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The Effects of Animation and Cooperative Learning on Chemistry Students' Academic Achievement and Conceptual Understanding about Aqueous Solutions

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Abstract: This study explores the effectiveness of a visual aid and cooperative learning method on first year undergraduate students' comprehension of chemistry concepts involving solutions. The lack of understanding of these concepts may be linked to the students' inability to visualize particulate behavior. This study included 109 first-year undergraduate students from three classes of a general chemistry course taught by the same teacher (author) in a faculty of education in a university. One of the classes was defined as the cooperative group, the second as the animation group and the third as the control group. The two experimental groups were compared with the control group. In this research, the students' conceptual understanding, misunderstanding and course achievement were measured. Both experimental groups had significantly higher conceptual understanding scores and fewer misunderstandings than did the control group. No differences were found in terms of course achievement. Analyses of covariance were used to determine variance in reasoning abilities. Animations may increase conceptual understanding by prompting the formation of dynamic mental models of the phenomena. The students in the cooperative group are learning more than their peers in competitive and individualistic situations, because they are engaging in higher-order thinking skills, are readily retaining the information and are collectively generating new ideas and solutions. Static mental models may fail to provide adequate understanding of these chemical processes.

Key words: Animations Technique · Cooperative Learning · Misunderstandings · Solutions

INTRODUCTION

The understanding of chemical processes such as melting, evaporating, dissolving, diffusion, electron transfer, ion conduction and intermolecular and intramolecular bonding is fundamental to learning high school and college chemistry. Chemists use particle models to account for these abstract constructs. However, students find it difficult to visualize chemists' conceptual models [1-7]. Interest among researchers and teachers in the science education community concerning the assessment of students' understanding of scientific concepts has grown since 1970's or even earlier. Various terminologies have evolved to describe students' understanding, which are different from or inconsistent with the consensus of the scientific community. The commonly used terminologies include preconceptions [8], misconceptions [9], alternative frameworks [10] and children's science [11]. We know that students have difficulty understanding concepts involving the particulate nature of matter and that this is an area of many misconceptions [12]. One possible reason for this lack of understanding is the inability of students to visualize particulate behavior. The need for methods or aids to increase understanding of the particulate nature of matter has been expressed [3,5,12]. Other research has shown that traditional visual aids might help in concept understanding. In addition to the above studies, some researchers extended their attention to the assessment of science teachers' misconceptions [5,3]. Science teachers are supposed to have adequate knowledge and understanding about the subject matter they teach. Unfortunately, research findings provide evidence that science teachers have various misconceptions in their knowledge of the subject matter.

The active learning method use demonstrated that, compared to teacher-centered environment, using animation techniques, cooperative learning, inquiry-based learning, project based learning, problem based learning which increases a student's knowledge and conceptual understanding of a subject. Recently, among these methods that animation technique and cooperative learning have been attracted attention of teachers, school managers and educational researchers [14-21].

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Animation technique is useful for teaching chemistry, general science, physics and biology concepts or improving conceptual understanding. Two-dimensional animated computer models show the dynamic characteristic of chemistry [16], [22]. Animated models in three dimensions can be rotated and used to teach spatial relationships [23, 24]. Animations are also effective aids for teaching concepts that involve motion at the molecular level [22], [25]. An animation is considered three dimensional if it has foreshortened lines, overlapping lines, differences in the relative sizes of objects and distortion of angles [26]. 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, on their own time and as many times as desired, or in the classroom by projection [27] [28]. 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 [29]. It is probable that students develop a concept from a model that is slightly different from what was intended [29, 30], 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 [23]. Studies show that students using a combination of model types representing the same concept have a better understanding of molecular level chemistry [31]. [32] 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 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 [2]. Cooperative learning can be defined as a method where students create small mixed groups and help each other for a common academic aim, boost each other's self-esteem, develop communication abilities, increase problem solving and critical thinking abilities and take an active part in learning [33-40]. Cooperative learning, which is more efficient than other methods, is widely used in education [18]. Research also indicated that cooperative learning can produce positive effects on academic achievement, especially for students with learning disabilities [41]. It is essential, however, to note that cooperative learning is not simply the process of grouping students, when it is carefully structured, students exhibited an increase in academic engaged time and elementary students remained on task [42]. For the cooperative learning method to be successful, students should be grouped carefully. Usually these groups are formed from students having different academic levels and different ethnic groups and they have different learning habits [43-45].

The purpose of this study was to investigate the effect of a visual aid and cooperative learning method on students' comprehension of chemistry concepts. Specifically, the effect of animation (dynamic, two- and three-dimensional graphic representation) and cooperative learning on the comprehension of concepts dealing with the dissolution mechanism of salts and compounds in water are examined. Differences in effects upon students of varying reasoning ability are explored. The specific research questions were:

- Will the conceptual understanding vary with the reasoning ability of students?
- Will computer animations technique and cooperative learning of concepts involving solutions enhance the understanding of those concepts?
- Will computer animations technique and cooperative learning of concepts involving solutions reduce misunderstandings held by students?
- Will computer animations technique and cooperative learning of concepts involving solutions increase course achievement?

MATERIAL AND METHODS

Sample: The participants of this study are composed of 109 first-year undergraduate students from three classes of a general chemistry course taught by the researcher (author) in a faculty of education in a university. One of the classes was defined as the cooperative group (n=34), in which cooperative learning was applied; the second was defined as the animation group (n=46), in which computer animation technique was applied; and the third was the control group (n=29), in which traditional learning was applied. Treatment groups were selected randomly. No pretest was given because all undergraduates enrolled at the university had passed an entrance exam and all were similar to each other in terms of academic achievement. In Turkey, there is a centralized university entrance exam system which is highly competitive. Each year, almost 1.6 million students take this exam and only ten percent of them can get a place in a university. The minimum and maximum marks to enter universities in Turkey are 200.4 and 380.0 respectively. Students' minimum and maximum marks in this study are 272.8 and 280.4 respectively. As seen from this range of marks it could be accepted that students participated in this study had similar academic achievement.

Instruments

Three Measure Instruments Were Used in this Study: 1) Understanding of the concepts was determined by a Solution Evaluation Test (SET) designed to cover the unit on solutions. This is an instrument requiring the students to make drawings, give explanations and answer multiple-choice questions. Items of SET are related to solution phenomenon, classifying solutions, concentration of solutions, electrolyte and non-electrolyte solutions and vapor pressure of solution, elevated boiling point and depressed freezing-point. "Satisfactory understanding" of the SET was established by a panel of experts, while "partial understanding" scores were given to responses that included only part of the scientifically accepted answers. The response reflects learning objectives clearly and in detail. The student shows a depth of understanding of the ideas related to the topic and understands important relationships. Scientifically incorrect responses were scored as "misunderstanding (MU)", the response is vague or not well developed and includes some misunderstanding or some inaccurate information. The response shows apparent gaps in the student's knowledge and understanding of the topic. "No understanding" responses were those that repeated the questions or gave irrelevant or unclear responses. Research studies in this area [12], [46] were used to develop the criteria and scale in our study. For statistical analysis, numeric scores of '1' were assigned to "satisfactory understanding" responses and '0' to all other categories of responses. This test gives continuous scale scores ranging from 0 to 10. A panel of experts established the content validity, while percentage agreement for multiple graders on papers randomly chosen established the inter-rater reliability. Percentage agreement was established for the unit on solutions at 82% or higher.

2) Course achievement was measured by student performance on the course exam (CE) covering the solutions topics. The CE has ten multiple-choice questions on solution unit, with each question worth five points. The CE was developed by the author and two chemistry teachers. CE was piloted with undergraduates from two classes of college chemistry. Item analyses were performed for each question and confusing or vague questions were rewritten before the test was used in the study. CE was conducted to the students who had seen the relevant unit before, to determine its reliability; and, the reliability co-efficiency (Cronbach Alpha) was found to be 0.68. Also, for the validity of CE developed, opinions of the chemistry lecturers and researchers on the subject have been taken into consideration. Researchers have pointed out that the gains of CE related to the subjects of solution have been high towards measurement.

3) The Test of Logical Thinking (TOLT), developed by [47], was used to determine the formal reasoning ability of students. This test gives continuous scale scores ranging from 0 to 10. The internal reliability for this test is reported as 0.85 [48]. [47] reports a strong correlation of 0.80 between scores on the TOLT and the formal reasoning skills, which are controlling variables, proportional reasoning, combinatorial reasoning, probabilistic reasoning and correlation reasoning. The TOLT used in this study contained eight test items designed to assess students' use of a particular reasoning skill. This test gives continuous scale scores ranging from 0 to 8.

Procedure: In this study, the researcher (author) began to teach the unit on aqueous solutions with a traditional approach in the control group and with cooperative learning and computer animation in the experimental groups. The learning objectives given Table 1 were taken into consideration during treatment in three groups.

The instructions were given during 16 course hours (four course hours per week and 50 minutes for each course) to three groups by the same chemistry teacher.

In the cooperative group, students were divided heterogeneously into two groups with five students and six groups with four students. 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. Students in the groups were encouraged to decide who would be the leader, recorder, timekeeper and reflector.

Table 1: The learning objectives were taken into consideration during treatment groups

- List and explain factors that affect the rate at which a solid solute dissolves in a liquid solvent.
- Distinguish between heterogeneous and homogeneous mixtures.
- Explain solution equilibrium and distinguish among saturated, unsaturated and supersaturated solutions.
- Compare the effects of temperature and pressure on solubility.
- Calculate the molality and mole fraction of a solution.
- Solve problems involving molarity of a solution.
- Describe how to prepare dilute solutions from more concentrated solutions of known molarity.
- Distinguish between electrolytes, non-electrolytes, strong electrolytes and weak electrolytes.
- Explain on a particle basis why a solution has a lower vapor pressure than the pure solvent of that solution.
- Explain on a particle basis why a solution has an elevated boiling point and a depressed freezing point compared with pure solvent.

Table 2: Animations used in the unit on solutions

Animations	Topic Shown	Length
Category 1	Intermolecular and intramolecular bonds and solution phenomenon	4 minutes
Category 2	Dissolving in water of some salts and compounds	4 minutes
Category 3	Electrical conductivity of some solutions and the strength of such conductivities	6 minutes
Category 4	Vapor pressure of solution, elevated boiling-point and depressed freezing-point	4 minutes

All the activities were completed by students under the guidance of the teacher. Later, the head of each group whose role was to organize the group meetings outside the class time and to coordinate the submission of group assignments was determined by the group members. The subjects of the related unit in the chemistry course were delivered to the group members by the heads of groups. Afterwards, Students were requested to search about the subjects related to the unit on solutions and share their ideas with the aim of mastering the content of the unit on solution and facilitating their partner's understanding. While students were discussing in small groups, the teacher visited all the groups and asked some guiding questions to lead students in an appropriate direction. Each of group members learned about their segments by conducting some research and experiments. Each group studied the unit on solutions both in and outside the class. They were asked to learn on their subtopic and to prepare it for presentation to their group, in which each member had been assigned a different

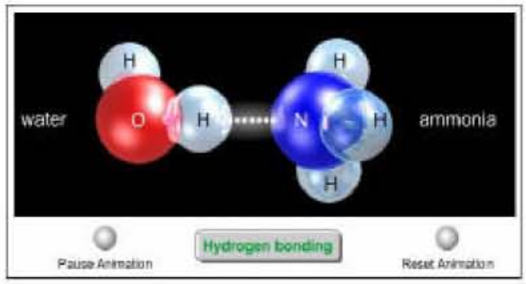


Fig. 1: Snapshots of some animations that represent hydrogen bonding (http://trc.ucdavis.edu/biosci10v/bis10v/media/ch02/bond_types.html)

subtopic of the unit on solutions. After, each of group members fulfilled their own presentation in groups, thus group presentations were completed. Then, each group was given 35 minutes to present their work in the classroom and 15 minutes for a class discussion. During this discussion, the group answered the questions asked by their classmates. All cooperative groups completed the subjects of the unit on solutions in four weeks.

In the animation group, animation techniques were used in the lectures. Their lesson focused on explaining the step-by-step process of solution through computer-animated presentation. The computer animations which are used in animation groups were received from various web addresses. These animations are shown after their arrangement by an expert who works at the department of computer and teaching technologies. For animations, we used Macromedia FLASI 5.0 for designing the whole courseware, because this program is easy for writing a common EXE and SWF files for Windows. Therefore, there are no compatibility problems and no extra installation process required for users. It is time-saving for the researcher. The animations used in lectures during the coverage of the unit on solutions were given as four main categories in Table 2. Also, one example for animation category is given in Figure 1. In the animation group, the researcher spent the first 5 minutes 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 minutes. The animations were shown by being projected on a white board, using a projection device compatible with computers. After the presentation of the animations, questions related to the subject were asked for 10 minutes. Parts of the subjects not fully understood were determined according to the answers; and these parts were instructed again using the animation technique. For each step, students were engaged in class discussion and animation sequences.

In the control group, the subjects were taught in the traditional learning method. The researcher planned the activities of the presenting the subjects which 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 aqueous solutions and by providing internet addresses and workbooks in order to construct the information to be presented to them. The same content was taught in the animation and cooperative group with the learning same objectives. In contrast with the experimental groups, students in the control group were required to use their textbooks; students were passive participants and rarely asked questions; they did not benefit from the library or internet sources; activities such as computer animations or brainstorming were not used; 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 feedbacks taken from them.

Data Analysis: In order to determine the differences among the three treatment groups, a one-way analysis of variance (ANOVA) calculation was made using scores on the TOLT. One-way analyses of covariance (ANCOVA) tests were used to analyze differences among groups with reasoning ability (the TOLT score) as a covariant. ANCOVA tests were formed for the CE and SET and Misunderstanding (MU) scores. Post hoc tests were used to determine how the groups differed. In addition, descriptive statistics related to total mean scores of the TOLT, SET and CE were analyzed for the groups.

RESULTS

Descriptive statistics related to total mean scores of the TOLT, SET and CE for the groups are presented in Table 3.

According to the data given in Table 3, mean scores of the groups range from 3.52 to 4.20, from 6.07 to 8.28, from 1.72 to 3.97 and from 27.35 to 29.67 for the TOLT, SET, MU and CE, respectively. The ANOVA results show no significant differences in the TOLT scores of the control, animation and cooperative groups [$F(2,108)=1.466$; $p > 0.05$)]. This finding supports the assumption that the groups should be considered equivalent.

Table 3: Descriptive Statistics for TOLT, SET, MU and CE

Groups		TOLT	SET	MU	CE
Control	Mean	3.52	6.07	3.97	27.76
	S.D.	1.84	2.09	2.10	6.63
Coope-rative	Mean	3.74	7.53	2.47	27.35
	S. D.	1.81	1.58	1.58	6.99
Animation	Mean	4.20	8.28	1.72	29.67
	S. D	1.67	1.31	1.31	7.48
Total	Mean	3.87	7.46	2.55	28.44
	S.D	1.77	1.85	1.86	7.13

Table 4: Results of ANCOVA on students' SET, MU and CE scores with TOLT scores as the covariate

	Source	DF	Mean Square	F	p
SET	TOLT	1	1.193	0.447	0.505
	Groups	2	44.238	16.562	0.001
	Error	105	2.671		
MU	TOLT	1	0.909	0.339	0.562
	Groups	2	45.432	16.925	0.001
	Error	105	2.684		
CE	TOLT	1	234.383	4.800	0.031
	Groups	2	38.633	0.791	0.456
	Error	105	48.827		

The first research question dealt with the relationship between concept understanding and reasoning ability. It was "Will the conceptual understanding vary with the reasoning ability of the students?" To answer this question and to determine the relationship between all the measures used, a correlation matrix of the TOLT scores, SET scores, the course exam scores was calculated for the unit on solutions. A correlation between the TOLT scores and the SET scores was $r = 0.42$ for the subjects involving in solutions. A lower correlation was found between the TOLT scores and the course exam scores ($r = 0.28$). The data in Table 3 show that the mean TOLT scores of the groups were different, although not significantly. Therefore, the TOLT score (reasoning ability) was used as a covariate in the subsequent analyses in order to partial out its effects. In addition, results of ANCOVA on students' SET, MU and CE scores were correlated with TOLT scores as the covariate was given Table 4.

The second research question, "Will computer animations technique and cooperative learning of concepts involving solutions enhance the understanding of those concepts?", dealt with conceptual understanding.

According to SET scores given Table 4, a significant difference between the three groups for the treatment effect was found F (2,105) = 16.562, p=0.001. The LSD post hoc analysis was used to determine where the differences existed. The control group had SET scores significantly different from those of the animation and cooperative groups. The scores of the two experimental groups were not significantly different. Effect sizes were calculated by dividing the difference in the means of the control group and one experimental group by the standard deviation of the control group. Effect sizes of 1.05 and 0.70 were found between the control group and the animation and cooperative groups, respectively, indicating a moderate effect.

The third research question dealt with students' misunderstanding. It asked: Will computer animations technique and cooperative learning of concepts involving solutions reduce the number of misunderstandings held by students? The number of items on the SET that contained misunderstanding (MU) was counted for each student. Very few scores different from the satisfactory understanding or misunderstandings were given on the SET. ANCOVA results for MU scores are given in Table 4. The ANCOVA results show significant differences by treatment in the misunderstanding score of SET even when the effects of the TOLT score are removed [$F(2,105)=16.925$, $p<0.05$)]. The LSD post hoc analysis was used to determine where the differences existed. The control group had scores significantly different from those of the animation and cooperative groups, but the scores of the two experimental groups were not significantly different (Table 3).

The fourth research question dealt with course achievement. The question was "Will computer animations technique and cooperative learning of concepts involving solutions increase course achievement?" Course achievement was measured by the CE. ANCOVA results for CE scores are given in Table 4. According to the ANCOVA results, no significant differences were found between the groups in terms of course exam achievement [$F(2,105)=0.791$; $p>0.05$)].

SET responses indicate some interesting similarities and differences among the groups. The results show that the explanation given by the majority of the students from the experimental groups to the question about the dissolving in water of NaCl is very similar. This question was answered correct by 65% of the students in the control group, 70% in the cooperative group and 72% in the animation group, without any misunderstanding. The main reason for this may be the fact that teachers give the example of dissolving by NaCl both in textbooks and on the internet. One example of the responses to this question is given in Figure 2.

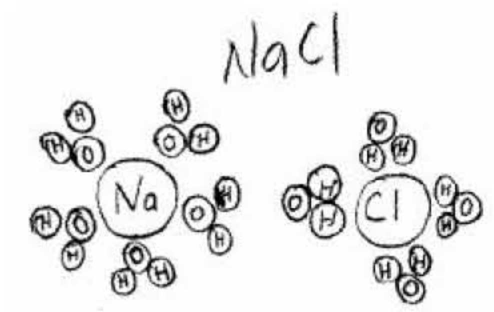


Fig. 2: One example of the responses of students showing the dissolving in water of NaCl

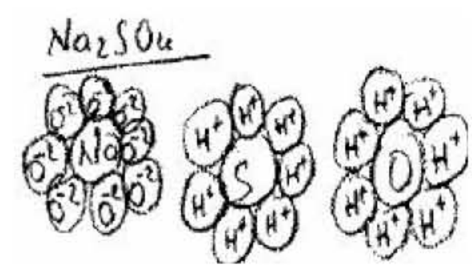
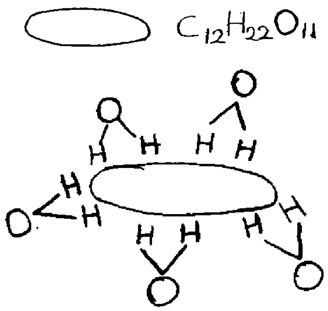


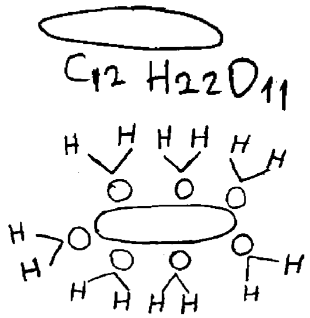
Fig. 3: One example from students' responses concerning with the dissolving in water of Na_2SO_4

Other similarities in the SET responses included answers given to the question about the dissolving in water of Na_2SO_4 by students in the treatment groups. Here, students did not depict the relation between SO_4^{2-} and Na^+ ions with water molecules. This question was answered correctly by 68% of the students in the control group, 56% in the cooperative group and 52% in the animation group, with misunderstanding (Figure 3). As seen in Figure 3, the students participating in the study continued their former habits with regard to the dissolving of NaCl again in this question. There are two ions of Na^+ and one of SO_4^{2-} in this question. The students take into consideration only one ion of Na^+ and neglect the other. Moreover, oxygen in the water molecules approaches the atom of S (sulfur) and the hydrogen approaches the oxygen in the SO_4^{2-} ion. Dissolution takes place as a result of this.

An interesting difference among the groups was found when the subjects were asked to draw a picture representing the change that occurs when sugar dissolves in water. One of the misunderstandings among students is the mechanism of the dissolving. As seen in Figure 4 (a), some students think that the sugar molecule dissolves as it approaches the hydrogen sides, while some of them, as seen in Figure 4 (b), think that the sugar molecule dissolves by approaching the oxygen side of the water.



(a)



(b)

Fig. 4: One example from students' responses concerning with the dissolving in water of sugar

DISCUSSION

The TOLT results showed no differences among the groups in this study. This helps to substantiate the assumption that the groups were similar. The mean TOLT scores in this study were higher than those found for college science students by [47], but lower than those found for college chemistry students by [46], [49]. On the other hand, many students without ability for proportional reasoning or controlling variables have dropped the course. These abilities were required for success in earlier units on stoichiometry, periodicity, chemical bonding and atomic structure. Since attendance was required for inclusion in the study, it may be that a large proportion of students with low TOLT scores chose not to attend class and were not included in the study. The CE showed no differences in course achievement among the groups (Table 4).

Prior to the study, gains in course achievement in the animation and cooperative groups were expected. Upon scrutiny of the questions on the CE, a possible explanation was found. The majority of the questions on the instructor-constructed exam were algorithmic in nature. Current literature supports the idea that students can work out algorithmic problems using "plug and chug" equations, without having a conceptual understanding of the phenomena [46], [49]. The proposition that students memorized equations and the manipulation of equations that were needed to answer algorithmic problems without gaining conceptual understanding may account for the lack of any difference between the groups on the course exam, when very different results were found with the SET scores. Conceptual understanding on the SET was related to the group (control or animation and cooperative) and the TOLT score (Table 4). One possible explanation might be that, with the simple, basic concepts that were depicted in this study, the maximum effect was achieved with both animations and cooperative study.

Another possible explanation may be that students only need to be cued to the dynamic particulate nature of these processes. The improved scores of the animation group are surprising when one considers that the duration of the animated sequences was short (five minutes maximum). Animations were used, however, consistently with the duration of the unit. Both of these facts added to the possibility that students, especially those with high reasoning ability scores as in this study, may only need to be cued to internally visualize dynamic, particle models. Research on cooperative learning showed that the cooperative setting provided students with the opportunities to engage in higher-order thinking skills and in processes of shared thinking, which helped them to not only gain a better understanding but also to build on their contributions to develop new understandings and knowledge [36-40]. Students could not learn by only working in a small group. They needed to construct their knowledge, too.

For this purpose, this study focused on the construction of knowledge in small cooperative groups. Many students tend not to learn meaningfully, having difficulties relating what is taught to them with their real-life experiences and with other scientific ideas previously learned [50].

The results for the misunderstanding (MU) scores on the SET instruments were directly related to the understanding scores (Table 4). The control group had significantly more misunderstandings than both experimental groups. In addition, the cooperative group had significantly more misunderstandings than the animation group. It is reasonable to expect the control group, which had less understanding than the other groups, to also have more misunderstandings. It is also reasonable to expect groups with higher understanding to have fewer misunderstandings.

CONCLUSIONS

This study indicates that, if cooperative learning instruction is organized, giving consideration to active learning methods students' achievement and social skills will improve. The present paper is also a comprehensive study for conceptual understanding. If the same studies can become reality and if teachers can be encouraged to apply them in their classes, then the formation of students' misunderstandings can be prevented. Thus, meaningful and effective learning can be provided. In this study, the animations provided a more scientifically correct visual model for submicroscopic processes which cannot be easily visualized. Students viewing the animations had fewer misunderstanding as a consequence. Students who viewed the animations held a more particulate view of matter, ions dissolving in water and chemical bonding structure. More conservation of particles between drawings and fewer "continuous matter" drawings were evidence of this. The use of animations may increase conceptual understanding by prompting the formation of dynamic mental models of the phenomena. The dynamic quality of animation may promote deeper encoding of information than that of static pictures. In this study, two important misunderstandings were identified: 1. Students take only one of the two Na^+ ions into consideration when a salt such as Na_2SO_4 is dissolved in water and ignore the other. In addition, students also consider that ions such as SO_4^{2-} dissolve as S and O elements in water. 2. When sugar ($C_{12}H_{22}O_{11}$) molecules dissolve in water, students thought that each sugar molecule was surrounded by either H or O sides of water molecules. Consequently, when correct and suitable learning strategies are used, we think it is more likely that misunderstandings will be remedied. Therefore, it is very important to keep continually developing textbooks based on constructivism including contemporary instructional methods.

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