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ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/crst20

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To cite this article: Yıldızay Ayyıldız, Leman Tarhan & Aylin Gil (2023) Comparing the effectiveness of the learning material and the learning method in students' achievement in chemistry lesson on chemical changes, Research in Science & Technological Education, 41:4, 1372-1393, DOI: 10.1080/02635143.2022.2086535

To link to this article: https://doi.org/10.1080/02635143.2022.2086535

Published online: 13 Jun 2022.

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RESEARCH IN SCIENCE & TECHNOLOGICAL EDUCATION
2023, VOL. 41, NO. 4, 1372–1393
https://doi.org/10.1080/02635143.2022.2086535

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Comparing the effectiveness of the learning material and the learning method in students' achievement in chemistry lesson on chemical changes

Yıldızay Ayyıldız[a], Leman Tarhan[b] and Aylin Gil[c]

[a]Torbalı Vocational School, Dokuz Eylul University, Izmir, Türkiye; [b]Faculty of Science, Dokuz Eylul University, Izmir, Türkiye; [c]50th Year Campus, Bahcesehir College, Izmir, Türkiye

ABSTRACT

Background: Research on chemistry education has found that students have commonly some difficulties in understanding chemical changes. These difficulties in the learning process have negatively affected students' success. For this reason, it is very important to overcome students' learning difficulties with new materials that prevent the occurrence of misconceptions and effective learning methods.

Purpose: This study aimed to compare the effectiveness of the learning method and the learning material in high-school students' achievements in chemical changes.

Sample: The population of the study consisted of 92 students from three-ninth grade high-school classes in Izmir, Türkiye ($N_{Group\text{-}I}$ = 30, $N_{Group\text{-}II}$ = 30 and $N_{Group\text{-}III}$ = 32).

Design and methods: The present study in which a pretest-posttest quasi-experimental design was used, was conducted with three groups. Group-I learned via the jigsaw technique using newly developed learning material. Group-II learned via the same technique using the current chemistry syllabus. Group-III learned by using the current chemistry syllabus in a teacher-centred environment. The effectiveness of the learning material was determined by comparing Group-I and Group-II, the effectiveness of the jigsaw technique of cooperative learning used by comparing Group-II and Group-III, and the effectiveness of both learning method and learning material was determined by comparing Group-I and Group-III. After the experiment process, a concept test was administered to identify students' understanding of chemical changes. To determine the students' misconceptions and their views about the learning method, semi-structured interviews were also conducted.

Results: The results of the concept test indicated that the mean score of Group-II was significantly higher than that of Group-III, and the mean score of Group-I was significantly higher than that of Group-II.

Conclusion: The results of this study showed that the learning material played a greater role than the learning method in achievement and the prevention of misconceptions regarding chemical changes.

KEYWORDS
Jigsaw cooperative learning method; learning material; chemical changes; misconception

CONTACT Yıldızay Ayyıldız yildizay.ayyildiz@deu.edu.tr Torbalı Vocational School, Dokuz Eylül University, Izmir 35860, Türkiye

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Introduction

In the learning process, the lack of knowledge and misconceptions negatively affect students' success in new subjects they will study (Osborne and Wittrock 1983). Thus, it is critically important to define the misconceptions in subjects where students have learning difficulties and to consider why these misconceptions occur.

In science, which includes a lot of abstract concepts, one of the subjects presenting difficulties to high-school students is 'Chemical Changes'. It has been reported that students cannot fully comprehend the phenomena based on physical and chemical changes and the differences between them (Tarhan et al. 2013). They also have difficulties in explaining some phenomena they face in their daily life by using their current knowledge (Boo and Watson 2001; Johnson 2000).

As has been indicated in studies on analysing some basic concepts used in chemistry, chemical change being among them, basing particulate nature upon explaining chemical changes also increases by upgrading the level of the students from first-year to senior, whereas most of the students have difficulties with basing the changes in particulate structure upon classifying the substantial changes (Abraham, Williamson, and Westbrook 1994; Stavridou and Solomonidou 1998). It has also been reported that students' understanding of chemical changes is poor, even if they succeed in overall examinations (Johnson 2000).

Research reports show that the most important problem with the subject is related to the classification of changes in daily life as physical or chemical (Tarhan et al. 2013). Interviews with high-school sophomores and college students reveal that they associate beer foam with a fermentation reaction and indicate that gas is released at the end of this reaction, causing beer to foam. For the phenomenon of water freezing, both college and high-school students make the wrong classification. Students also believe that dissolution is always a chemical process (Stavridou and Solomonidou 1998; Tsaparlis 2003). In explaining chemical change, they use their daily ideas intuitively and claim that there is no change except in view. Another conclusion is that students assume the mass of steel bobble does not change during combustion, and they define this as physical (Driver 1985). It has also been noted that many concepts in chemistry are only briefly covered during the educational process. However, students should fully comprehend the three main dimensions of chemistry – macroscopic, microscopic, and symbolic – and relate them in the right way in order to understand many chemical concepts. According to students, physical changes can be recycled, while chemical changes cannot. Cooking an egg, burning wood, and many other widely used examples make the students think this way (Gabel 1999). Similarly, when the expressions and models used to explain dissolution are analysed, it emerges that 74% of teacher candidates classify dissolution as a physical concept, 17% label it as chemical, and 9% consider it both physical and chemical (Gödek 1997).

Some of the misconceptions or misunderstandings about the subject result from the lack of knowledge about intramolecular and intermolecular forces. According to Caamaño Ros (1993), students have difficulties in distinguishing physical and chemical changes when they are expected to define the broken bonds during phase change. It has also been reported that high-school juniors and seniors and first-year college students have the misconception of breaking of covalent bonds inside the molecule in contradistinction to

intermolecular bonds during the phase change of a substance (Kiokaew 1989; Peterson and Treagust 1989). Some misconceptions have also been identified regarding the law of mass conservation in physical and chemical changes (Geban and Bayır 2000; Özmen and Ayas 2003).

The classification of reactions also plays a key role in the subject. Gabel et al. (2001) have analysed what children think about combustion, the ability of students to think in a more scientific way after education, and if the age-related understanding of combustion changes or not. The results of the research show that a very limited number of students can explain the concept of combustion scientifically. This phenomenon has also been studied by Meheut (1985), and similar results are found with Driver (1985) and Hesse and Anderson (1992). Regarding the results, students classify oxidising as physical change, and they fail in understanding the role of invisible gas reactant and/or products. In their study related to the phenomenon of burning a candle, Abraham, Williamson, and Westbrook (1994) found that 70% of students had misconceptions and classified it as physical since it is not chemical and the shape of the candle changes.

Given that these misconceptions will negatively affect the academic progress of students, preventing or correcting them with newly developed materials is critically important (Acar and Tarhan 2007; Wu 2003). On the other hand, in the subject of chemical changes, where misconceptions are very common, the learning methods to be applied to overcome students' learning difficulties are also as important as the material developed. One of the most effective learning methods used to eliminate students' misunderstandings, misconceptions, and learning difficulties is cooperative learning (Johnson, Johnson, and Smith 2006). Cooperative learning is an active learning approach in which students work together in and out of the classroom to achieve a goal in heterogeneous groups of 3–7 people, contribute to each other's academic, social, and psychological development, shared leadership and each individual in the group has responsibility towards the group (Abramczyk and Jurkowski 2020; Avcı 2022; Johnson and Johnson 2018; Lin 2006; Slavin 1980). In cooperative learning, students' individual responsibilities towards their groups and positive in-group commitment motivate students and positively affect academic success (Doymus 2008; Doymus, Karacop, and Simsek 2010; Jones, Graham, and Schaller 2012; Kartika, Firdaus, and Swistoro 2020; Yaayin, Oppong, and Hanson 2021). In many studies, it has been determined that the cooperative learning approach helps conceptual learning and has positive effects in preventing and eliminating misconceptions (Abdullah et al. 2018; Okumus, Özdilek, and Arslan 2020; Şeşen, Kırbaşlar, and Avcı 2019; Tarhan et al. 2013). In addition, it has been revealed by the researchers that the cooperative learning method improves skills such as critical thinking, team building, problem solving, empathy, communication, and leadership, and increases self-confidence (Atallah et al. 2021; Petre 2020; Scager et al. 2016; Van Ryzin and Roseth 2019; Warsah et al. 2021).

Cooperative learning comprises different sub-techniques, such as student teams-achievement divisions (Slavin 1978), team-game-tournament (DeVries and Edwards 1974), learning together (Johnson and Johnson 1991), group investigation (Sharan and Hertz-Lazarowitz 1980), and jigsaw (Aronson 1978; Slavin 1980). In this study, the jigsaw technique of cooperative learning was used. In the jigsaw technique, students work in two different groups, 'home groups' and 'jigsaw groups'. First, students come together in home groups, taking into account heterogeneous characteristics, and each team member is given a specific task. Then, the students who take the same task in the home groups are

divided into pieces like a puzzle and the students join the jigsaw groups created in this way. The formation of jigsaw groups from home groups is shown in Figure 1. These jigsaw groups come together to study the same topic and work together until they learn and master the material given to them. After learning the subject in the jigsaw group, the students return to their home group and share the information learned with their home group members (Aronson et al. 1978; Clarke 1999).

In the jigsaw technique, the teacher is not the only provider of knowledge because most of what needs to be done is done by the students. This makes learning effective. Students take ownership of what they have done and achieved in the learning process, and therefore students are held responsible for what they do in the context of accountability among their peers. This technique is useful in teaching because learning is based on interaction with peers, students are active participants in the learning process and thus help develop interpersonal skills among students. Jigsaw technique enables students to be more effective and active, and to participate in the learning process with interest and enthusiasm in cooperation and solidarity with each other (Eilks 2005). Its contribution to the teaching process is extremely important in terms of encouraging students to work together and learning from each other (Costouros 2020). Considering all these benefits to the teaching process, the jigsaw technique was chosen as a learning method in order to increase the effectiveness of the learning material developed in this study in academic success.

Purpose of the study

The purpose of the study was to compare the effects of the learning material and the jigsaw cooperative learning method on the students' understanding of chemical changes. In accordance with this aim, the following sub-questions were investigated:

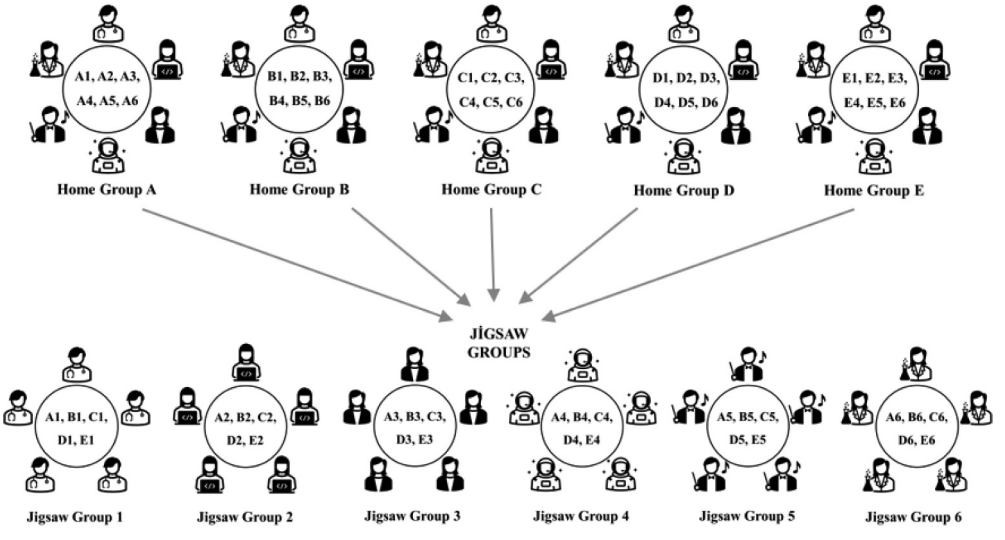


Figure 1. Formation of jigsaw groups from home groups.

•Is there any significant difference in terms of achievement between the students in Group-I, where the material developed for the chemical changes unit is presented via the jigsaw technique, and the students in Group-II, where the current syllabus for the unit is presented using the jigsaw technique?

•Is there any significant difference in terms of achievement between students in Group-II, where the current syllabus for the unit is presented using the jigsaw technique, and Group-III, where the current syllabus is presented using teacher-oriented instruction?

•What are the opinions of the Group-I and Group-II students on jigsaw cooperative learning?

Method

Participants

The subject of chemical changes is a subject covered in the 9th grade chemistry curriculum in Türkiye. Therefore, this study involved three 9th-grade classes totalling 92 students in a high school in Izmir, Türkiye. All necessary ethics approvals for this research have been obtained from the Ministry of National Education and the administration of the high school. Also, all participants have provided appropriate informed consent. One of the classes was defined randomly as Group-I ($N_{Group\text{-}I}$ = 30), one as Group-II ($N_{Group\text{-}II}$ = 30), and one as Group-III ($N_{Group\text{-}III}$ = 32). The students in each group had a similar socio-economic status, with the majority of them coming from middle-class families. Instruction in Turkish high schools is typically teacher-centred, characterised by a lecture-type format and passive student participation in the learning process. The students only listen to their teacher, take notes, and use textbooks as a learning material.

Data collection tools

Prerequisite knowledge test (PKT)

The prerequisite knowledge test was developed to identify students' prerequisite knowledge on the subject of chemical changes by considering misconceptions determined in the literature (Boo and Watson 2001; Coll and Treagust 2001). The contents of the test were validated by five chemistry educators, three science and technology teachers, and three chemistry teachers. The test was piloted with a sample of 164 students in the 10th grade who had previously studied the subjects and the concepts. For the construct validity of the PKT, firstly, the item difficulty and discrimination values of each question were examined. As a result of the item analysis, it was determined that the item discrimination values ranged from 0.39 to 0.81, and the item difficulty values ranged between 0.42 and 0.68. At the end of the factor analysis, which was also performed for construct validity, the Kaiser Meyer Olkin (KMO) value of the test was 0.65, and the Bartlett's test was found to be significant ($p < 0.05$). According to the results obtained from the KMO and Bartlett's tests, it was decided that the sample size and normality of distribution of the data were appropriate to continue the factor analysis. After determining that the test is suitable for factorization, factor loadings of each item were found by exploratory factor analysis (EFA). With reference to the item and factor analysis results, items giving low load were excluded from the test, the PKT was finalised with a total of 25

items. The reliability coefficient (KR-20) was found to be 0.83. The test carried a maximum score of 100 points, with 4 points for each question. The distribution of the items to the subjects is presented in Table 1.

Chemical changes concept test (CCCT)

The chemical changes concept test was developed to identify students' understanding of chemical changes by considering the misconceptions determined in the literature (Table 2).

As the first step, an item pool comprising 32 multiple-choice questions with an open-ended part was constructed. The contents of the test were validated by five chemistry educators, three science and technology teachers, and three chemistry teachers. The test was administered to 145 students in the 10^{th} grade who had previously studied the relevant subjects and concepts. Item and factor analyses were performed for the construct validity of the CCCT. As a result of the item analysis, it was determined that the item discrimination values ranged between 0.40 and 0.86, and the average difficulty of the test was 0.51. The KMO value, which was used to determine the suitability of the sample structure of the test for factor analysis, was found to be 0.88. Since this value is between 0.80 and 0.90, it was determined to be perfectly suitable (Field 2013). The result of Bartlett's sphericity test was found to be significant at the $p < 0.05$ level, and based on this result, it was concluded that the CCCT was suitable for factorization. Then, EFA was performed. As a result of EFA, 5 items with a factor load value of less than 0.30 and contributing the least to the common variance were excluded from the test considering the content validity. With reference to the item and factor analysis results, the CCCT was finalised with a total of 25 items. The reliability coefficient was found to be 0.79. The test carried a maximum score of 75 points, with 3 points for each question. The rubric for evaluating the CCCT is as follows:

- Correct answer and correct explanation without misconception: 3 points
- Correct answer and inadequate explanation/misconception: 2 points
- Correct answer without explanation: 1 point
- False or blank answer: 0 point

Semi-structured interviews (SSI)

In order to determine the students' lack of knowledge and misconceptions after the application, in addition to the CCCT, 10-min semi-structured individual interviews were conducted with nine students from each of the three groups. Furthermore, interviews about the application of the jigsaw technique were conducted for approximately 10 minutes with 15 students from each group. Both Group-I and Group-II students were divided into three sub-groups according to their achievement on the CCCT, and five students

Table 1. The distribution of items in the PKT to the subjects.

Subjects in the PKT	Number of items used in the test	Percentage of the items about the subject
States of Matter and Particulate Structure	8	32.0
Physical/Chemical Change and Particulate Structure	5	20.0
Elements/Compounds and Particulate Structure	12	48.0

Table 2. Misconceptions about the chemical changes defined in the literature.

1. Misconceptions about the classification of physical and chemical changes
(1) State changes such as freezing, boiling, vaporization are chemical changes (Tsaparlis 2003).
(2) Physical changes are reversible, chemical changes are irreversible changes (Tsaparlis 2003; Gabel 1999; Geban and Bayır 2000).
(3) All solution events are examples of chemical change (Tsaparlis 2003).
(4) All solution events are examples of physical change (Gödek 1997).
(5) Changes which result in gas, bubble or vapour formation are always chemical changes (Tsaparlis 2003).
(6) Chemical event and chemical reaction are different notions and chemical reactions are only realized by humans (Tsaparlis 2003).
(7) Intramolecular bonds break during phase changes (Kiokaew 1989).
(8) The matters which enter into reaction in chemical reactions disappear (Kiokaew 1989).
(9) Freezing of water is a chemical change, vaporization of water is shown by equations, it is a chemical event, and a chemical reaction occurs during state change (Tsaparlis 2003).
(10) In the vaporization of cologne, vapour exhaust is chemical, and during the vaporization of cologne, the chemical properties of cologne change (Tsaparlis 2003).
2. Misconceptions about the chemical reaction types
(1) In events like oxidation, the internal structure of the matter remains the same, while the outer structure changes. Therefore, these changes are physical (Çalık and Ayas 2005; Driver 1985).
(2) Oxidation is a physical change; because, when the oxidised layer is cleared, the appearance of the matter is restored (Çalık and Ayas 2005).
(3) In combustion reactions total mass and/or volume changes (Kiokaew 1989).
(4) In combustion, the significance of oxygen and carbon dioxide can be neglected (Kiokaew 1989).
(5) Combustion comprises only fire or flame (Kiokaew 1989; Geban and Bayır 2000).
(6) Only strong acids and strong bases can enter into neutralization reaction; since the solution formed as the result of neutralization is neutral, pH is 7; therefore, the solution does not comprise OH^- and H_3O^+ ions (Schmidt 1991; Vidyapati and Seetharamappa 1995).
(7) Having misconceptions about neutralization; confusing acid and base properties; inability to understand the function of the indicator; and inability to explain the behaviour of HCl in water environment, at a molecular level (Bradley and Mosimege 1998).
(8) Inability to explain the behaviors of acid and base solutions in water environment at a molecular level (Demircioglu, Ayas, and Demircioglu 2005).
(9) Antacid is a kind of acid (Vidyapati and Seetharamappa 1995).
(10) Acids burn and melt every kind of matter (Toplis 1998; Özmen and Ayas 2003).
(11) Darkening of water pipes through time is a physical change because there is not any oxidation (Çalık and Ayas 2005).
(12) Changes like ripening of an apple, rotting of tree leaves are examples of physical change (Tsaparlis 2003).
(13) Boiling of an egg is a biological change (Tsaparlis 2003).
(14) Sparkling of beer produces a gas which results from the fermentation reaction. Beer which comes into contact with air enters into a reaction and thus foams are produced. During sparkling $H_{2\ (g)}$ is produced (Tsaparlis 2003).
(15) Sugar dissolves and decomposes into its ions as a result of a chemical reaction. Salty water is a compound, because salt is decomposed into its ions in water (Çalık and Ayas 2005).
(16) Sugar melts and disappears in water (Ebenezer and Erickson 1996).
(17) Most of the dissolved matter in a solution gathers at the bottom (Prieto, Blanco, and Rodriguez 1989).

from each sub-groups were selected randomly for the SSI. The questions directed at Group-I and Group-II students during the semi-structured interviews are provided in Table 3 (Acar and Tarhan 2007).

Procedure

This study related to chemical changes as presented in a 9^{th}-grade chemistry lesson. The pretest-posttest quasi-experimental design was chosen for it. Before the study, an experienced chemistry teacher was trained in how to conduct the instruction based on jigsaw cooperative learning. The teacher and the researcher discussed the instructional plans and the activities. In this study, it was ensured that the lessons were given by the same

Table 3. Semi-structured interview questions.

Interview Questions
1. What are your perceptions of the course where you studied in small cooperative groups?2. What were the strengths of working in a group?3. How did your group mates help to you in the learning process?4. What do you think about your score in the post-test?5. Would you like to study in cooperative groups again? Why?6. What occurred within the course that helped you increase your understanding?7. Do you have any other comments that you have about the course?

experienced chemistry teacher in all three groups in order to compare the results in a valid and reliable way. Before the implementations, all the students and their families were informed about the aims of this study and the privacy of their personal information, after which permissions for participation were obtained from all families.

The first step was administering the PKT to determine the students' prerequisite knowledge for learning about chemical changes. Then, a preparatory lesson was conducted over two class hours by using the question-answer technique to correct misconceptions and address lack of knowledge. Instruction on chemical changes was accomplished using newly developed learning material via the jigsaw technique in Group-I, the current chemistry syllabus via the jigsaw technique in Group-II, and the current chemistry syllabus via a teacher-centred approach in Group-III. The research design is presented in Table 4.

The instruction continued for up to six weeks over two class hours weekly and was provided by the same chemistry teacher. After the instruction, the CCCT was administered to all the participants, and SSIs were conducted with selected ones to determine the students' understanding of chemical changes. Such interviews were also used to obtain information about the students' opinions on jigsaw cooperative learning.

Forming jigsaw cooperative learning groups

The sub-groups of Group-I and Group-II were formed by using the stratified random sampling design (Felder et al. 1995) considering first semester GPA for chemistry lesson and social skills determined by the teacher. Prior to the instructions, Group-I and Group-II students were informed about working in jigsaw cooperative learning groups, the responsibilities of the students and the teacher during the process, and the assessment techniques. The instructions in both groups are detailed below.

Table 4. Research design.

Study Groups	Pre-Experiment	Experiment Process	Post-Experiment
Group-I	Preparatory CoursePKT	Jigsaw Technique applications using the newly developed learning material	CCCTSSI
Group-II	Preparatory CoursePKT	Jigsaw Technique applications using the chemistry syllabus	CCCTSSI
Group-III	Preparatory CoursePKT	Teacher-oriented applications using chemistry syllabus	CCCTSSI

Instruction in group-I

In this group, jigsaw cooperative learning instruction was conducted under the guidance of a teacher using the learning material developed in this study. Group-I was subdivided into five homogenous home groups, each consisting of six students and each heterogeneous in itself. Every student in a home group was assigned to one of the sub-headings below.

The students assigned to the same sub-headings met the students from the other home groups in jigsaw groups. Six jigsaw groups comprising five students were formed (Figure 1). Each of the jigsaw groups specialised in a designated subject by completing their studies as outlined in the worksheets distributed. Later, they re-joined their home groups and participated in their peers' learning process with their specialist knowledge under the guidance of their teacher.

Misconceptions about chemical changes were mostly collected under the sub-headings of *Combustion, Solution-Precipitation, Acid-Base, Oxidation-Reduction, Polymerisation-Hydrolysis*, and *Heat Treatment and Catalytic Decay*. For this reason, the learning material for the chemical changes were developed based on strategies to prevent the occurrence of misconceptions determined from the literature in a way to meet the learning objectives as defined in the current syllabus. The validity of the material was upheld by seven college professors and nine chemistry teachers with at least 10 years of experience in the field. In the learning material, six activities were devised to enable students to understand the necessity of examining the particulate structure of the matter in order to classify a material change as physical or chemical:

Activity 1: combustion reactions

Objectives

•Ability to explain combustible matters, the combustion process, combustion conditions, slow and rapid combustion events with examples, and the effects of the combustion process on the environment.

Content of the activity

•The definitions of combustible matters are given; the combustion conditions in candle example, the start of combustion, the combustion process, and the effect of oxygen on combustion are associated with examples. The 'flammable' warning sign on hydrogen tanks and the lack of one on helium tanks is discussed and total combustion explained by association with the maximum oxidation state that a combustible element could have. Students explain why CO_2 tanks are used as fire extinguishers.

•To prevent the misconception 2.5 in Table 2, slow and rapid combustion events are discussed using iron and fireworks examples. Then, Jigsaw 1 group conducts the magnesium band combustion experiment in a laboratory and discusses how magnesium enters into a reaction, what the equation is, and what the oxidation states are; later, the combustion speeds of more passive metals, such as iron, are interpreted.

•To prevent the misconception in 2.1, mention is made of the fact that the corrosion of balcony parapets and metals in aqueous media as well as the oxidation of silver jewellery are examples of slow combustion, and it is not possible for this event to be stoichiometric, i.e. there will be limited loss in the mass of the pure metal due to time.

Activity 2: solution–precipitation reactions

Objectives

•Ability to explain the solution process at the microscopic level; ionic and molecular solution, considering the particulate structure of the matter.

•Ability to understand that it is necessary to check whether a change occurs in the structure of the solvent and dissolved particles to define a solution event as physical or chemical.

•Ability to explain precipitation events by giving examples of soluble/insoluble ionic compounds from daily life and the solution/precipitation reactions of ionic compounds in water.

Content of the activity

•Mention is made of the necessity to consider the microscopic distribution of the particles so as to make a distinction between homogenous and heterogeneous by discussing previously learned concepts such as pure matter, homogenous mixture, heterogeneous mixture, and solution through daily life examples such as air, tap water, and milk.

•To prevent the misconception in 2.15, the structure of the particles and the differences in particulate interactions between molecular and ionic structures during the solution process are discussed using as examples sugar or table salt solution in water; various examples from daily life are given for physical/chemical change and solution.

•To prevent the misconceptions in 1.3 and 1.4, the existence of a relation between the structures and solution types of the acidic HBr and the basic $Ba(OH)_2$ is discussed. It is concluded that HBr, which has a covalent character, dissolves in water ionically with a chemical change, while $Ba(OH)_2$, which has ionic structure, dissolves in water ionically with a physical change.

•A distinction between soluble and insoluble salts is made by giving table salt and limestone as examples. It is ensured that the precipitation reactions are defined by discussing the significance of the reaction between calcium and carbonate ions in the development of crustaceans. Jigsaw 2 group conducts the silver chloride and PbI_2 compound reaction experiments in a laboratory and writes the total equation and the absolute ion equation of the reaction. Reinforcing occurs through daily life examples of precipitation events.

Activity 3: acid and base reactions

Objectives

•Ability to give daily life examples of acidic and basic matter.

•Ability to explain the general properties of acids and bases.

•Ability to explain the general properties of neutralisation reactions and their similarities to precipitation reactions using reaction equations.

Content of the activity

•To elicit knowledge on the subject, the acidic/basic properties of material such as lemon, marine acid, baking soda, and washing soda are discussed. To prevent the misconceptions in 2.8, it is questioned whether the particulate structure changes when dissolving NaOH

and HCl compounds in water considering the atomic numbers of the elements forming the compounds; the first one of these solution events is defined as a physical change, while the second one is defined as a chemical change.

•It is inferred that the basic principle of neutralisation events is water production from the absolute ion equation about water production over examples about the batch equations of neutralisation reactions of acids and bases. To prevent the misconception in 2.7, it is discussed whether the emergence of a white mist observed in a glass pipe with absorbent cotton on both ends dipped into HCl and NH_3 solutions is due to chemical or physical change. It is concluded that water production will not occur if the base used in the experiment is ammonia and that the phase change of HCl and NH_3 molecules (from water solution to vapour phase) is a chemical change.

•It is discussed which kinds of changes occur after reactions between acidic and basic matters in daily life, for example, a mixture of orange juice and baking soda. To prevent the misconceptions in 1.5 and 1.10, it is discussed whether sparkling is always an indicator of a chemical change. As another example, Jigsaw 3 group discusses how the eggshell softens if soaked in vinegar.

•To prevent the misconceptions in 2.9 and 2.10, discussion takes places on the composition and use of antacids, the reasons for using limestone and dead lime in pH-low soil due to acid rains, and the composition of drain cleaners.

Activity 4: oxidation–reduction reactions

Objectives

•Ability to associate the change in the electron order of atoms and ions with the octet/doublet rule.

•Ability to present examples of oxidation and reduction events over chemical reactions.

•Ability to determine the oxidised and reduced particles in a redox reaction considering the electron exchange trends.

•Ability to understand that some matters have both oxidising and reducing properties.

Content of the activity

•The octet and the doublet rules, learnt in previous lessons, are associated with the stability trend of particulate structures in chemical reactions. The kinds of changes that may occur in the electron order of particles in chemical reactions are discussed. In redox reactions, which are based on electron exchange, the reduced (oxidising agent) and the oxidised (reducing agent) type are determined using the oxidation state concept covered in previous lessons.

•The change in the oxidation states of the particles during the formation of NaCl from its elements is discussed by associating the change in the electrons of atoms with the Lewis structures in the formation of ionic compounds. The reason for the element's oxidation states being +1 and −1, respectively, is associated with the place of these elements in the periodic table. Whether a change occurs in the physical properties of the elements during the reaction is questioned.

•The redox reactions are discussed through using daily life examples such as water electrolysis coating of metals, the disinfection of potable water supplies, and the removal of stains from clothes using bleach.

•Using the three different redox reactions hydrogen peroxide enters in water media, the examples in which the element presents oxidising and reducing properties are examined, and it is concluded that the particles in the compound may present reducing properties in some reactions and oxidising properties in others.

Activity 5: polymerisation and hydrolysis reactions

Objectives

•Ability to define polymers, monomers, and the concept of polymerisation.

•Ability to explain polymerisation and hydrolysis events in daily life, as well as the difference between addition polymerisation and condensation polymerisation.

•Ability to understand the changes in the physical and chemical properties of matters in the polymerisation process.

Content of the activity

•To present some basic notions regarding polymerization reactions (such as monomer, dimer, polymer, homopolymer, and copolymer), examples are given of synthetic and natural polymers, which are encountered frequently in daily life (polyethylene, polyester, silk, etc.). After emphasising that polymerisation processes are mostly processes which start with the activation of monomers, addition polymerization is defined over styrene molecule.

•Condensation polymerisation – which is used for producing fibre and artificial hearts, among other things – is defined and its difference from addition polymerisation discussed.

•By examining the structure of amylose and amylopectin molecules – which are natural polymers and form starch – hydrolysis is discussed over the catabolism operations that occur during the decomposition of these larger molecules into smaller structures.

Activity 6: heat treatment and catalytic decay reactions

Objectives

•Ability to classify the changes that occur due to heat treatment in the particulate structure of the matters entering into reaction as chemical changes.

•Ability to understand that temperature is a crucial factor in the reaction rate in changes related to heat treatment.

•Ability to notice that some physical changes may occur during chemical reactions.

Content of the activity

•Through the example of the caramelisation of sucrose, which undergoes a chemical change contrary to matters in which a state change is observed after heating, discussion takes place on the physical and chemical changes that occur in some organic compounds subjected to heat treatment. In this discussion, the differentiation of physical properties such as colour, taste, smell, and solubility is emphasised.

•The changes that occur in some daily life processes are examined, such as the catalytic decay of fruits, food preparation, leaf decay, fermentation, bread staling, and the processes of digestion. It is concluded that these changes, which are seen in living systems, are generally chemical changes, occurring due to changes in the enzyme activities dependent on environmental factors. To prevent the misconception in 2.14, some fermentation reactions are expressed through equations.

Instruction in group-II

This group was sub-divided into six homogenous home groups, each comprising five students and each heterogeneous in itself (Figure 1). The members of a home group carried out one of the six sub-headings, same as Group-I. Additionally, the learning objectives of the process applied to Group-II were the same as those for Group-I. The course book, prepared according to the contents and subject sequence of the current syllabus, was used in jigsaw groups. Students who specialised in each jigsaw group returned to their home group and shared their knowledge with their peers by making presentations.

Instruction in group-III

The chemical changes unit was presented to the students in Group-III via teacher-oriented instruction by the same teacher instructing Group-I and Group-II and through the course book prepared according to the contents and subject sequence of the current syllabus in the same period.

Results

In data analysis process, it was first of all controlled whether data, assumptions of parametric tests are met or not. Normality test and skewness-kurtosis values were analysed in order to determine whether scores of participants in the three groups obtained from data collection tools have normal distribution or not and it was determined that data have normal distribution. Descriptive statistical values such as sample sizes (N), means ($\overline{X}$), standard deviations (SD), and standard errors (SE) related to the PKT and CCCT scores for three groups were given in Table 5. It was seen that students' mean scores for the PKT were similar but their mean scores for the CCCT were not similar between the groups.

In order to determine whether there was a significant difference between the groups before the study according to the scores obtained from the PKT, and after the study according to the scores obtained from the CCCT, one-way analysis of variance (ANOVA) was performed, and the results are presented in Table 6.

Table 5. Descriptive statistics for PKT and CCCT scores.

Variable	Group	N	$\overline{X}$	SD	SE
PKT	I	30	50.8	13.33	2.43
	II	30	49.6	16.83	3.07
	III	32	53.0	11.72	2.07
CCCT	I	30	57.87	7.21	1.32
	II	30	48.57	14.03	2.56
	III	32	41.44	8.34	1.47

Table 6. ANOVA results for PKT and CCCT scores.

Variable	Source	Sum of Squares	df	Mean Square	F	p
PKT	Between Groups	2.863	2	1.431	0.469	0.627
	Within Groups	341.833	89	3.052		
	Total	344.696	91			
CCCT	Between Groups	691.800	2	345.900	34.786	0.000
	Within Groups	865.100	89	9.944		
	Total	1556.900	91			

The results of ANOVA showed no significant difference among the PKT scores of the students in the 3 groups ($F_{(2,89)} = 0.469$; $p > 0.05$). From the findings of the one-way ANOVA analysis made according to the students' PCT scores; it can be stated that students participating in the research have similar characteristics before the study in terms of prerequisite knowledge for learning about chemical changes. According to the data in Table 6, it is seen that there is a significant difference between the CCCT mean scores of the groups ($F_{(2,89)} = 34.786$; $p < 0.05$). The least significant difference (LSD) test, 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, CCCT scores of both the Group-I and Group-II were observed to be higher than those of the Group-III, and CCCT score of Group-I was also observed to be higher than the Group-II ($\overline{X}_{\text{Group-I}} = 57.87$; $\overline{X}_{\text{Group-II}} = 48.57$; $\overline{X}_{\text{Group-III}} = 41.44$). From the findings, it can be stated that the jigsaw cooperative learning method has a significant effect on the high-school students' achievements in chemical changes, compared to the teacher-centred environment. When the learning material and the jigsaw cooperative learning method are compared on the students' understanding of chemical changes, it can be said that the newly developed learning material in this study is more effective than the jigsaw learning method.

In the present study, the students' lack of knowledge and misconceptions about chemical changes after the application were determined by way of the open-ended parts in CCCT. In addition, SSIs were conducted with nine students from each of the three groups to enter into the core of the studied concepts, to better identify students' way of thinking about the concepts. These misconceptions from CCCT and SSIs, and their frequencies and percentage values in each group are shown in Table 7. According to the results of the CCCT and the SSIs, a significantly lower number of misconceptions was established in Group-I as compared to Group-II and Group-III.

This table lists 11 misconceptions about chemical changes determined in this study, among which three were identified for the first time in this study. The misconceptions identified for the first time in this study are presented in Table 7 with an asterisk (*). The most common misconception in Group-III is '*The reaction of magnesium band with oxygen is a combustion reaction. This reaction cannot be defined as a redox or a synthesis reaction*'. and it was identified for the first time in this study. Moreover, this misconception was found in 14 out of 32 students in Group-III. This rate corresponds to approximately 44% of the Group-III. This misconception is also important because it is the most common misconception in a group.

When Table 7 is examined carefully, it is noteworthy that 6 of the 11 observed misconceptions were not encountered in any of the students in Group-I, where the learning material developed in the study was applied. Considered in this context, it can be said that the learning material for the chemical changes developed based on strategies to prevent the occurrence of misconceptions determined from the literature is successful

Table 7. Misconceptions about chemical changes determined in this study.

	Group-I (N = 30)		Group-II (N = 30)		Group-III (N = 32)	
Misconception	f	%	f	%	f	%
Reversible changes are physical, irreversible changes are chemical.	0	0.0	5	16.7	12	37.5
The nuclear structures of atoms change in chemical reactions.	5	16.7	7	23.3	8	25.0
In chemical reactions only the chemical properties change, while in physical changes, only the appearance changes.*	0	0.0	4	13.3	10	31.3
Corrosion of balcony parapets is a physical change since the appearance of matter changes.	0	0.0	6	20.0	10	31.3
Corrosion of balcony parapets is a physical change, because when the layer on top is cleared, the iron returns to its original state.	0	0.0	5	16.7	8	25.0
All events in which the colour, taste and smell of the matter changes are physical changes.	0	0.0	5	16.7	9	28.1
A chemical change occurs during the transfer of electric current on a metal part.*	3	10.0	4	13.3	8	25.0
The size of the particles changes in matters which undergo a physical change.	3	10.0	6	20.0	8	25.0
The changes that occur in organic matters are not physical or chemical but biological.	3	10.0	8	26.7	10	31.3
The reaction of magnesium band with oxygen is a combustion reaction. This reaction cannot be defined as a redox or a synthesis reaction.*	0	0.0	7	23.3	14	43.8
Particle which takes an electron is reducing agent; particle which gives an electron is oxidizing agent.	6	20.0	8	26.7	9	28.1

* *First determined misconceptions in this study.*

at this point. On the other hand, when the students in all groups are evaluated as a whole, that is, the most common misconception among 92 students (23 students in total have this misconception) is '*Particle which takes an electron is reducing agent; particle which gives an electron is oxidizing agent*'. This result showed that some of students confused reducing or oxidizing agent with reduction or oxidation.

SSIs were conducted with a total 30 students selected from Group-I and Group-II. Of those, 24 expressed a positive opinion about the jigsaw technique despite remarking that they had difficulties in the initial lessons since they had not been familiar with this technique. Later, however, the group members successfully participated in the activities. Six students from Group-I and Group-II expressed negative opinions about the technique, stating that it might cause timing issues, and its continuous use could lead to chaos in the classroom, so teacher-oriented instruction might be more effective. The percentages and frequency distribution of the opinions of the students in Group-I and Group-II on the jigsaw technique of cooperative learning are given in Table 8.

On the other hand, 90% of the students (27 students) who participated in the interviews about the method of jigsaw cooperative learning stated that the daily life-related activities have motivated them. 80% of them (24 students) said that they have studied chemistry more fondly and willingly during the jigsaw applications, and the feeling of success in the tasks given in the applications has increased their self-confidence.

Discussion

In this study, the effects of newly developed learning material and the jigsaw cooperative learning method on 9th-grade students' understanding of chemical changes were compared. The research highlighted that most of the misconceptions stem from classifying some changes (solvation, combustion, boiling, and evaporation) as physical or chemical

Table 8. Opinions of group-I and group-II students on cooperative learning application.

Opinion	Frequency (f) (N = 30)	Percent (%) (N = 30)
The daily life related examples used in the cooperative learning activities aimed at active learning have motivated us.	27	90.0
Our friendship relations have developed due to the collaboration and responsibility in the group.	20	66.7
We have studied chemistry more fondly and willingly during the Jigsaw applications.	24	80.0
Chemistry lesson has become a more achievable lesson since we were responsible for learning in the applications.	24	80.0
The feeling of success in the tasks given in the applications has increased our self-confidence.	24	80.0
Cooperative learning activities were funny, but I think that they will not contribute to my success in the exams.	6	20.0
Teacher-oriented studies will be more productive for us since chemistry lesson is a difficult one.	6	20.0
The application was funny, but it took so much time.	8	26.7
We were not successful enough, since all group members have not fulfilled their duties with the same effort and care.	5	16.7

without taking into consideration the changes in the particulate structure. The material developed in this study mention that a solvation event alone cannot describe a physical or a chemical change, and it is necessary to consider the behaviors of solute and solvent particles during the solvation process to determine the type of change. In particular, they emphasise that the presentation of acidic and basic properties by covalent molecules such as HBr and NH_3 when dissolving in water occurs as a result of a chemical change. The aim was for the students to become aware that it is necessary to examine the particulate structures of the matters subject to change by evaluating each example as a unique event instead of grouping the changes while investigating the types of reactions.

Most of the misconceptions observed in Group-II and Group-III students arise from the lack of overt presentation of the criteria to be considered in the classification of physical and chemical changes. The absence of these misconceptions in Group-I was due to the prioritisation of the particulate structure of matters during the applications in this group. This finding was similar to what is reported in the literature (Ayyıldız 2012; Caamaño Ros 1993; Hesse and Anderson 1992; Johnson 2000; Tarhan et al. 2013). Encountering fewer misconceptions in Group-I than in Group-II and Group-III by giving particular importance to the consideration of the issues mentioned above in developing the learning material in this study indicates that these issues should be examined carefully when teaching physical and chemical changes and chemical reaction types.

In this study as well as in the others from literature, it turned out that students confused the terms oxidation and oxidizing agent, reduction and reducing agent, and oxidation and reduction (Easa and Blonder 2022; Schmidt and Volke 2003). However, there is no good reason for students to do so. This is not seen as a well-thought-out concept.

The study also revealed some misconceptions that had not been mentioned yet in the literature. Some of the students in Group-I and Group-III stated that there would be no change in the physical properties of matters during a chemical change, but there would be a change in their chemical properties. This misconception was not present in the results of the CCCT and in the SSIs with Group-I students. The reason for this outcome is

that the learning material developed place an emphasis on the particulate structure of the matter as well as on the change of physical properties (such as colour and appearance) during a chemical change.

Some misconceptions, albeit at a low rate, were found in Group-II and Group-III students, such as the notion that there is a change in the nuclear structure of the atoms during chemical changes. It is possible that this misconception is the result of failure to mention the change in the atomic structure when teaching the atomic structure unit in a 9^{th}-grade chemistry lesson.

As indicated by these results, a learning material that would preclude misconceptions and the teaching method are of great importance in improving academic achievement and preventing the misconceptions defined in the literature. Also considering the literature on the conceptual difficulties of lower-than-high school students on many related topics in chemistry, it is clear that such learning materials and suitable learning methods should be used at all levels of education. At secondary school levels, where students are introduced to science lessons, the use of learning methods that will make students like science lessons and actively participate, and the use of materials that can prevent the occurrence of misconceptions in abstract and difficult science subjects are more important than high school, which is the next level, as it will positively affect further learning.

According to the interviews with Group-I and Group-II students, the jigsaw technique contributed to developing friendship and responsibility awareness in the groups, producing an idea and integrating it with the older ones, and feeling important. These students stated that they initially had difficulties with task distribution and group roles due to first-time use of this technique, but they understood the mechanism of the application better in later lessons and could keep a better pace. The students remarked that their skill at self-expression and the ability to discuss events in detail from different perspectives could improve as the number of applications increases. Similar results were revealed in the research of Cooper and Mueck (1990), Baer (2003), Doymus (2008), and Siam and Abdo (2020). Two students from Group-I and three students from Group-II stated that they could not participate in the lesson since they abstain during lessons and when a question-answer method is employed; however, they could share their ideas with their friends in smaller groups. This situation supports the view that the jigsaw technique encourages timid students to participate in the lesson. The post-application interview with the teacher, who acted as an observer and a guide, revealed that the students in the jigsaw groups fulfilled their duties, were willing to solve the problem at hand, created an environment conducive to discussion, and shared their ideas. Thus, there was positive development in the communication and critical thinking skills of the Group-I and Group-II students.

It is worthy of attention that there was positive development in the social skills of the students in Group-I and Group-II, where the jigsaw technique was applied, and their motivation for learning increased compared to Group-III students. The same material was presented in Group-II and Group-III, using the jigsaw technique in the former and the teacher-oriented method in the latter. The achievement level was significantly higher and the misconceptions significantly fewer in Group-II, indicating that the teaching method is of great importance. This outcome can be interpreted as resulting from the discussions and information sharing that the students in Group-II engaged in during the learning process. Similar results of the cooperative learning method with this study are also found in the literature (Abdullah et al. 2018; Acar and Tarhan 2007; Baer 2003; Bowen 2000; Tarhan et al. 2013). On the other hand,

the importance of teaching material designed to prevent misconceptions becomes evident when considering the significantly different academic achievement of 57.87 and 48.57 in Group-I and Group-II, respectively, and the fewer misconceptions in Group-I, where different material was presented using the same learning method. This indicates that the teaching method may not be adequate for preventing misconceptions. Studies on science teaching have argued that teaching materials based on the constructivist approach (i.e. prepared to ensure the active participation of the students) increase the learning performance (Acar Sesen and Tarhan 2010; Ayyıldız 2012; Ayyıldız and Tarhan 2018; Ifeoma 2013). With its findings from the CCCT and the SSI, this study also indicates that, to a large extent, misconceptions were prevented by introducing novel material based on constructivism. Therefore, it can be argued that learning materials developed by experts and with consideration for the literature on preventing misconceptions in chemistry lessons plays a crucial role in enhancing active learning outcomes. In this context, the development of a learning material based on strategies to prevent the occurrence of misconceptions determined from the literature in a way to meet the learning objectives as defined in the current syllabus is the most powerful and innovative aspect of this research.

In conclusion, it is clear that the learning material has a greater impact than the learning method on achievement and the prevention of misconceptions regarding chemical changes. For this reason, learning materials should be developed and used widely in chemistry and the other science lessons.

Limitations of the study

The study is limited to a small research sample of three 9th-grade classes totalling 92 students in a high school in Izmir, Türkiye. Therefore, the generalizability of the present research findings is limited by the nature of the sample used in the study. Although it is reasonable to generalise the present findings for other students, care should be taken in extrapolating the findings to universe.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Yıldızay Ayyıldız http://orcid.org/0000-0003-0984-6224
Leman Tarhan http://orcid.org/0000-0001-7990-0869

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