education researchers have demonstrated that computer animations can help students think about chemical processes on the molecular level (Chang and Quintana 2006; Kelly et al. 2004; Williamson and Abraham 1995; Wu and Shah 2004).

Many jigsaw cooperative learning techniques make use of the principles of cooperative learning for specific purposes. These techniques can be categorized into the following models: (a) Jigsaw, developed by Aronson et al. (1978); (b) Jigsaw II, developed by Slavin (1986); (c) Jigsaw III, developed by Stahl (1994); (d) Jigsaw IV, developed by Holliday (1995); (e) Reverse Jigsaw, developed by Hedeen (2003), and (f) Subjects Jigsaw, developed by Doymus (2007).

The basic parts of the strategies are the same. In all the students are divided into groups and then into teams. The teacher gives questions for the students to answer. The students leave their group and go to their team to answer the expert sheets or questions. They then return to their group with their expert sheets (Avsar and Alkis 2007; Ghaith and El-Malak 2004; Souvignier and Kronenberger 2007) answered and pass each other their respective expert sheets. Then they are tested on the material. Different iterations of the jigsaw build in specific steps to evaluate the group mastery of the material. Jigsaw and Jigsaw II differ only in the fact that team competition is allowed in Jigsaw II. In Jigsaw II the grades are averaged and the team with the best average score is rewarded (Slavin 1995). Jigsaw II adds the element of competition among groups for reward based on test score improvement by group members, while Jigsaw III has been designed specifically to increase interaction among students of differing language proficiencies in bilingual classrooms. Jigsaw IV builds on II and III by incorporating quizzes during the process to assess which areas of the curriculum have been well understood by students and which require additional teaching by the instructor. The Reverse Jigsaw shares a complicated relationship with the original Jigsaw. While it closely resembles the original Jigsaw in the some ways, the Reverse Jigsaw is designed to accomplish a very different set of goals. Where the Jigsaw is meant to achieve student comprehension of the instructor's material, the Reverse Jigsaw is meant to facilitate understanding of the range of participant interpretations on a number of topics through a highly participatory structure (Hedeen 2003). In this research, we used the Subjects Jigsaw developed by Doymus in 2007. The main difference between this jigsaw and the others is that both subjects and students are jigsawed in the Subjects Jigsaw. This jigsaw practice involves three steps. In the first step, the unit of the lesson that will be taught in the classroom is separated into subjects. Then every subject is assigned to home groups, which consist of 2–6 persons. Every group investigates the assigned subjects, learns the subjects, completes the assignment, and makes presentations.

In the second step, two or more subjects are brought together and second subject groups are formed. Every second subject groups consists of half the number of students in the first subject groups. Every group formed investigates its own assigned subjects, learns the subjects, completes the preparations, and makes presentations. In the third step, unit groups are formed by selecting students from the second groups. Every unit groups completes the preparations and make a final presentation for the whole unit (Doymus 2007). In this study, if there is not enough time then the groups formed in the second step complete their work outside the classroom. In the first and third steps, work is done both in and outside the classroom environment (during lesson hours).

To improve students' comprehension of chemistry topics at the molecular (particulate) level, researchers have implemented such teaching pedagogies as inquiry-based learning, cooperative learning, discrepant events, (social) constructivism, analogies, concrete models, and visual tools/multiple representations. In recent years, using visual tools such as static or computer animated molecular models accompanied by oral and written discourse has gained prominence and has been acknowledged to be promising in the construction of scientific conceptions (Adadan 2006). Furthermore, cooperative learning has become an important alternative to the standard education strategies used in high schools and universities (Siegel 2005). The reason for its popularity is the fact that it gives students the chance to learn from each other's different approaches and decisions by cooperating according to the strategies and problem-solving techniques that are used (Bearison et al. 1986). Chemistry education researchers have suggested that as a facilitating tool the methods and techniques above mentioned should be used in future research. On the basis of this suggestion, in the present study, jigsaw and animation techniques versus traditional teaching were selected to compare their effectiveness on students' molecular level understanding of electrochemical concepts.

The main aim of this study was to examine the impact of the Subject Jigsaw and animation technique on the teaching and students' understanding of the subjects of electrochemistry, a difficult part of the general chemistry course.

Method

Sample

This study included 122 first-year undergraduate students from three classes of a general chemistry course taught by the researcher (second author) in a faculty of education in a university in the 2007–2008 academic year. One of the classes was defined as the Jigsaw Group ((JG) (n = 40)), in which cooperative learning (Subjects jigsaw technique) was applied; the second was defined as the Animation Group ((AG) (n = 42)), in which computer animation technique was applied; and the third was the Control Group ((CG) (n = 40)), in which traditional teaching was applied. The experimental groups were selected randomly. In Turkey, there is a centralized university entrance exam system, which is highly competitive. Each year almost two million students take this exam and only 10% of them can gain a place in a university. The minimum and maximum marks to enter all universities in Turkey are 200.4 and 391.2, respectively. Students' minimum and maximum marks in this study are 272.6 and 289.1, respectively. As seen from this range of marks the students that participated in this study can be assumed to be of similar academic level. Once the teaching of the subjects of electrochemistry was completed, which lasted 5 weeks, the Particulate Nature of Matter Evaluation Test (PNMET) was taken by the groups.

Instruments

Two instruments, the Test of Scientific Reasoning (TOSR), published previously (Yezierski 2003), and the Particulate Nature of Matter Evaluation Test (PNMET), developed for the present study, were used to collect data. Students in the experimental groups answered the TOSR and PNMET pre-test 2 weeks before the intervention. Once the teaching of the subjects of electrochemistry was completed, which lasted 5 weeks, the PNMET post-test was taken by the experimental groups.

The Test of Scientific Reasoning (TOSR), developed by Yezierski (2003), was used to determine the formal scientific reasoning ability of students. This test gives continuous scale scores ranging from 0 to 12. The internal reliability for this test is reported as 0.78 (Yezierski 2003). Yezierski reported a strong correlation of 0.80 between scores on the TOSR and formal reasoning skills, which are controlling variables, proportional reasoning, combinatorial reasoning, probabilistic reasoning, and correlation reasoning. The TOSR was translated into Turkish for this research. The appropriateness of the questions in Turkish in terms of their expressions and meanings was analyzed by two instructors at the Turkish Language Teaching Department of an Education Faculty and the suggested corrections were made by the researcher. The consistency between the adapted and original versions was checked by two instructors at the language center of a university as well and the necessary revisions were made. The TOSR used in this study contained 12 items designed to assess students' use of a particular reasoning skill. The internal reliability for TOSR used this paper was 0.75. This test gives continuous scale scores ranging from 0 to 12.

The PNMET was designed to determine understanding of the concepts relevant to the electrochemistry unit. This is an instrument requiring the students to make drawings at molecular level, give explanations, and answer multiple-choice questions. The categories of responses for the PNMET were established by a panel of experts. Responses given in terms of molecules, atoms, ions, and so on are classified as showing scientific (at molecular level) understanding. Responses that repeat the question or are irrelevant or unclear are classified as showing no understanding. Student answers that are different from the acceptable scientific answers are classified as showing misunderstanding. The criteria and scale used in this study were developed by adapting the scale used for misconceptions by Haidar and Abraham (1991). Items of the PNMET are related to Electrode Potential and Their Measurement, Standard Electrode Potential, Electrolyte and Non-Electrolyte Solutions, E_{cell} and Spontaneous Change, Batteries, Corrosion, and Electrolysis. Moreover, to ensure the validity of the PNMET developed by researchers, opinions of chemistry lecturers and researchers on the subject were taken into consideration. Researchers have pointed out that the gains achieved with the PNMET related to the subjects of electrochemistry have been high concerning measurement. For statistical analysis, numeric scores of '1' were assigned to "satisfactory (scientific) understanding" responses and '0' to all other categories of responses. This test gives continuous scale scores ranging from 0 to 7.

Procedure

Students from both the experimental (AG and JG) and control groups studied the topic of electrochemistry during the same period of time in different ways (instructional methods). The same content was taught in all groups by the same teacher and the learning objectives were the same.

In the JG, 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.

The students in this part were divided into five "home groups" since the topic electrochemistry is divided into five subtopics:

These subjects and the home groups are as follows:

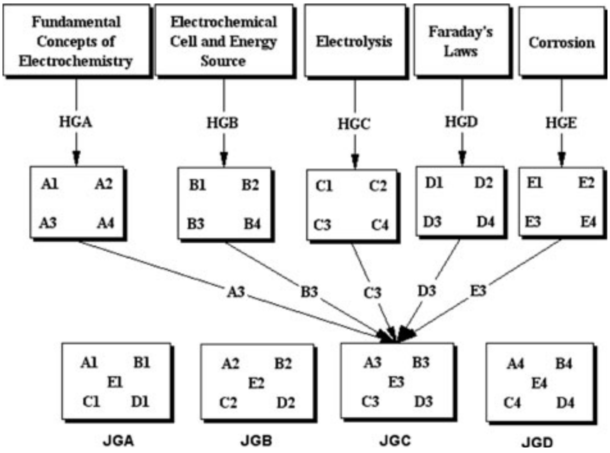

Fig. 1 Subtopics of the electrochemistry unit and home groups representing (A1, A2, A3 etc. Represents an individual student from a group) and forming of Jigsaw groups from home groups

Home Group A (HGA): Representing the fundamental concepts of electrochemistry. The students in HGA prepared and presented the subjects ‘anode’, ‘cathode’, ‘electrolyte’, ‘metallic conduction’, ‘electrolytic conduction’, and ‘salt bridge’.

Home Group B (HGB): Representing the electrochemical cell and energy source. The students in HGB prepared and the subjects ‘electrolysis versus galvanic cell: differences?’, ‘set up and operation of an electrolytic cell’, ‘anode and cathode half-reactions in an electrolytic cell’, and ‘set up and operation of a galvanic cell, cell diagrams, wet and dry cell batteries’.

Home Group C (HGC): Representing electrolysis. The students in HGC prepared and presented the subjects ‘electrolysis of aqueous solutions—the possible oxidation/reduction of H_2O’, ‘electroplating’, and ‘quantifying electrolysis using time, current, and moles electrons transferred’.

Home Group D (HGD): Representing Faraday’s laws. The students in HGD prepared and presented the following subjects to the class: ‘anode and cathode half-reactions in a galvanic cell’, ‘electromotive force and the volt’, ‘reduction (or oxidation) potentials (E^*) and cell potentials (E^*_{cell})’, and ‘using reduction/oxidation potentials to determine which substances are more easily reduced or oxidized and which are better reducing/oxidizing agents, using the Nernst equation to determine the effect of nonstandard concentrations on cell potentials’.

Home Group E (HGE): Representing corrosion. The students in HGE prepared and presented the following subject to the class: ‘corrosion of metals and its prevention’.

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.

Then the students in the home groups, following the presentation of all subtopics in the electrochemistry unit, formed jigsaw groups containing JGA, JGB, JGC, and JGD, with one student from each of the home groups (see Fig. 1). These jigsaw groups represent the electrochemistry unit. 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 the electrochemistry

Table 1 Electrochemistry subtopics and animations used

Electrochemistry topics	Animations used
Electrochemistry cells	Reducing agent
	Oxidizing agent
	Zn/Cu cells and salt bridge
	Voltaic cells
	Galvanic cells
Electrochemistry energy source	Leclanche cells
	H_2–O_2 fuel cells and lead battery
Electrolysis and Faraday's laws	Electrolysis and electrolytic processes
Corrosion	Corrosion of iron
	Corrosion prevention and plating

unit to the rest of the class. Each student in the jigsaw group presented their own topic to the class for 20 min, and then discussed the related topics for 5 min.

In the AG, the students used animation. Their lesson focused on explaining the step-by-step process of electrochemistry through a computer-animated presentation. The computer animations used in the animation group were obtained from various web addresses. These animations were shown after arrangement by an expert from the department of computer and teaching technologies. Four main categories of animations (Table 1) were used in lectures during the coverage of the unit on electrochemistry.

The computer animations used in the first category depict the electrochemical processes occurring in a copper–zinc galvanic cell at the microscopic level and focus on the chemical half-reactions occurring at each metal electrode and the transfer of ions from the salt bridge to the two half-cell compartments. Four print-screen views of the chemical half-reactions occurring at the copper electrode are given in Fig. 2 as an example.

In the second category animations, processes occurring in PEM (Proton Exchange Membrane) fuel cells, car batteries, and dry cells are shown step by step. For example, these animations illustrated the processes occurring in a hydrogen fuel cell at the microscopic level and focused on the hydrogen's split into positive hydrogen ions (proton) and negatively charged electrons occurring at the anode, the transfer of positively charged ions (proton) from the PEM to the cathode, and negatively charged electrons and positively charged hydrogen ions combining with oxygen to form water, which flows out of the cell at the cathode.

In the third category, the animations illustrating the subject of electrolysis including the accumulation of substance (material electroplating) on metal surfaces as color changes were used. Moreover, animations illustrating electrolysis of copper chloride, sodium chloride, water (acidified), sodium bromide, lead bromide, potassium hydroxide, and silver nitrate and formation of bubbles, coating, and colored and colorless gas as products at the anode and cathode were used.

In the fourth category of animations, processes occurring during the corrosion of iron and its prevention are shown step by step, and these are dynamic animations in which students are able to see that iron is attacked by H^+ to form H_2 and Fe(II); the latter then reacts with O_2 to form the various colored Fe(III) oxides that constitute "rust". In addition, animations illustrating the control of corrosion processes by coating the object with paint or other protective coatings were used.

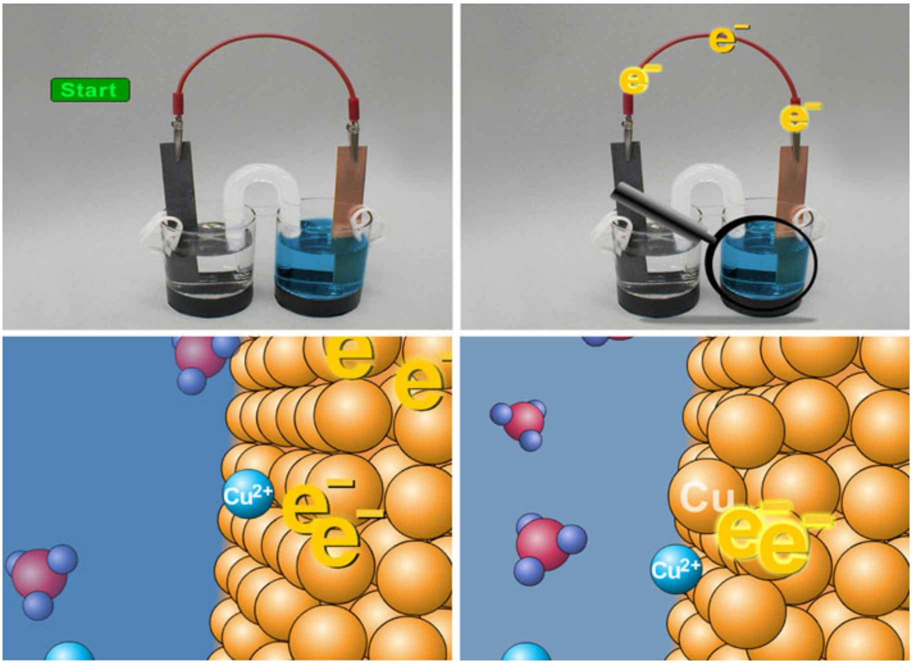

Fig. 2 Example of relative animation categories

Then the researcher spent the first 5 min of the lesson asking questions to the class, in order to determine the students' previous knowledge on the subject. Later, the subject was taught and the related animations were shown to the class for 35 min. The animations were shown by projecting them on a white board, using a computer compatible with the projection device. After the presentation of the animations, questions related to the subject were asked for 10 min. Parts of the subjects not fully understood were determined according to the answers and these parts were covered again using the animations related to the subject. For each step, the students were engaged in a class discussion and animation sequences over a course hour.

In the CG, the students were taught by a teacher-centered approach (traditional teaching method) involving the teacher's explanations of the concepts related to electrochemistry using the textbook for examples and illustrations in 'talk-and-chalk' type lessons. About 75–80% of the class hour covered the teacher's explanations related to electrochemistry. Some concepts were discussed after the teacher's explanation. 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. The teacher passed out the problem solving exercises including mathematical and conceptual questions related to electrochemistry to students. While the students were solving the problems requiring written responses, the teacher walked around the classroom and helped them when necessary. The students had the opportunity to ask questions during this process. Such a teaching approach used in the CG generally required students to sit passively and did not engage the students very actively in learning; sometimes they raised their hands to answer questions. The students became listeners, the teacher gave out the facts and defined important ideas, and the students' participation was often limited to listening to the teacher.

During this process, the students' performances were observed and the studies were directed according to the feedback received from them. Once the teaching of the subjects of electrochemistry was completed, which lasted 5 weeks, the PNMET was taken by the groups.

Analysis of the data

The equivalence of the research groups at the pre-test were compared by the use of one-way ANOVA of the scores obtained from the TOSR. For the PNMET, the students' written answers were analyzed and their levels of understanding of electrochemical subjects at molecular level were determined. In the evaluation of the PNMET pre-test, only the satisfactory (scientific) answers related to understanding at molecular level were taken into consideration. Other answers were disregarded. From the answers related to understanding at molecular level the PNMET pre-test scores were obtained. One-way ANOVA was performed to determine whether there were significant differences between the research groups according to the PNMET pre-test scores before the study. The answers from the PNMET post-test were evaluated under three categories: (1) scientific (at molecular level) understanding (SU); answers including a part or the whole of scientific opinions related to the question, (2) misunderstanding (MU); student answers that are different from the acceptable scientific answers, (3) no understanding (NU); this covers the answers that are only slightly related to the question and those completely or partly repeating the questions, non-scientific answers, and the ones left unanswered (Abraham et al. 1992; Ayas and Ozmen 2002).

Giving "1" point for each question in the category of SU in molecular level, PNMET scores were obtained. PNMET post-test scores were analyzed through one-way analysis of covariance (ANCOVA) by taking PNMET pre-test and TOSR scores as covariates.

In the analyses of MU and NU categories, drawings by students with non-scientific features were verbally grouped at question level individually in the first phase by the researcher. In the second phase, groups of answers from each student were compared and their consistency was measured. In the case of inconsistent answers, the original answer paper was analyzed and a common categorization was carried out. The percentage values of the NU category obtained from the PNMET post-test and related to the expressions obtained from the drawings in the MU category, and samples from student drawings were given.

Results

In order to determine whether there was a significant difference between the groups before the study according to the scores obtained from the PNMET pre-test and TOSR, one-way ANOVA was applied and the results are presented in Table 2.

The results of the ANOVA analysis in Table 2 show no significant difference between TOSR scores of the students in the Jigsaw Group (JG), Animation Group (AG), and Control Group (CG) ($F_{(2,117)} = 1.786$; $p > 0.05$). However, a significant difference was found between the mean PNMET scores ($F_{(2,113)} = 14.336$; $p < 0.05$). LSD, a post hoc test, was applied in order to determine in which groups there was such a difference. As a result of the LSD analysis, PNMET scores of the AG were observed to be higher than those of both the JG and CG ($X_{AG} = 1.47$; $X_{JG} = 0.75$; $X_{CG} = 0.51$). According to the results of the ANOVA analysis in Table 2, the students involved in the research had similar

Table 2 ANOVA results for PNMET pre-test and TOSR scores

Dependent variable	Source	Sum of squares	df	Mean square	F	*p*
TOSR	Between groups	10.684	2	5.342	1.786	0.172
	Within groups	349.982	117	2.991		
	Total	360.667	119			
PNMET	Between groups	19.887	2	9.943	15.043	0.001
	Within groups	74.691	113	0.661		
	Total	94.578	115			

characteristics in terms of scientific reasoning abilities, whereas they had different levels of understanding of electrochemical issues at molecular level.

Findings relating to the scientific understanding (su) category

Before testing whether there was a statistically significant difference between the groups according to the post-test score averages of the PNMET, the correlation between PNMET pre-test scores, TOSR scores, and PNMET post-test scores was taken into consideration. Pearson correlation analysis indicated that the correlation between the PNMET pre-test scores and post-test scores of the students was not significant ($r_{(119)} = 0.05, p > 0.05$). The descriptive statistics of data obtained from the PNMET pre-test and post-test of the experimental groups are given in Table 3.

Table 3 shows the mean scores and standard deviations for the CG, JG, and AG on measures of the PNMET pre-test and post-test. According to these data, mean scores of the groups range from 0.51 to 1.47, and from 0.81 to 4.19 for the pre-test and post-test, respectively.

One-way ANCOVA on the PNMET post-test scores with PNMET pre-test and TOSR scores as the covariates was conducted, and the findings obtained are presented in Table 4.

The results in Table 4 show a significant difference among the adjusted mean scores of the PNMET post-test of the students in the experimental groups ($F_{(2,110)} = 43.322$; $p < 0.05$; partial eta squared (η_p^2) = 0.441). According to the results of the Bonferroni test, which was applied in order to determine between which groups there was a difference, the AG showed a better understanding of molecular level than both the JG and CG. In addition, the JG was more successful than the CG ($X_{AG} = 4.126$; $X_{JG} = 2.881$; $X_{CG} = 0.865$). Adjusted R^2 refers to the multiple correlation coefficients, squared and adjusted for number of independent variables, N, and effect size. R^2 indicates how much variance or variability

Table 3 Descriptive statistics for PNMET pre- and post-test scores

Variable	Group	N	Mean	SD
PNMET pre-test	CG	37	0.51	0.731
	JG	36	0.75	0.806
	AG	42	1.47	0.882
PNMET post-test	CG	37	0.81	0.845
	JG	36	2.75	1.645
	AG	42	4.19	1.534

Table 4 ANCOVA results for PNMET post-test scores

Source	Type III sum of squares	df	Mean square	F	p	η_p^2
Corrected model	230.984[a]	4	57.746	29.172	0.001	0.515
Intercept	51.441	1	51.441	25.987	0.001	0.191
PNMET pre-test	2.412	1	2.412	1.218	0.272	0.011
TOSR	2.179	1	2.179	1.101	0.296	0.010
Groups	171.514	2	85.757	43.322	0.001	0.441
Error	217.746	110	1.980			
Total	1279.000	115				
Corrected total	448.730	114				

[a] $R^2 = 0.515$ (Adjusted $R^2 = 0.497$)

in the dependent variable can be predicted. R^2 values are calculated by dividing the SS (sum of squares) for the model by the SS of the total. An R^2 of 0.10, 0.36, and 0.51 denotes small, medium, and large effect sizes, respectively (Cohen 1988; Leech et al. 2005). The effect size was large in our study ($R^2 = 0.515$).

Findings relating to the no-understanding category

The answers given by the students in the experimental groups to PNMET tasks including molecular level drawings in the no-understanding category are listed as percentages in Table 5.

Table 5 shows that all of the answers given by 22–84% of the students in the CG, 10–43% of the students in the JG, and 0–29% of the students in the AG to the PNMET tasks including molecular level drawings were in the "no-understanding category".

The answers given by the students in the JG and CG for the no-understanding category were higher when compared to the AG. In addition, the answers given by the students in the CG were higher when compared to the JG.

A high proportion of answers given by students in CG were in the no-understanding category. This might have led to lower proportions in the categories SU and MU at molecular level in comparison with the JG and AG.

Findings relating to the misunderstanding (mu) category

The answers given by the students in the experimental groups showing misunderstanding of the tasks on the PNMET post-test, including molecular level drawings except scientific

Table 5 Percentages for values related to the no-understanding category of the experimental groups for each task

Groups	Task questions					
	Q1	Q2	Q3	Q4	Q5	Q6
CG	22	46	84	81	49	41
JG	10	35	33	33	23	43
AG	0	29	5	14	5	10

Table 6 The percentages of written expressions obtained from students' drawings related to the MU category of task 1 on the PNMET

Written expressions obtained from the incorrect drawings by students	CG	JG	AG
Students' drawings show that $Zn(NO_3)_2$ dissolves in water by being surrounded by Zn^{2+} and NO_3^- ions with only O ends of water molecules (Fig. 3a)	19	18	22
Students' drawings show that $Zn(NO_3)_2$ does not dissolve in water (Fig. 3b)	32	20	12
Students' drawings show that $Zn(NO_3)_2$ dissolves in water by being not surrounded by Zn^{2+} and NO_3^- ions with O and H ends of water molecules (Fig. 3c)	27	30	21

Note: percentages were calculated on the basis of the number of students in each group

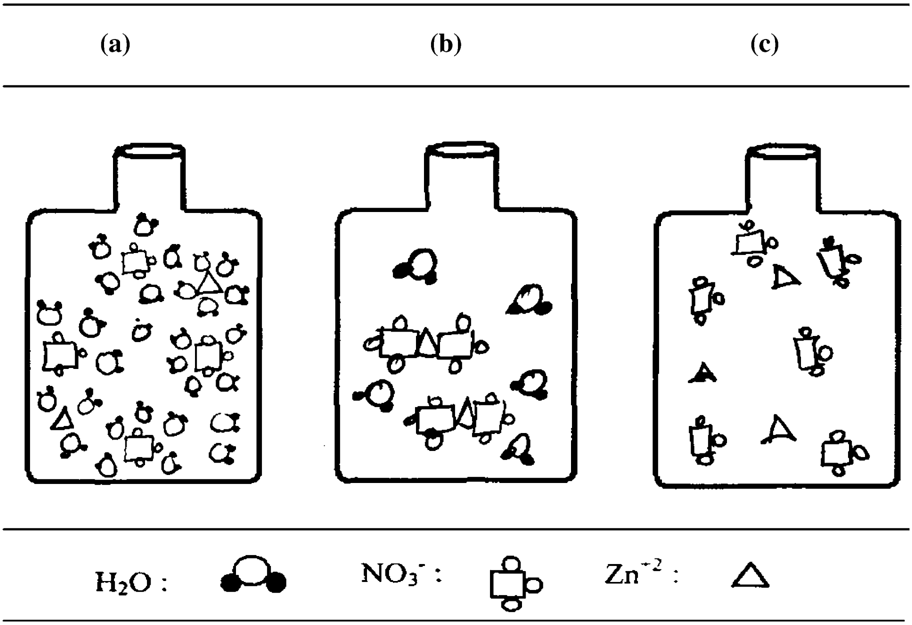

Fig. 3 Some students' drawings in the misunderstanding category of task 1 on the PNMET

ones (which are categorized in the MU part) and some of the samples of these drawings are shown below. The written expressions obtained from the students' drawings for Task 1 on the PNMET and the percentages of these expressions are given in Table 6 and some drawings are given in Fig. 3.

In Table 6, 78% of the students in the CG, 68% of the students in the JG, and 55% of the students in the AG gave unscientific answers at the molecular level about the dissolving mechanism in water of $Zn(NO_3)_2$. The answers given to this question showed that the students in the experimental groups did not understand the interaction between the solvent and the solute in an ionic solution at the molecular level and that they misunderstood this topic.

Task 3 on the PNMET was given in order to determine whether the students understood the relations between ions on the salt bridge with given/released ions or electrons from the

Table 7 The percentages of written expressions obtained from students' drawings related to the MU category of task 3 on the PNMET

Written expressions obtained from the incorrect drawings by students	CG	JG	AG
Drawings presenting the transmission of Zn^{2+} ions into $CuSO_4$ solution and Cu^{2+} ions into $ZnSO_4$ solution through the salt bridge (Fig. 4a)	5	5	2
Drawings presenting the transmission of K^+ ions to anode division and NO_3^- ions to cathode division through the salt bridge (Fig. 4b)	0	10	10
Drawings showing that K^+ ions from the salt bridge formed the K_2SO_4 precipitate with SO_4^{2-}; and that NO_3^- ions formed the $Zn(NO_3)_2$ precipitate with Zn^{2+} and the $Cu(NO_3)_2$ precipitate with Cu^{2+} ions	5	5	7
Drawings showing that some students believed that electrons flow through the salt bridge	3	0	2

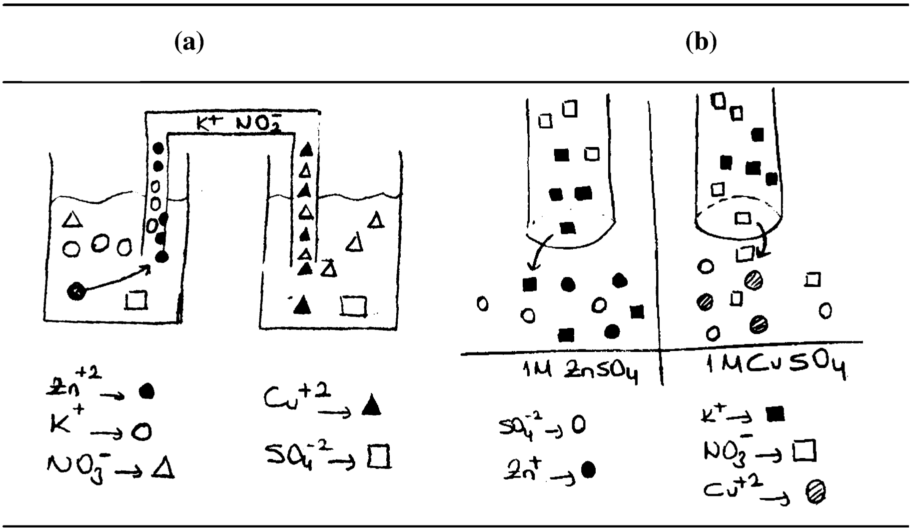

Fig. 4 Some students' drawings in the misunderstanding category of task 3 on the PNMET

anode (oxidation) and cathode (reduction) in electrochemical cells. The answers obtained from students' drawings for this task are categorized in Table 7 and some drawings are given in Fig. 4.

In Table 7, the percentages obtained in the MU category (and obtained from students' drawings related to the salt bridge containing KNO_3 in zinc-copper electrochemical cells and the particle movements between the anode and cathode parts) were 13% in the CG, 20% in the JG, and 21% in the AG. MU percentages about the function of the salt bridge in electrochemical cells were higher in the students in the AG and JG than they were in the students in the CG. The fact that the percentages were higher in the JG and AG does not mean that these two groups were unsuccessful as only a few of the students in the CG tried to answer this question with molecular level drawings while the great majority did not answer the question. As a result, mean scores of students in the CG in the MU category are lower. The students' drawings suggested that misunderstanding was greater in the JG and AG about the salt bridge at the molecular level.

Table 8 The percentages of written expressions obtained from students' drawings related to the MU category of task 5 on the PNMET

Written expressions obtained from the incorrect drawings by students	CG	JG	AG
Drawings showing Cu amounts collected in the partitioned Zn electrode bound to the negative end of the generator in electrolysis of the $Cu(NO_3)_2$ solution as III (Low) > II(Middle) > I(High) (Fig. 5a,b,c)	30	40	31
Drawings showing Cu amounts collected in the partitioned Zn electrode bound to the negative end of the generator in electrolysis of the $Cu(NO_3)_2$ solution as III (Low) < II(Middle) < I(High) (Fig. 5d,e)	8	8	19

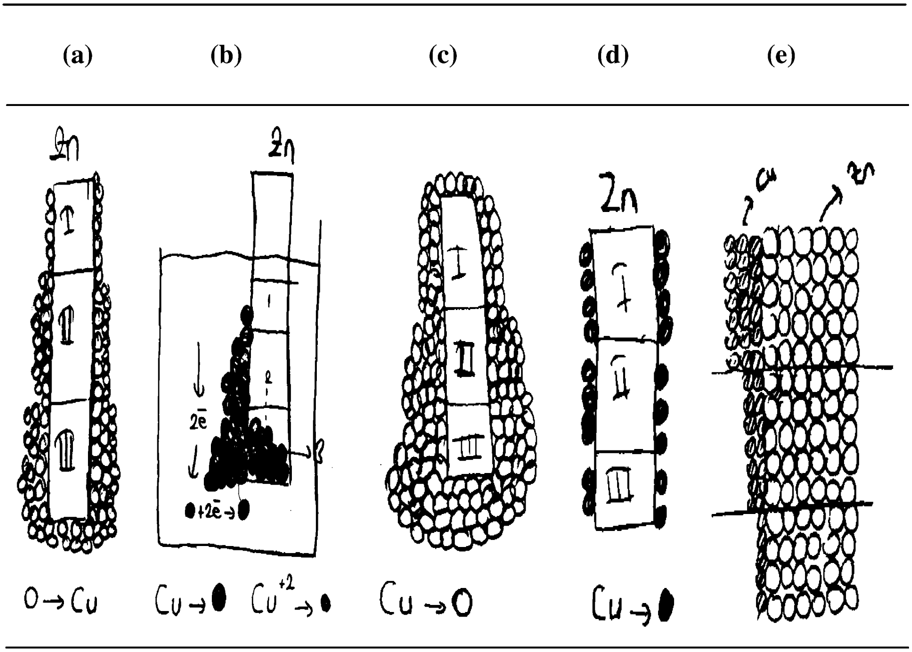

Fig. 5 Some students' drawings in the misunderstanding category of task 5 on the PNMET

Task 5 on the PNMET was related to the material collected from the Zn electrode (cathode) in the electrolysis of $Cu(NO_3)_2$ at molecular level. The answers obtained from students' drawings for this task are categorized in Table 8 and some drawings are given in Fig. 5.

As shown in Table 8, 38% of the CG students, 48% of the JG students, and 50% of the AG students misunderstood this topic as they assumed that the amount of sedimentary material on the electrode (which was divided into I (top), II (middle) and III (bottom) and which was connected to the negative end of the generator in the electrolysis of $Cu(NO_3)_2$) would change according to the position of the metal to be covered in the solution.

Task 6 on the PNMET was related to the material electroplating at molecular level on the Zn electrode in the electrolysis of $Ag(NO_3)$ solutions having different concentrations. The answers obtained from students' drawings for this task are categorized in Table 9 and some drawings are given in Fig. 6.

Table 9 The percentages of written expressions obtained from students' drawings related to the MU category of task 6 on the PNMET

Written expressions obtained from the incorrect drawings by students	CG	JG	AG
Drawings showing that less Ag was accumulated on the Zn electrode bound in electrolysis of $Ag(NO_3)$ solution that was more concentrated (Fig. 6a)	5	10	7
Drawings showing that more Ag was accumulated on the Zn electrode bound in electrolysis of $Ag(NO_3)$ solution that was more concentrated (Fig. 6b)	3	7.5	10

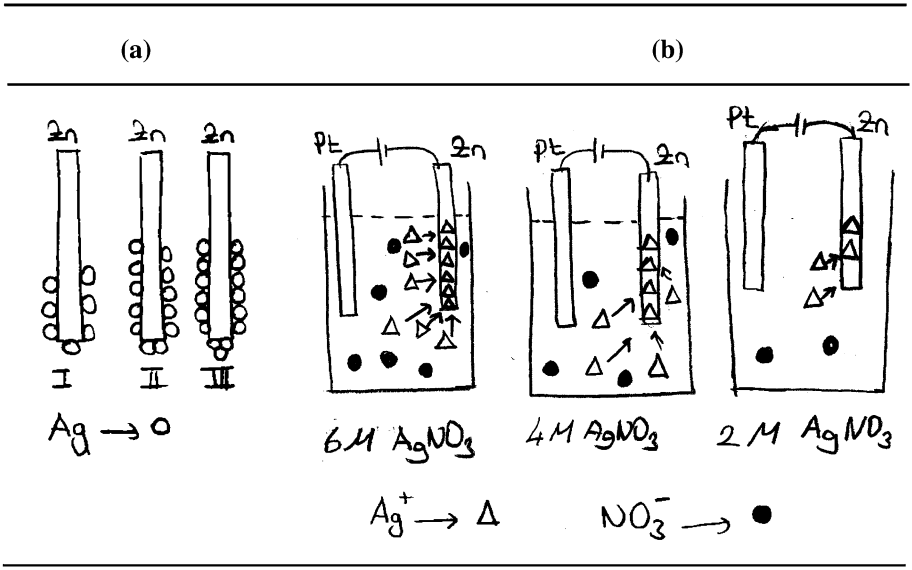

Fig. 6 Some students' drawings in the misunderstanding category of task 6 on the PNMET

As seen in Table 9, 8% of the CG students, 18% of the JG students, and 17% of the AG students gave answers in the MU category to the question related to the molecular level of the material electroplating on the electrode in the electrolysis of $Ag(NO_3)$ solutions having different concentrations. The JG and AG students gave a larger percentage of answers in the MU category than the CG students for this task. However, the answers given in the NU category for this task given in Table 5 were more than 40% in the JG and CG, but the AG was more successful in understanding the facts of electrolysis at molecular level. Some students' drawings showing misunderstanding presented in Table 9 are given in Fig. 6.

Conclusion

Our research findings showed that the students that participated in this study had similar characteristics in terms of their scientific reasoning ability, but their levels of understanding of the subjects in electrochemistry at molecular level differed from each other before the study (Table 2). Those students' understanding levels of the subjects in electrochemistry at molecular level varied significantly after the experiment. When the effect of differences between the initial understanding levels of the students who participated in the study was covariate, it was seen that teaching with computer animations resulted in better understanding at molecular level than both teaching with the jigsaw technique and the traditional teaching method. In addition, teaching with the jigsaw technique resulted in a better understanding at molecular level than the traditional teaching method according to the results of the Bonferroni test. These results are consistent with those of previous studies (Ayas and Ozmen 2002; Novick and Nusbaum 1981; Williamson and Abraham 1995).

In this study, although it was found that level of comprehension of electrochemistry among the students in the AG and JG was higher than the level of those in the CG, some misunderstandings were identified in both of the experimental groups (from the expressions belonging to the category MU).

Some of the misunderstandings identified in the present study were not reported in previous research studies (tasks 5 and 6). In this study, animations illustrating the subject of electrolysis including tasks 5 and 6, in general the accumulation of substance (material electroplating) on metal surfaces as color changes, were used. In the JG and CG, these representations (electroplating on the surface of metal) were presented through static drawings. The results revealed that animations and static drawings were not sufficient for the students to understand the idea of electrolysis at the molecular level. To remedy this situation, it was suggested that some animations representing tasks 5 and 6 at the molecular level be developed and their effects be investigated.

According to the results obtained from the present study, students in the CG either misunderstood the subjects in electrochemistry at the molecular level to a considerable extent or could not understand them at all; those in the JG and AG understood the subjects partially. Although the students were asked to use the term “molecular level” in all questions, they completely neglected this concept when answering some questions (Q2 and Q4) (The second and fourth questions of the PNMET were related to the representation at molecular level of oxidation in the anode and reduction in the cathode part of the electrochemical Zn/Cu cell and representation at molecular level of corrosion of an iron nail, respectively). According to the PNMET results, students’ high levels of no understanding or misunderstanding show that there have been problems in the teaching of the electrochemistry at molecular level. There may be various reasons for these problems. For example, besides the absence of enlightening and exemplification, inadequacy of the methods used by teachers in teaching may also be important. Since the concept of “molecular level” is abstract, it is not possible for the students to make a direct observation. In this study, the fact that the students in the CG and JG misunderstood the subjects or left the questions unanswered and those in the AG gave more correct answers at molecular level supports the thesis above. For this reason, chemistry teachers should supplement the instruction of difficult electrochemistry units with animations that show the molecular level.

One of the reasons for the high levels of expressions in the category of MU at molecular level related to some subtopics in electrochemistry may be the students’ conceptions they had gained before university and which were not scientific. Such conceptions and the ones taught during formal education might result in misunderstandings (Ayas and Ozmen 2002). For this reason, the units that are difficult to understand should be presented at molecular level using computer animations. Otherwise, it will be very difficult for the teacher to teach anything unless the students are willing and make an effort (Bodner 1990).

Jigsaw cooperative learning groups can be very effective because students can establish a supportive, comfortable learning environment. They can be more actively engaged in the content of the course, and eventuality, they can experience greater gains in mastering the course content, which could translate into improved grades. An important part of the cooperative learning experience for most students is learning how to function successfully in a group (Colosi and Zales 1998). In this study the jigsaw technique was not more effective than animation. The reason for AG students' being more successful than JG students is that the former group was not only provided with animations but their teaching program also included pre-questions, lectures, post-animation questions and answers, discussions, and re-teaching. Thus, the use of animation in learning science concepts made a significant difference to the students' achievement.

The idea of molecular level is practical in turning complex chemical and physical events into comprehensible and interpretable ones. However, the case is different for students, because they have difficulty in imagining this abstract phenomenon (Osborne et al. 1982). Some students even store the permanent state of matter in their minds together with the molecular level (Schollum and Osborne 1985).

In addition, as a limitation of the study, students' skills of learning through visual representations were not investigated. The students' drawings at the molecular level were analyzed in order to evaluate their levels of comprehension of electrochemistry. However, students' abilities to access to visual representations through both written and online resources and to utilize them effectively during individual and group studies were not researched. Inadequacy in the abilities of students to turn the images in their minds into drawings may have inhibited their achievement. Studies showed that images and modeling in the mind had significant roles in the formation of the representations at molecular levels. Future research may focus on trying to find out the effects of such skills in students.

When generalizing these results, one should keep in mind, however, that the distinction between high and low learning prerequisites is always relative. For instance, students with little prior knowledge in the respective subject matter can have severe difficulties in systematically relating different external representations to each other and adequately processing dynamic representations (Ploetzner et al. 2009). As a consequence, these students fail to construct coherent mental representations.

In conclusion, for students to be more successful in learning the subjects in chemistry at the molecular level they should participate in group research rather than studying alone and they should be supported by animations that present the molecular level in class.

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