Science Education International
34(4), 323-338
https://doi.org/10.33828/sei.v34.i4.8

ORIGINAL ARTICLE

Improving Conceptual Understanding of Density and Buoyancy of Liquids through Common Knowledge Construction Model

Ahmet Taşdere[1], Mehmet Fatih Kaya[2]*

[1]Department of Mathematics and Science Education, Faculty of Education, Uşak University, Türkiye, [2]Department of Educational Sciences, Faculty of Education, Uşak University, Türkiye

***Corresponding Author:** mfatih.kaya@usak.edu.tr

ABSTRACT

The aim of the study was to investigate the effect of the Common Knowledge Construction Model (CKCM) on 10th-grade students' conceptual understanding of the buoyancy and density of liquids topic. Within a pre-experimental (one group pre-test/post-test) research design, this study was conducted with 22 of 10th-grade students. To collect data, the Word Association Test (WAT) and Structural Grid (SG) were employed as pre- and post-test. Students' conceptual understanding of the states of objects in different positions (swimming, sinking, and suspending) in the liquid was determined by means of the SG. Through the WAT, the cognitive structure of the students for the stimulus words of mass, volume, density, buoyancy, and Archimedes was determined. According to the post-tests for the SG questions, it was determined that there was a significant increase in the number of correct boxes selected and a significant decrease in the number of incorrect boxes selected. In addition, it was determined that the mind map obtained from the post-WAT, which revealed the cognitive structures of the students, had a much more interrelated and complex network. The findings obtained are compared with other related studies in the literature and some suggestions for teaching science subjects of CKCM are given.

KEY WORDS: Buoyancy and density of liquids liquids; common knowledge construction model; conceptual change; conceptual understanding

INTRODUCTION

The identification of students' misconceptions and the elimination of these misconceptions are one of the most important objectives of science education. Various models and approaches were proposed for this process, also known as conceptual change (Chi and Roscoe, 2002; Duit and Treagust, 2003; Ebenezer et al., 2010; Posner et al., 1982). According to Posner et al. (1982), for a conceptual change to take place, students must be dissatisfied with their current conception, find the new conception comprehensible and plausible, and find it productive. On the other hand, Chi and Roscoe (2002) view conceptual change as a process in which misconceptions are eliminated and prior conceptions are reorganized, corrected, or adjusted during an ongoing development process. As a result of implementing various models in learning environments in the literature, the aim has been to achieve conceptual understanding and learning of science subjects (Campbell, 2006; Karslı and Yiğit, 2015; King, 2013; Özsevgeç and Çepni, 2006).

In this context, Akar (2005), who aimed to achieve conceptual change through the 5E learning cycle model, examined students' conceptual understanding of acids and bases. Campbell (2006) investigated 5th-grade students' understanding of force and motion concepts using the 5E learning cycle. Another frequently used model to achieve conceptual change is context-based learning, which was employed by King et al. (2011) in environmental science, and Karslı and Yiğit (2015) in organic chemistry to improve students' conceptual understanding levels.

In recent years, one of the models that actively engage students in learning environments and enable them to discover and construct knowledge themselves is the "Common Knowledge Construction Model" (CKCM). Particularly, this model, which possesses an enriched content that combines various teaching methods and instructional materials, addresses the processes of conceptual change in its stages with a distinct approach, specifically examining the subject matter (Biernacka, 2006; Ebenezer et al., 2004; Ebenezer et al., 2010).

Theoretical Framework of the CKCM

CKCM, grounded in Marton's theory of variation in learning and Piaget's work on conceptual change, is considered a synthesis of perspectives that define learning through diverse viewpoints (Biernacka, 2006; Ebenezer et. al., 2010). Within this context, the CKCM, which is based on Bruner's cultural symbolic representation, Vygotsky's zone of proximal development, and Doll's postmodernism thoughts on scientific discourse and curriculum development, places particular emphasis on the importance of prior knowledge. By identifying potential misconceptions, the model supports conceptual understanding to establish a foundation for new learning experiences (Ebenezer et al., 2004).

Defining learning as an endeavor to understand an event through various methods, Ebenezer et al. (2010) recommended the use of multiple activities and approaches at each stage of the model. In the model, where activities are categorized into four stages based on their implementation objectives, the first stage, *Discovery and Classification*, aims to reveal students' readiness levels related to the topic and encourages them to question their prior knowledge. Students are expected to freely express multiple ideas concerning the relevant subject. For this purpose, using activities such as pictures, diagrams, visualizations, and videos, opinions about a scientific phenomenon or event are elicited, and explanatory conceptual categories are established (Ebenezer and Fraser, 2001). With the second stage, *Structuring and Negotiating*, instructional activities are diversified, and multiple communication, negotiation, and discussion environments are created. Under the guidance of the teacher, peer-to-peer (student-student) and teacher-student(s) interactions are facilitated for acquiring and constructing new knowledge (Biernacka, 2006). The primary objective of this multilayered communication process is to demonstrate that science is not solely based on observation and experimentation, but also negotiable and constructible within social interaction processes. In the *Transfer and Expansion* stage, the socioscientific dimension of the topics is considered. The open-ended and debatable aspects of the subject are discussed in the context of different disciplines, and solutions are sought by relating them to local or national societal and environmental issues (Ebenezer et al., 2004). At the end of this process, students are expected to transfer their conceptions to other contexts such as science, technology, society, and environment. In the *Reflection and Evaluation* stage, it is recommended to employ complementary assessment techniques to evaluate the multiple learning domains that students constructed throughout the process.

Earlier Studies of the CKCM

Numerous studies were conducted on the implementation of the CKCM for various instructional purposes. In this regard, studies focusing on achieving conceptual change through CKCM (Bakırcı and Ensari, 2018; Duruk et al., 2021; Ebenezer et al., 2010; İyibil, 2011; Wood, 2012; Vural, 2016), descriptive research investigating teachers' and pre-service teachers' opinions (Bakırcı et al., 2015; Çavuş Güngören and Hamzaoğlu, 2020), and studies comparing CKCM with different learning models (Bakırcı and Çepni, 2012; Çavuş Güngören, 2015) are noteworthy.

The science topics addressed in these studies also vary. Kıryak (2013) examined the effect of CKCM on water pollution, Bayar (2019) focused on the solar system and eclipses, Bakırcı (2014) investigated light and sound, while Çavuş Güngören (2015) studied the teaching of the nature of science using CKCM. In these research studies, multiple activities such as Predict-Observe-Explain (POE), Conceptual Change Text (CCT), Concept Cartoon (CC), group discussions, and visualization tools (videos, banners, posters, current news, diagrams, and charts, etc.) were incorporated, particularly in the second and third stages of the model, thus, it is aimed to develop multiple knowledge, skills, and competencies in students (Bakırcı, 2014; Caymaz, 2018; Ebenezer et al., 2010; Kıryak, 2013; Vural, 2016).

In relevant research studies, it was emphasized that the CKCM is effective in increasing academic achievement, facilitating conceptual change, enhancing the level of conceptual understanding, developing views on the nature of science, and fostering scientific process skills such as critical thinking, decision-making, and problem-solving (Bakırcı and Çepni, 2014; Caymaz and Aydın, 2021; Karakaya Cirit, 2020; Yıldızbaş, 2017). However, there have also been negative outcomes mentioned, such as its unsuitability for teaching all science topics (Bakırcı, 2014) and the time-consuming nature of some stages (Çavuş Güngören and Hamzaoğlu, 2020).

Previous Studies of Density and Buoyancy of Liquids

Studies on the density of liquids and buoyancy force in the literature appear to revolve around three main objectives. Descriptive studies identifying students' potential misconceptions, conceptual understanding, and knowledge levels (Dorji, 2021; Harrell and Subramaniam, 2014; Kılınç, 2017; Kıray et al., 2015; Shaker, 2012; Wong et al., 2010), conceptual change/teaching studies aimed at addressing these misconceptions and improving the level of conceptual understanding (Çepni and Şahin, 2012; Hardy at al., 2006; Harrell et al., 2022; Potvin and Cyr, 2017; She, 2005), and pedagogical content knowledge studies that address these two objectives within a broader pedagogical context (Dawkins et al., 2008; Jang and Chen, 2010; Kwak and Choi, 2012) are notable. When examining conceptual change/teaching studies directly related to the purpose of this study, it is observed that various models and techniques are used. Çepni and Şahin (2012) revealed the impact of the 5E learning cycle model on the conceptual understanding level of 8th-grade students regarding buoyancy force. Conducting a similar study for teaching the concepts of floating and sinking, Çepni et al. (2010) demonstrated the effectiveness of the 5E learning cycle model enriched with teaching techniques such as conceptual change texts, animations, and concept cartoons. Radovanović and Sliško (2013) investigated the effectiveness of the POE technique in addressing alternative conceptions related to buoyancy force. Ünal (2008) attempted to address conceptual misconceptions about floating and sinking by implementing hands-on activities supported by techniques such as POE and conceptual change texts. In a similar study, Hardy et al. (2006) investigated the impact of instruction enriched with activities based on a constructivist learning approach on primary school students' conceptual changes regarding floating and sinking. In related research, application examples were presented for teaching specific concepts such as buoyancy force of liquids (Çepni and Şahin, 2012; Radovanović and Sliško, 2013), floating and sinking (Çepni et al., 2010; Hardy et al., 2006; Paik et al., 2017; Ünal, 2008; Zoupidis et al., 2021), Archimedes' principle (Dahl et al., 2020; Gianino, 2008;

Loverude et al., 2003), and density (Gianino, 2008; Harrell and Subramaniam, 2014). In this study, the teaching of the density of liquids, floating-sinking, and buoyancy force is carried out by addressing many concepts mentioned above on a holistic and comprehensive ground. The reason for addressing them on a comprehensive ground is the preference for the CKCM, which has highly diversified multiple teaching practices at each stage. Accordingly, it is believed that the chosen subject matter is compatible with the teaching model.

The Significance of the Study

In the study, it is presented in detail which topics and concepts are taught at each stage of the CKCM, and the roles of teachers and students are specified. In this way, example applications of CKCM stages for the topic of liquid density and buoyancy force are provided for teachers. In each stage, the aspects of the subject emphasized are detailed, and activities that can be applied by every teacher in their own classrooms are included. Thus, it is believed that this study is guiding and encouraging for similar CKCM studies. In a very recent study specifically emphasizing this situation, Candaş and Çalık (2022) suggested that teachers and science educators develop similar instructional designs for other science subjects following their CKCM implementation for the sustainable development topic. As a result of this research, an exemplary instructional design suitable for CKCM for the topic of liquid density and buoyancy force will be presented. Moreover, different types of misconceptions related to the density and buoyancy force of liquids in the minds of students were revealed before and after CKCM using WAT and structural grid (SG) in the data collection processes. In this way, comprehensive and rich findings were obtained, and the changes/developments in students' cognitive structures were presented with visualized models.

The Aim of the Study

The aim of the study was to investigate the effect of the CKCM lesson sequence on 10th-grade students' conceptual understanding of the density and buoyancy of liquids topic. The following research questions guided the current study:

1. What are 10th-grade students' cognitive structure of density and buoyancy of liquids in pre-WAT and post-WAT?
2. What are 10th-grade students' misconceptions about density and buoyancy of liquids in pre-SG and post-SG?

METHODOLOGY

Research Method

The present study included a pre-experimental research design to determine the extent to which CKCM improved students' conceptual understanding of the topic of density and buoyancy of liquids (Trochim, 2001). Because innovative teaching interventions and instruments are designed in regard to the experimental group - not the control one, the experimental group is expected to perform better than the control one in post-test (Çalık et al., 2010; Kıryak and Çalık, 2018; Sadler, 2009). As Çalık (2013) stated, since the experimental group is exposed to the teaching intervention within a significant amount of time, it is expected that the students at the experimental group routinely outperform those in the control one on the post-test scores. Further, a pre-experimental research design was introduced as the methodology of the current study, since the principal aim of the current study was to provide the conceptual growth of the experimental group with the CKCM intervention rather than comparing it with different teaching models (Kıryak and Çalık, 2018). Also, many studies with a pre-experimental research design assume that such a pre-application serves as a starting point for investigating the effectiveness of the instructional intervention in a pre-test/post-test design (Candaş and Çalik, 2022; Çalık et al., 2015). Therefore, the author preferred to use only a one-group experimental design measured its own conceptual growth without any comparison (control) group.

Sample

This study was conducted with 22 (12 females and 10 males) 10th-grade students aged 15-16 enrolled in a middle school in the city of Uşak in Türkiye. The students were generally from socioeconomically average groups and volunteered to take part in the study. Throughout the study, activities developed according to CKCM phases were administered to the students in the format of worksheets.

Data Collection

The study has made use of two data collection tools: (1) SG and (2) Word Association Test (WAT). These techniques have been extensively used in other studies in the assessment of relationships, associations, misconceptions, and conceptual changes in student's cognitive structure (Bahar et al., 1999; Ercan et al., 2010; Kıryak and Çalık, 2018; Nakiboglu, 2008). These techniques are among the alternative assessment and evaluation techniques that are recommended to be used in the science, physics, chemical, etc. curriculum in Turkey. The techniques were administered at the commencement and end of the teaching process and were used in identifying conceptual change in students.

SG consists of different cases for floating and sinking delivered in boxes for selection and students were asked questions regarding these cases and required to select the boxes that they found to be correct. This technique was instrumental in determining the level of conceptual understanding in students.

WAT provided the students with stimulus words related to the topic and the students were asked to write down what these words brought to their minds. A frequency table was created by these concepts and the words supplied in their answers to obtain mind mapping which was later used in the interpretations of conceptual change.

Ethical Procedures

Ethical permission was obtained from Uşak University Social and Human Sciences Ethics Committee for the research to comply with ethical rules. Then, the participants voluntarily participated in the study. Within the scope of research ethics, attention was paid to privacy and confidentiality and the names of the participants were not used.

Data Analysis

SG

SG is an important tool since it provides an assessment of meaningful learning and identification of misconceptions in student's cognitive structures and shortcomings and problems in the knowledge e network (Johnstone et. al., 2000; Tasdere and Ercan, 2011). In this study, students were provided with 9 boxes, each of which contained cases related to 'floating and sinking' situations (Appendix 1). Students were asked some questions according to the information provided inside these boxes and required to select the boxes that they thought to contain the correct information. The information in the selected boxes in the grid provided as pre- and post-test to the students were analyzed and interpreted in terms of conceptual change. The interpretations took the number of selections of correct and incorrect boxes into consideration. SG, which was developed by the first author of this study, was also used as a data collection tool in a study carried out to detect students' misconceptions. (Taşdere and Ercan, 2011). According to the results obtained from this research, it was thought that SG was an effective data collection tool in determining the level of misconceptions and conceptual understanding of the density and buoyancy of liquids. In addition, views of four academicians in the field of science, physics, and assessment and evaluation were sought for the validity of the technique before it was finalized to be used with the students. Since SG was used to determine misconceptions in this study, the results obtained from Taşdere and Ercan (2011) and the opinions of the experts are considered to be sufficient for the validity and reliability of the data collection process.

According to the findings obtained from the SG, different types/content of misconceptions have been identified. If all the boxes selected by the students for each question are correct, they are in the scientifically correct information category; if the boxes selected by the students contain scientifically correct answers along with incorrect boxes, they are in the partial misconception category; if all the boxes selected by the students are incorrect, they are in the misconception category. Each question was analyzed separately according to this categorization and presented in tables in the findings. Thus, by comparing the answers obtained from the pre-test and post-test based on the correct information and misconceptions they contain, the development in students' conceptual understanding levels was determined.

WAT

One of the tests that display the students' cognitive structure and the associations between the concepts in this structure (Bahar et al., 1999). The WAT reveals students' cognitive structures, inter-and intralinks between them. In this technique, the student answers in a given time period (generally 30 s or 1 min) by providing words/vocabulary that he/she associates with a given stimulus word a given topic. It is assumed that the consecutive answers provided by students to a given stimulus word from long-term memory set forth relationships between concepts in the cognitive structure and show semantic connections (Bahar et al., 2006). It is important that these stimulus words are crucial for the topic, in other words, the words should be related to the concepts that the topic is built on.

Five stimulus words representing the density and buoyancy of fluids were selected to create the WAT. In selecting the stimulus words for the density and buoyancy topic, a group of experts (two experienced physic teachers and two academicians in science education) were employed for negotiation and content validity. Given the Turkish Physics curriculum and textbooks, they consensually agreed the stimulus words "Mass, Volume, Density, Buoyancy, and Archimedes." The stimulus words were selected within the scope of density and buoyancy topic, and they were presented to students in a sub-section under WAT. Sample WAT pages presented to each participant are shown below:

All WAT sheets had the same format. Thereby, the interconnectedness between stimulus and response words emerged using word frequencies in pre- and post-WAT. In the WAT, answer words for each stimulus words were identified individually. A frequency table was prepared that shows how many types of answer words were used and how often they were used for given stimulus words. Two separate mind maps were created after examining both pre- and post-tests. Cutoff point (CP) technique developed by Bahar et al. (1999) is used in the preparation of mind maps. In this technique, 3–5 words below the number of answers that are most frequently provided for any stimulus words in the WAT in the frequency table are used as the cutoff point and the answers found to be above that frequency are written in the first section on the map. Later, the cutoff point is pulled down gradually and the process continues until all stimulus words are mapped (Bahar et al., 1999; Nakiboglu, 2008).

Another analysis method used in WAT is the relatedness coefficient (RC) method index. In the calculation of this index proposed by Bahar et al. (1999), rank values (degrees) are given according to the number of stimulus words produced by students. Taking these values into account, RC is calculated, which reveals the strength of the relationship between any two stimulus words. While calculating, the common (same) words produced for the two stimulus words selected are taken into account. RC is calculated according to the formula presented in Figure 1:

$$RC = \frac{\begin{array}{c}\textit{Sum of Multiplications of Sequence}\\ \textit{Numbers of Common Words}\end{array}}{\sum n^2 - 1}$$

N=The number of words with many words

Figure 1: RC calculating formula

Table 1: WAT pages

PAGE 1	PAGE 2	PAGE 3	PAGE 4	PAGE 5
MASS………………	VOLUME.	DENSITY.	BUOYANCY………………	ARCHIMEDES ………………
MASS………………	VOLUME.	DENSITY.	BUOYANCY………………	ARCHIMEDES ………………
MASS………………	VOLUME.	DENSITY.	BUOYANCY………………	ARCHIMEDES ………………
MASS………………	VOLUME.	DENSITY.	BUOYANCY………………	ARCHIMEDES ………………
MASS………………	VOLUME.	DENSITY.	BUOYANCY………………	ARCHIMEDES ………………
MASS………………	VOLUME.	DENSITY.	BUOYANCY………………	ARCHIMEDES ………………
MASS………………	VOLUME.	DENSITY.	BUOYANCY………………	ARCHIMEDES ………………
MASS………………	VOLUME.	DENSITY.	BUOYANCY………………	ARCHIMEDES ………………
MASS………………	VOLUME.	DENSITY.	BUOYANCY………………	ARCHIMEDES ………………
MASS………………	VOLUME.	DENSITY.	BUOYANCY………………	ARCHIMEDES ………………
Related Sentence……	Related Sentence………	Related Sentence………	Related Sentence…………..	Related Sentence…………..

Table 2 presents the formula and sample table to calculate the related connectedness for any two stimulus words (e.g., MASS and DENSITY).

According to Table 1, for example, the common words in the MASS-DENSITY were mass (degrees 7 and 1), weight (degrees 6 and 4), and density (degrees 4 and 6). Accordingly, the related coefficient between the concepts of Mass and Density:

$$RC = \frac{(7x1)+(6x4)+(4x6)}{7^2+6^2+5^2+4^2+3^2+2^2+1^2-1^2} = \frac{45}{139} = 0.395$$

Table 2: Response words for MASS and DENSITY

Response words and frequency for mass	Degree	Response words and frequency for density	Degree
MASS*	7	DENSITY*	6
Weight (*f*=16)	6	Mass (*f*=14)	5
Water (*f*=14)	5	Weight (*f*=13)	4
Density (*f*=11)	4	Liquid (*f*=9)	3
Scales (*f*=7)	3	Buoyancy (*f*=4)	2
Kg (*f*=6)	2	Mass (*f*=3)	1
Measurement (*f*=3)	1		

RC values for all stimulus words are calculated separately according to the formula and the values are shown in the table. Based on this Table 4, mind maps showing the relationships between stimulus words are drawn.

Teaching Intervention

Researchers developed rich content activities for each stage of CKCM for the topic of density and buoyancy of liquids. Activities prepared in accordance with the character of each stage are presented to students in the form of group discussions, case studies, visualization tools (TGA, cartoons, media news, etc.), and worksheets. How the relevant activities were applied at each phase can be seen in detail Table 3:

Findings

Findings obtained from the WAT and SG are presented in this section.

Findings from the WAT

Table 2 displays the number of words chosen as answers for each stimulus word in the pre- and post-WAT. The use of the number of words students produced is one of the techniques utilized in the analysis of the data. The number and quality of words associated with the concept can be used to identify whether the stimulus word is understood or not since understanding is related to the other words associated with the stimulus words (Bahar et al., 2006). A concept that does not invoke any associations may be argued to be meaningless and it can be said that meaning increases with associations. In this study, total answer words were found to be 245 and 420 for pre-test and post-test, consecutively. An increase in the number of answer words associated with all stimulus words was observed; as a result, that highlights development in the understanding of stimulus words.

The second method used in the analysis of the findings from the WAT is RC analysis. Accordingly, RC values among stimulus words are presented in Table 5.

RC values are mapped from strong to weak to visualize the strength of the relationship between stimulus words. For this, the cutoff point technique proposed by Bahar et al. (1999) was used. Accordingly, the cutoff point range with the strongest relationship was preferred RC≥750. Cutoff points that are drawn down at certain intervals are terminated in the range of 0.250≥RC≥0.499, where relations between all stimulus words occur. Relations between stimulus words are shown in Figure 2, from strong to weak.

For RC = 750 and above, the strongest relationship between the stimulus words emerged in the final WAT between Mass-Density-Volume and Buoyancy-Archimedes. In the initial WAT, however, no related network structure among the stimulus words was observed within this range.

For RC > 500 ≥ 749: In this range, the initial WAT revealed two different related networks between the Mass-Volume-Density and Buoyancy-Archimedes stimulus words. In the final WAT, however, multiple associations emerged among all the stimulus words. Accordingly, Mass-Volume, Volume-Buoyancy, Volume-Archimedes, Density-Buoyancy, and

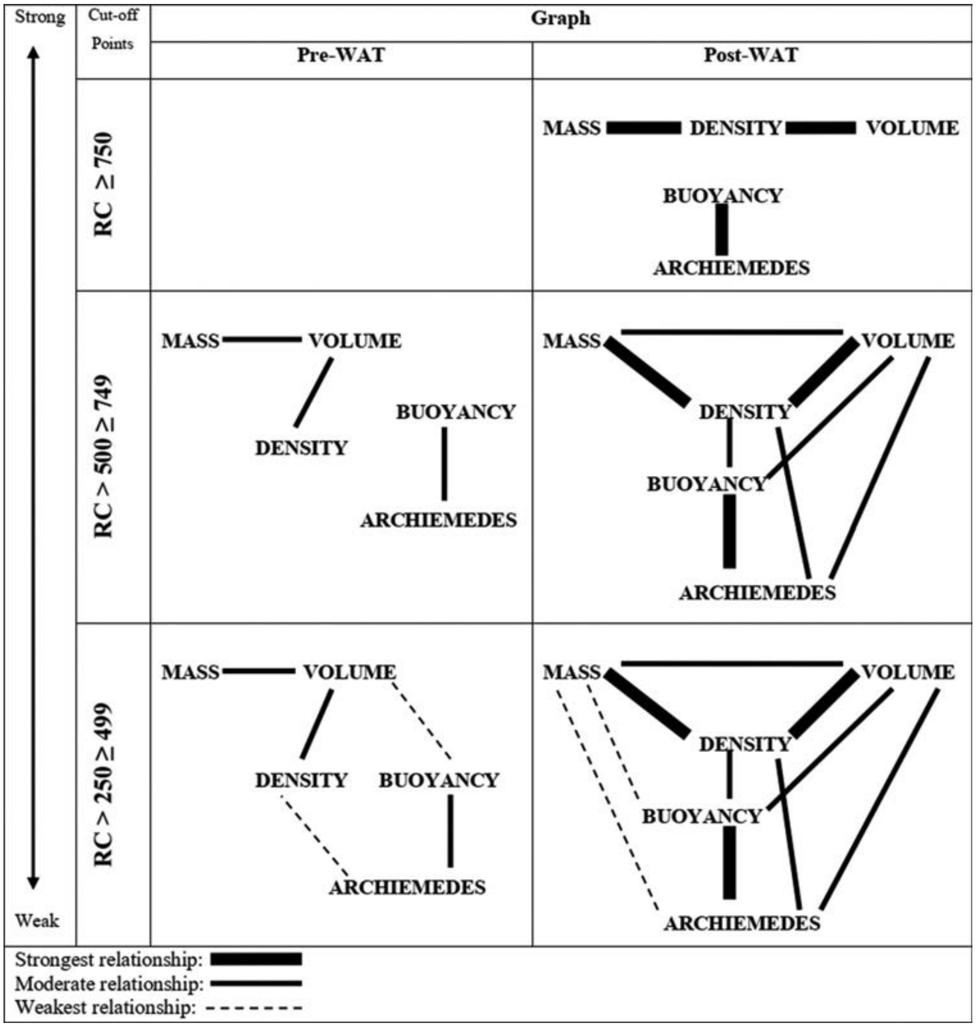


Figure 2: Relationship among the stimulus words according to RC values

Density-Archimedes associations appeared within this range.

For RC > 250 ≥ 499: In this range, related structures emerged among all the stimulus words for both the initial WAT and the final WAT. In the initial WAT, Volume-Buoyancy and Density-Archimedes associations were notable, while in the final WAT, Mass-Buoyancy and Mass-Archimedes associations stood out. Accordingly, the fewest number of common response words were generated among these stimulus words.

Another technique used in the analysis of WAT findings is the cutoff point technique. In this context, a frequency table consisting of response words given to stimulus words was created (Table 6).

The most frequently produced answer words are placed at the top of the mind map. In Figure 2, the mind map demonstrating the cognitive structures of the students is seen when the cutoff points are drawn down at certain intervals until all the stimulus words revealed.

Cutoff point 15 and above: In the pre-test, the weight response word was produced most frequently for the mass key concept. In the post-test, in addition to this association, mass-volume and volume-density relationships emerged to form a holistic network.

Cutoff point between 10 and 14: In this range, no new word was produced in the pre-test. In the post-test, however, the holistic network from the pre-test emerged with stronger bidirectional relationships. In addition, the Archimedes-Buoyancy relationship also appeared in this range.

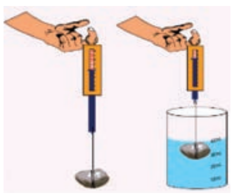
Cutoff point between 5 and 9: In this range where all stimulus words emerged, in the pre-test, the word "*Weight*" was the common response word produced for the stimulus words mass, volume, density, and buoyancy. The word "*Water*" was the response word for density and buoyancy stimulus words, and the word "*Scientist*" was the response word for the Archimedes key concept. In the post-test, a highly related, complex, and holistic cognitive structure, represented by a conceptual network, emerged. Accordingly, the word "*Weight*" was the common response word produced for the stimulus words: Mass, Buoyancy, and Archimedes; the word "*Object*" for Mass, Density, and Volume stimulus words; the word

Table 3: Teaching intervention

Learning strategies	Activities

Phase 1: Exploring and categorizing

- To determine the level of student pre-knowledge, SG and WAT (Appendix 1 and Table 1) were implemented first to display their cognitive levels (possible misconceptions). Since these techniques are patterned to expose the relationships and associations between the concepts in the cognitive structures, they will also help categorize student pre-conceptions.
- A bowlful of water was used to drop objects that sank, suspended, and floated in order for the students to explore the concept of "buoyancy". The students were asked questions related to the situations of the objects in the water.
- Students were presented with a problem situation and a discussion was encouraged in line with the answers; they provided to this problem situation. The problem situation used in the activity was the narrative related to Archimedes' discovery of buoyancy. The teacher-guided teacher-student and student-student discourses through these activities.



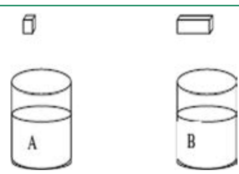
- The next phase helped students to discuss the reasons for the difference among the weights measured by dynamometer and each group was taught about buoyancy; the reverse effect of water over objects and they were supported to reach the deduction of "buoyancy=weight in air-weight in water" using the values from the chart. They were also asked to fill in the values in the table by making different measurements.
- The directions help receive student ideas (thesis). They are asked to explain the reasons (data) and rationale for their ideas and to compare them with each other while filling in the values in the table.

- A bowl filled with water that can be observed by the whole class is used to drop objects in (or each group may bring their own bowls for group observations) such as rubbers, iron, candle, and wood pieces. The questions below are directed to students by focusing on the different states of the objects in the water:
  1. What affects the conditions of the objects in the water?
  2. Can you give examples from your daily life of objects that swim is suspended or sinks in a liquid?
  3. How is it that while some objects swim or get suspended in the water the others sink?
  4. Can you give examples from your environment to the objects or events related to objects swimming, suspending or sinking in liquids?
- Later students were asked to measure the weights of objects in air and in water by tying a weight to the dynamometer. The values are turned into a table and student ideas are questioned about the differences in these values.

Weight of rock in air (N)	Guess about the weight of the rock in water			Weight of the rock in water (N)	Explanation (result)
	Increases	Decreases	Does not Change		

In a Worksheet mentions a narrative in the time of Archimedes. The worksheet consists of questions regarding the solution he found about the task given by the King while he was taking a bath. Student–student discourses were actively applied in this process. In the questions, it was asked what the weights and volumes of the liquids displaced by different objects could be when they were left in the liquid. This process was continued by having the groups have discussions both within and between groups.

Phase 2: Constructing and Negotiating



- Worksheet checks the student ideas and information about the floating and sinking situations in different liquids. With this aim in mind, a candle was left both in water and ethyl alcohol and students were asked about their opinions. Different objects were released in different amounts of liquids and student views were gathered. The activity follows the socio-cognitive conflict activity of Skoumios (2009) that examines floating and sinking positions. Argumentation-based Predict-Observe-Explain method was developed and a climate for discussion was created in the class in and between groups.
- During the activity variables (dependent-independent) were checked individually and students were expected to reach the conclusion that objects take different positions in liquids due to the differences in liquid density.
- To support this activity a new activity was implemented regarding the concepts that have been learned. Diagnostic Tree (DT) developed regarding the different float-sink situations in liquids was turned into

- An activity was designed based on argumentation with a Predict-Observe-Explain approach.

"Water and alcohol were placed in separate bowls. The water was determined to be 250 ml and alcohol was 500 ml. A big piece of candle and a smaller candle, half size of the bigger one, was prepared to be placed in the water and alcohol, respectively. Students were asked to guess what will happen when the candle was placed in liquids. They were also asked to explain their rationales and compare their ideas with the members of their group"

- The students wrote their predictions on the worksheet and shared their reasons with class. Later, they were given opportunities to observe the accuracy of their claims by testing the ideas of each group individually (teacher also shares his/her ideas at this point to promote discussions). This phase was especially designed to create conflicts in the minds of the students.
- The students were given chances to test each guess individually to observe the accuracy of their own ideas. Meanwhile, the teacher also shared her opinion to involve the students in the discussion.
- In this manner, students were provided with a climate in which they can obtain correct knowledge not only through experiments and observations but also through discussions and by developing dissenting opinions (with DT-based argumentation)

(Contd...)

Table 3: (Continued)

Learning strategies	Activities
Phase-3: Extending and Translating	
an argumentation (racing ideas) based activity and presented to the students. In this activity, students propose their own claims, proofs (dataset), and rationales and compare their own ideas with the ideas of their friends in the group in a discussion climate (Appendix 1) ● Although DT is an assessment-evaluation tool in actuality, it was adapted to the teaching process in this activity. Thus, the learning–teaching process and the measurement-evaluation process were carried out together. ● In this phase, relationships related to science-technology-society-environment were examined and class discussions were developed through these relationships. Predict-Explain-Observe-Explain activity was implemented with this purpose. ● The activity aims to have students find the reasons for why the unpeeled orange swims in water whereas the peeled orange sinks. Right after this activity, why play dough (or aluminum foil) containing an iron marble sink in water but the same play dough does not sink when it was molded into the shape of a ship and the marble is placed inside it was questioned. ● The activities were objectified by providing examples that reflect the technological and societal dimensions and by having students watch related videos. ● In these examples, the passage of ships through the Panama Canal, accidents during the construction of the canal, etc., Socioscientific discussions were made taking into account the circumstances (advantages/disadvantages, human deaths/economic benefits, etc.) ● After the activities in this phase, performance tasks were assigned to the students which presented different situations from daily life related to the topic. These performance tasks were shared in the class in the format of posters.	● The activity first asked the students what happens to the peeled and unpeeled oranges when they are placed in water. Later they were asked to give reasons for their deliberations. The initial guesses of the students were compared with the final solution after the observation and testing were completed. The students who had differences in their guesses and observations were asked questions regarding the reasons for the situation to direct them to reach the correct way of thinking (Predict-Explain-Observe-Explain activity) ● Videos related to the applications of these activities in daily life were watched by the students to objectify the topics and the learning (how ships weighing tons float on water, the moments of the ships being released into the sea, etc.). ● The performance task assigned to the students required the students to find examples from various technological and societal applications related to the topic to be presented to the class in the formats of posters. ● Examples of these situations: Is it easier to swim in the sea or in the pool? Why? Glaciers' swimming closer to the surface on the oceans, passing of ships thorough Panama Canal, separating the tomatoes in the tomato processing factory, etc.
Phase-4: Reflecting and assessing	
● WAT and SG given as pre-tests to determine whether conceptual change has taken place and the level of conceptual change was also implemented as post-tests to reveal student cognitive structures and conceptual levels of knowledge. ● In fact, the evaluation phase which is represented as the last phase in the model hierarchy (CKCM) should be process oriented and needs to be undertaken according to the alternative assessment and evaluation approach. In this context, different assessment techniques (concept map, diagnostic tree, posters) were adapted into the teaching process and implemented during the process in different techniques.	● In this study, WAT was used to determine student cognitive structures and to reveal the relationships and associations among the concepts in their minds. WAT implemented as pre- and post-test helped determine the level of realization in conceptual change. ● Structured grid technique was implemented as pre- and post-tests to determine the level of knowledge in conceptual levels and to test whether meaningful learning takes place or not. ● Since these techniques are implemented at the commencement and end of the teaching process, they act as reflective evaluations that help us identify the initial and current levels of students

Table 4: Stimulus words and vocabulary count in the answers

Stimulus words	Vocabulary count	
	Pre-test	Post-test
Mass	44	88
Volume	58	84
Density	46	78
Buoyancy	60	86
Archimedes	37	84
Total	245	420

"*Water*" for Mass, Density, and Buoyancy stimulus words; the word "*Liquid*" for Density and Volume stimulus words; and the word "*Rock*" for Buoyancy and Archimedes stimulus words. Additionally, the relationships Archimedes-Floating, Archimedes-Sinking, Archimedes-Scientist, Archimedes-Eureka! Eureka!, Mass-Kg, Mass-Unit, and Buoyancy-Force emerged in this range. Particularly, the strong relationship that emerged in the correlation coefficient analysis (Figure 1) between the stimulus words: Mass, Density, and Volume, and between Buoyancy and Archimedes, formed a bidirectional structure in this range.

Table 5: The mean relatedness coefficients (RC)

	2		3		4		5	
	Pre-WAT	Post-WAT	Pre-WAT	Post-WAT	Pre-WAT	Post-WAT	Pre-WAT	Post-WAT
1	0.576	0.744	0.336	0.796	0.352	0.485	0.122	0.406
2			0.571	0.846	0.374	0.615	0.197	0.69
3					0.477	0.702	0.27	0.744
4							0.618	0.768

1: Mass, 2: Volume, 3: Density, 4: Buoyancy, 5: Archimedes

Findings from SG

The findings obtained from the structured grid were analyzed separately for each question. Students' answers were categorized as correct information, misconceptions, and partial misconceptions. In total, 7 different content/types of misconceptions and 11 different partial misconceptions emerged. The development in the conceptual understanding levels was revealed by comparing the findings obtained from the pre-test and post-test. This development process is presented in tables, specific to each question.

1. Answers to first SG question

Answers	Pre-SG	Post-SG	Misconception content-type
Correct Answer	-	17 Students (3., 5., 8. boxes)	
Partial Misconception	7 students (1.,3., 5., 6., 7., 8. 9. boxes)	2 students (1.,3., 5., 6., 7., 8., 9. boxes	Suspended objects as well as floating objects have a density equal to the liquid density.
Misconception	9 students (1. box)	2 students (1. box)	The density of an object that is half submerged in the liquid is equal to the liquid density.
	3 students (9. box)	-	The density of objects that are mostly submerged in the liquid is equal to the liquid density.
No Answered	3 students	1 student	
Total	22 students	22 students	

Correct Answer: In the pre-test, none of the students answered the first question of the SG correctly. In the post-test, however, seventeen students chose boxes 3, 5, and 8, providing the correct answers.

Partial Misconception: In the pre-test, seven students chose boxes 1, 3, 5, 6, 7, 8, and 9, revealing the partial misconception that "Suspended objects as well as floating objects have a density equal to the liquid density." In the post-test, this number decreased, and two students displayed partial misconceptions.

Misconception: In the pre-test, nine students exhibited the misconception that "the density of an object that is half submerged in the liquid is equal to the liquid density" by selecting only the first checkbox. In the final test, only two students selected the first checkbox exclusively. Similarly, in the pre-test, three students exhibited the misconception that the density of objects that are mostly submerged in the liquid is equal to the liquid density by selecting only the ninth checkbox. However, in the final test, no student exhibited this misconception by selecting only the ninth checkbox.

No Answered: In the pre-test, three students were unable to answer this question, while in the final test, one student left the question unanswered.

2. Answers to second SG question

Answers	Pre-SG	Post-SG	Misconception content-type
Correct Answer	4 students (2. and 4. boxes)	18 students (2. and 4. boxes)	
Partial Misconception	8 students (2., 3., 4., 5. and 8. boxes)	2 students (2., 3., 4., 5. and 8. boxes)	The density of suspended objects, as well as sinking objects, is greater than the density of the liquid.
	3 students (2., 4., and 8. boxes)	-	The density of suspended objects near the bottom, along with sinking objects, is also greater than the density of the liquid.
Misconception	5 students (1., 6., 7. and 9. boxes)	1 student (1., 6., 7. and 9. boxes)	The density of floating objects is greater than the density of the object.
No Answered	2 students	1 student	
Total	22 students	22 students	

Correct Answer: In SG's second question, four students selected the correct checkboxes in the pre-test, while in the final test, 18 students selected the correct checkboxes (2 and 4 boxes)

Partial Misconception: In the pre-test, eight students exhibited partial conceptual misconceptions by selecting checkboxes 2, 3, 4, 5, and 8, indicating that "the density of suspended objects, as well as sinking objects, is greater than the density of the liquid". In the final test, this number decreased, and two students exhibited partial conceptual misconceptions.

Similarly, in the pre-test, three students exhibited partial conceptual misconceptions by selecting checkboxes 2, 4, and 8, suggesting that "the density of suspended objects near the

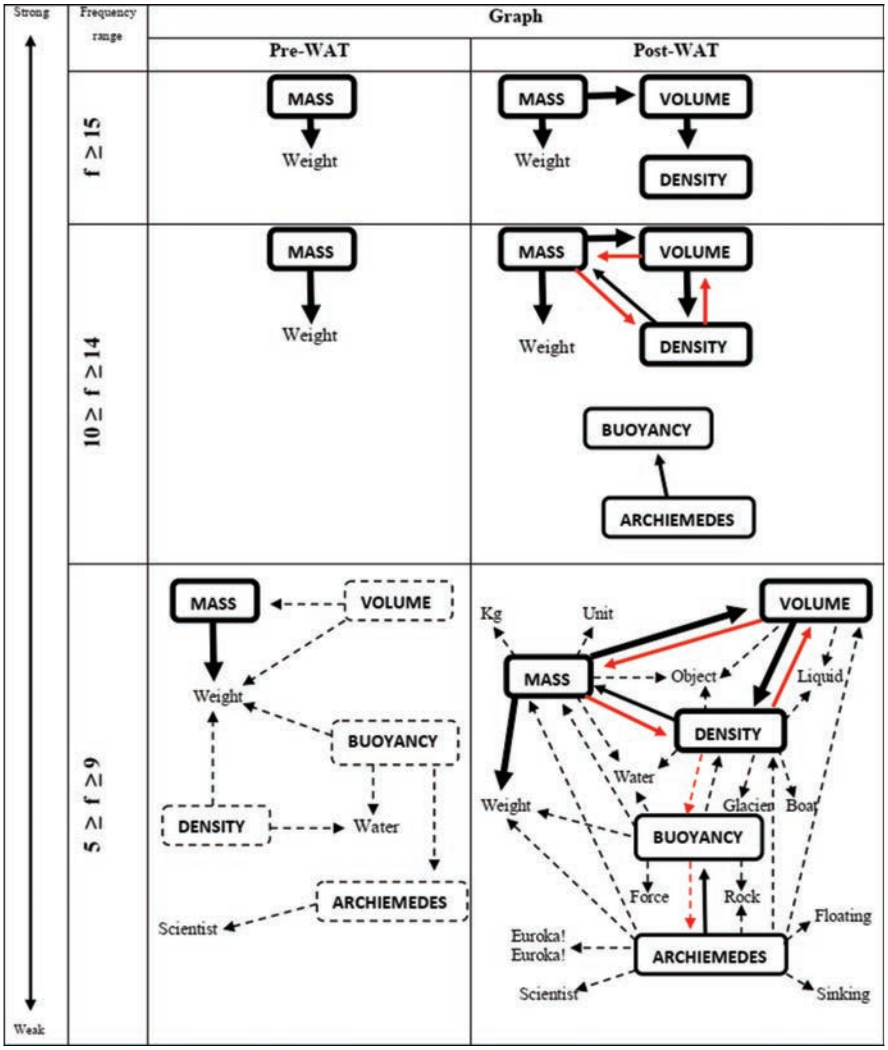


Figure 3: The cognitive structure of students according to cutoff point technique

Table 6: Response words to stimulus words of the frequency table

Response words	STIMULUS WORDS									
	MASS		VOLUME		DENSITY		BUOYANCY		ARCHIMEDES	
	Pre-WAT	Post-WAT	Pre-WAT	Post-WAT	Pre-WAT	Post-WAT	Pre-WAT	Post-WAT	Pre-WAT	Post-WAT
Mass			6	10	3	10	2	7		7
Volume	3	15			4	11	2	9	2	7
Density		12	1	15			2	8	2	7
Buoyancy		3		3	2	5			3	12
Archimedes							5	5		
Weight	15	15	7	3	5	5	5	6	1	3
Kg		5		2		1				
Object		9		5		5		2		1
Water		5	4	4	6	8	7	8	3	5
Scientist									6	6
Liquid				5		5		1		2
Floatink						1		2		5
Sinking						1		1		5
Euroka! Euroka!								1		6
Rock				1		2	5	5	2	5
Force	2	5			1		3	5		
Glacier		3		2		5		1		
Boat				3		5				

bottom, along with sinking objects, is greater than the density of the liquid". However, in the final test, no student exhibited this partial conceptual misconception.

Misconception: In the pre-test, five students exhibited the misconception that "the density of floating objects is greater than the density of the object" by selecting checkboxes 1, 6, 7, and 9. In the final test, only one student exhibited this misconception.

No Answered: In the pre-test, two students were unable to answer this question, while in the final test, one student left the question unanswered.

3. Answers to third SG question

Answers	Pre-SG	Post-SG	Misconception content-type
Correct answer	3 students (1., 6., 7. and 9. boxes)	15 students (1., 6., 7. and 9. boxes)	
Partial Misconception	6 students (6. box)	2 students (6. box)	The density of objects that have only a majority of their volume (more than half) outside of the liquid is less than the density of the liquid.
	4 students (1. and 6. boxes)	2 students (1. and 6. boxes)	The density of objects that have only half and a majority of their volume (more than half) outside of the liquid is less than the density of the liquid.
	3 students (7. and 9. boxes)	1 student (7. and 9. boxes)	The density of floating objects that have only a majority of their volume (more than half) submerged in the liquid is less than the density of the liquid.
Misconception	3 students (3. box)	1 student (3. box)	The density of suspended objects that are positioned close to the liquid surface is less than the density of the liquid.
	1 student (3. and 5 boxes)	-	The density of suspended objects that are positioned close to both the liquid surface and the middle of the liquid is less than the density of the liquid.
No Answered	3 students	1 student	
Total	22 students	22 students	

Correct Answer: In SG's third question, three students selected the correct checkboxes in the pre-test, while in the final test, 15 students selected the correct checkboxes (1, 6, 7, and 9 boxes).

Partial Misconception: In the pre-test, six students exhibited partial conceptual misconceptions by selecting only checkbox 6, indicating that "the density of objects that have only a majority of their volume (more than half) outside of the liquid is less than the density of the liquid." In the final test, this number decreased, with only two students exhibiting partial conceptual misconceptions.

Similarly, in the pre-test, four students exhibited partial conceptual misconceptions by selecting checkboxes 1 and 6, indicating that "the density of objects that have only half or a majority of their volume (more than half) outside of the liquid is less than the density of the liquid." In the final test, one student exhibited partial conceptual misconceptions.

In the pre-test, three students selected checkboxes 7 and 9, indicating that "The density of floating objects that have only a majority of their volume (more than half) submerged in the liquid is less than the density of the liquid," and exhibiting partial conceptual misconceptions. In the final test, only one student exhibited partial conceptual misconceptions.

Misconception: In the pre-test, three students exhibited the misconception that "the density of suspended objects that are positioned close to the liquid surface is less than the density of the liquid" by selecting checkbox 3. In the final test, only one student exhibited this misconception.

No Answered: In the pre-test, three students were unable to answer this question, while in the final test, one student left the question unanswered.

4. Answers to forth SG question

Answers	Pre-SG	Post-SG	Misconception content-type
Correct Answer	1 student (1., 3., 5., 6., 7., 8. and 9. boxes)	15 students (1., 3., 5., 6., 7., 8. and 9. boxes)	
Partial Misconception	6 students (3., 5. and 8. boxes)	2 students (3., 5. and 8. boxes)	The buoyant force applied to only suspended objects is equal to the weight of the object.
	1 student (1., 6.,7. and 9. boxes)	-	The buoyant force applied to only floating objects is equal to the weight of the object.
	3 students (1. box)	1 student (1. box)	The buoyant force applied to floating objects that have only half of their volume submerged in the liquid is equal to the weight of the object.
	2 students (5. box)	1 student (5. box)	The buoyant force applied to suspended objects positioned in the middle of the liquid is equal to the weight of the object.
Misconception	4 students (2., 3., 4., 5. and 8. boxes)	1 student (2., 3., 4., 5. and 8. boxes)	The buoyant force applied to both suspended and sinking objects is equal to the weight of the object.
No Answered	5 students	2 students	
Total	22 students	22 students	

Correct Answer: In SG's fourth question, one student selected the correct checkboxes in the pre-test, while in the final test, 15 students selected the correct checkboxes (1, 6, 7, and 9 boxes).

Partial Misconception: In the pre-test, six students exhibited partial conceptual misconceptions by selecting checkboxes

3, 5, and 8, indicating that "the buoyant force applied to only suspended objects is equal to the weight of the object." In the final test, this number decreased, and two students exhibited partial conceptual misconceptions.

One student exhibited partial conceptual misconceptions in the pre-test by selecting checkboxes 1, 6, 7, and 9, indicating that "the buoyant force applied to only floating objects is equal to the weight of the object." In the final test, there was no student exhibiting this partial conceptual misconception.

Three students exhibited partial conceptual misconceptions in the pre-test by selecting only checkbox 1, indicating that "the buoyant force applied to floating objects that have only half of their volume submerged in the liquid is equal to the weight of the object." In the final test, only one student exhibited this partial conceptual misconception.

Two students exhibited partial conceptual misconceptions in the pre-test by selecting only checkbox 5, indicating that "The buoyant force applied to suspended objects positioned in the middle of the liquid is equal to the weight of the object." In the final test, only one student exhibited this partial conceptual misconception.

Misconception: In the pre-test, four students exhibited conceptual misconceptions by selecting checkboxes 2, 3, 4, 5, and 8, indicating that "the buoyant force applied to both suspended and sinking objects is equal to the weight of the object". In the final test, one student exhibited this conceptual misconception.

No Answered: In the pre-test, five students were unable to answer this question, while in the final test, two students left the question unanswered.

5. Answers to fifth SG question

Answers	Pre-SG	Post-SG	Misconception content-type
Correct Answer	2 students (2. and 4. boxes)	17 students (2. and 4. boxes)	
Partial Misconception	10 students (2., 4. and 8. boxes)	3 students (2., 4. and 8. boxes)	The buoyant force applied to objects in contact with the base as well as objects suspended close to the base is less than the weight of the object.
Misconception	5 students (8. box)	1 student (8. box)	The buoyant force applied to objects suspended close to the base is less than the weight of the object.
	3 students (3., 5. and 8. boxes)	1 student (3., 5. and 8. boxes)	The buoyant force applied to suspended objects is less than the weight of the object.
No Answered	2 students	-	
Total	22 students	22 students	

Correct Answer: In the pre-test of question five, two students selected the correct checkboxes, while in the final test, seventeen students selected the correct checkboxes (2 and 4 boxes).

Partial Misconception: In the pre-test, ten students exhibited partial conceptual misconceptions by selecting checkboxes 2, 4, and 8, indicating that "The buoyant force applied to objects in contact with the base as well as objects suspended close to the base is less than the weight of the object." In the final test, there were no students indicating this partial conceptual misconception.

Misconception: In the pre-test, five students selected only box 8, indicating the partial conceptual misconception that "The buoyant force applied to objects suspended close to the base is less than the weight of the object." One student showed this partial conceptual misconception in the post-test.

Additionally, three students in the pre-test selected boxes 3, 5, and 8, indicating the partial conceptual misconception that "The buoyant force applied to suspended objects is less than the weight of the object." One student mentioned this conceptual misconception in the post-test.

No Answered: In the pre-test, two students were unable to answer this question, while in the post-test, no student left the question unanswered.

DISCUSSION AND CONCLUSIONS

One of the commonly used data collection tools in studies examining students' conceptual change with CKCM is WAT (Bakırcı, 2014; Kıryak and Çalık, 2018; Uzunkaya, 2019). In this study, it was determined that a disconnected and unrelated knowledge network existed in the students' cognitive structures for the selected stimulus words: Mass, Volume, Density, Buoyancy, and Archimedes before CKCM. Accordingly, while MASS-weight association was frequently made in the pre-test, weak associations between other stimulus words and response words emerged. In the post-test, highly complex, bidirectional, and strong relationships were found. Especially a strong network was formed among Mass, Volume, and Density, and this network formed a conceptual structure related to Density, Buoyancy, and Archimedes. Thus, it can be said that the CKCM resulted in the development of the conceptual level of students' cognitive structures regarding the density of liquids and buoyant force. However, it is also considered that WAT is an effective technique for categorizing students' pre-conceptions conceptually and determining the development of these categories in the post-test, which is an important feature of the first stage of CKCM (Bakırcı, 2014; Balaban and Özdemir, 2021).

A variety of instructional activities were implemented throughout all stages of CKCM, which were enriched and diversified. During this process, P(E)OE, peer-to-peer discussions, examples from everyday life, identifying diagnostic tree, and other activities were integrated into the learning process in line with the stages of the model. In this way, the conceptual understanding levels of 10th-grade students on the density of fluids and buoyant force were attempted to be developed. According to the data obtained from SG, it was found that the conceptual understanding levels of 10th-grade students improved, and the conceptual misconceptions identified before CKCM were largely eliminated. Despite studies showing that CKCM improves students' conceptual understanding levels (Ebenezer et al., 2010; Kıryak, 2013; Vural, 2016; Yurtbakan et al., 2021) largely overlap with these results, it was observed that some misconceptions could not be resolved and still exist as a new conceptual understanding in students' minds, and some learning difficulties arise. According to the findings in the literature, different types of misconceptions still exist in students' conceptual understanding even with the acquisition of new scientific knowledge about the density of fluids, buoyancy, and floating-sinking situations (Chi, 2005; Harrell et al., 2022; She, 2002). Djudin (2021), who emphasized this issue, revealed that some misconceptions about the density of fluids still persist to some extent among 11th-grade students after the teaching process. Loverude et al. (2003) emphasized learning difficulties that are resistant to permanent and conceptual change related to buoyancy and floating-sinking concepts and principles. Zoupidis et al. (2021) stated that teaching and learning the swimming and sinking phenomenon are a challenging topic within the subject of physics. Although Ünal (2008) stated that the conceptual misconceptions of the students were largely eliminated after the teaching process carried out with some hands-on activities, some students still had misconceptions about the relationship between floating objects and buoyancy, the relationship between the density of fluids and buoyancy, and the effect of weight and volume on the floating-sinking status of objects in fluids. Dawkins et al. (2008) stated that although students develop intuitive understandings related to density, they have difficulty in linking these understandings to relevant mathematical relationships.

In this context, although progress was made in the students' conceptual understanding levels after the teaching process related to the density of fluids, floating-sinking concepts and principles, and buoyancy, some misconceptions appear to be resistant to change, and new misconceptions may arise. These research findings partially overlap with the results of the literature in the Turkish education system. While the density of fluids, floating-sinking concepts and principles, and buoyancy were taught at the 8th-grade level in middle school until 2013, they have been taught at the 10th-grade level in high school since then, where abstract thinking skills are further developed. One of the significant advantages of CKCM is the enrichment of the application processes with various teaching techniques (Çelik et al., 2018; Ebenezer et al., 2010; Sungur Alhan, 2022). Çepni et al. (2010) implemented the enriched processes (P(E)OE, worksheets, conceptual change text, concept cartoons, and animation activities with the 5E learning cycle model, which is quite similar to CKCM, and reported that the students' misconceptions about the buoyancy of liquids, as in this study, were largely eliminated. Considering the commonalities between CKCM and the 5E learning cycle model, as pointed out by Bakırcı and Çepni (2012), it can be suggested that teaching models enriched with multiple and diverse teaching activities are effective in learning about the density, buoyancy, and floating-sinking phenomena. Therefore, researchers planning teaching studies on similar topics are advised to enrich the learning environment with multiple and diverse teaching activities.

REFERENCES

Akar, E. (2005). *Effectiveness of 5E Learning Cycle Model on Students' Understanding of Acid-base Concepts. Unpublished Master's Thesis*. Ankara, Turkey: Middle East Technical University.

Bahar, M., Johnstone, A.H., & Sutcliffe, R.G. (1999). Investigation of students' cognitive structure in elementary genetics through word association tests. *Journal of Biological Education*, 33, 134-141.

Bahar, M., Nartgün, Z., Durmuş, S., & Bıçak, B. (2006). Traditional and Alternative Assessment and Evaluation Teacher's Handbook. Ankara: Pegema.

Bakırcı, H. (2014). *Ortak Bilgi Yapılandırma Modeline Dayalı Öğretim Materyali Tasarlama, Uygulama ve Modelin Etkililiğini Değerlendirme Çalışması: Işık ve ses Ünitesi Örneği* [*The Study on Evaluation of Designing, Implementing, and Investigating the Effects of Teaching Material based on Common Knowledge Construction Model: Light and Voice Unit Sample*]. (Doktora Tezi) (Unpublished Doctoral Dissertation). Trabzon: Eğitim Bilimleri Enstitüsü, Karadeniz Teknik Üniversitesi.

Bakırcı, H., & Çepni, S. (2012). *Fen ve Teknoloji Öğretimi İçin Yeni Bir Model: Ortak Bilgi Yapılandırma Modeli* [*A New Model for Science and Technology Teaching: The Common Knowledge Construction Model*], X. Ulusal Fen Bilimleri ve Matematik Eğitimi Kongresinde Sunulan Bildiri, Niğde Üniversitesi.

Bakırcı, H., & Ensari, Ö. (2018). Ortak bilgi yapılandırma modelinin ısı ve sıcaklık konusunda lise öğrencilerinin akademik başarılarına ve kavramsal anlamalarına etkisi [The effect of common knowledge construction model on academic achievement and conceptual understandings of high school students on heat and temperature]. *Eğitim ve Bilim*, 43(196), 171-188.

Bakırcı, H., & ve Çepni, S. (2014). Fen bilimleri dersi öğretim programı temelinde ortak bilgi yapılandırma modelinin irdelenmesi [Investigation of the common knowledge construction model on the basis of science curriculum]. *Fen Bilimleri Öğretimi Dergisi*, 2(2), 83-94.

Bakırcı, H., Çepni, S., & Ayvacı, H.Ş. (2015). Ortak bilgi yapılandırma modeli hakkında fen bilimleri öğretmenlerinin görüşleri [Science teachers' opinions about common knowledge construction model]. *Yüzüncü Yıl Üniversitesi Eğitim Fakültesi Dergisi*, 12(1), 97-127.

Balaban, H., & Özdemir, R. (2021). Ortak bilgi yapılandırma modelinin su kirliliği konusunda fen bilgisi öğretmen adaylarının kavramsal anlamaları üzerindeki etkisi [The effect of common knowledge construction model on prospective science teachers' conceptual understandings on water pollution]. *Journal of International Social Research*, 14(77), 844-856.

Bayar, M.F. (2019). The effect of common knowledge construction model on science process skills and academic achievement of secondary school students on solar system and eclipse. *Online Fen Eğitimi Dergisi*, 4(1), 4-19.

Biernacka, B. (2006). *Developing Scientific Literacy of Grade Five Students: A Teacher-researcher Collaborative Effort*. Unpublished Ph.D. Dissertation, University of Manitoba.

Çalık, M. (2013). Effect of technology-embedded scientific inquiry on senior science student teachers' self-efficacy. *Eurasia Journal of Mathematics Science and Technology Education*, 9(9), 223-232.

Çalık, M., Ayas, A., & Coll, R.K. (2010). Investigating the effectiveness of teaching methods based on a four-step constructivist strategy. *Journal of Science Education and Technology*, 19(1), 32-48.

Campbell, M.A. (2006). *The Effects of the 5E Learning Cycle Model on Students' Understanding of Force and Motion Concepts*. Orlando: University of Central Florida.

Candaş, B., & Çalik, M. (2022). The effect of CKCM-oriented instruction on Grade 8 students' conceptual understanding of sustainable development. *Journal of Biological Education*, 57, 986-1005.

Çavuş Güngören, S. (2015). *Fen Bilgisi Öğretmen Adaylarının Farklı Öğretim Yöntemleriyle Bilimin Doğasının Öğrenimi ve Öğretimi Hakkındaki Gelişimleri* [*Development of Pre-service Science Teachers' Learning and Teaching of Nature of Science with Different Teaching Methods*]. (Doktora Tezi). Ankara: Eğitim Bilimleri Enstitüsü, Gazi Üniversitesi.

Çavuş Güngören, S., & Hamzaoğlu, E. (2020). Fen bilgisi öğretmen adaylarinin ortak bilgi yapilandirma modeli hakkindaki görüşleri [The pre-service science teachers views' about common knowledge construction model]. *Kastamonu Eğitim Dergisi*, 28(1), 107-124.

Caymaz, B. (2018). *Farklı Sosyo-ekonomik Düzeylerdeki Okullarda 7. Sınıf Elektrik Enerjisi Ünitesinin Öğretiminde Ortak Bilgi Yapılandırma Modelinin Etkisinin Incelenmesi [Investigation of the Effect of the Common Knowledge Construction Model on Teaching of the 7th Grade Electrical Energy Unit at School with Different Socio-economic Levels*]. (Yayımlanmamış Doktora Tezi). Kastamonu: Kastamonu Üniversitesi.

Caymaz, B., & Aydin, A. (2021). The effect of common knowledge construction model-based instruction on 7th grade students' academic achievement and their views about the nature of science in the electrical energy unit at schools of different socio-economic levels. *International Journal of Science and Mathematics Education*, 19(2), 233-265.

Çelik, H., Pektaş, H.M., & Karamustafaoğlu, O. (2018). Science teaching laboratory applications: Common knowledge construction, learning cycle models and STEM approach. *International Journal on New Trends in Education and their Implications*, 9(3), 11-29.

Çepni, S., & Şahin, Ç. (2012). Effect of different teaching methods and techniques embedded in the 5E instructional model on students' learning about buoyancy force. *Eurasian Journal of Physics and Chemistry Education*, 4(2), 97-127.

Çepni, S., Şahin, Ç., & Ipek, H. (2010). Teaching floating and sinking concepts with different methods and techniques based on the 5E instructional model. *Asia-Pacific Forum on Science Learning and Teaching*, 11(2), 1-39.

Chi, M.T., & Roscoe, R.D. (2002). The processes and challenges of conceptual change. In: *Reconsidering Conceptual Change: Issues in Theory and Practice*. Dordrecht: Springer, pp. 3-27.

Chi, M.T.H. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *Journal of the Learning Sciences*, 14(2), 161-199.

Dahl, O., Eklund, B., & Pendrill, A.M. (2020). Is the Archimedes principle a law of nature? Discussions in an 'extended teacher room'. *Physics Education*, 55(6), 065025.

Dawkins, K.R., Dickerson, D.L., McKinney, S.E., & Butler, S. (2008). Teaching density to middle school students: Preservice science teachers' content knowledge and pedagogical practices. *The Clearing House: A Journal of Educational Strategies, Issues and Ideas*, 82(1), 21-26.

Djudin, T. (2021). Promoting students' conceptual change by integrating the 3-2-1 reading technique with refutation text in the physics learning of buoyancy. *Journal of Turkish Science Education*, 18(2), 290-303.

Dorji, U. (2021). Misconception on floating and sinking. *International Journal of English Literature and Social Sciences*, 6(5), 243-249.

Duit, R., & Treagust, D.F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education*, 25(6), 671-688.

Duruk, Ü., Akgün, A., & Güngörmez, H.G. (2021). Exploring the impact of common knowledge construction model on students' understandings of heat transfer. *International Journal of Curriculum and Instruction*, 13(1), 114-136.

Ebenezer, J., Chacko, S., & Immanuel, N. (2004). *Common Knowledge Construction Model for Teaching and Learning Science: Application in the Indian Context*. In: An International Conference to Review Research on Science, Technology and Mathematics Education International Centre (epiSTEME-1), Dona Paula, Goa, India.

Ebenezer, J., Chacko, S., Kaya, O.N., Koya, S.K., & Ebenezer, D.L. (2010). The effects of common knowledge construction model sequence of lessons on science achievement and relational conceptual change. *Journal of Research in Science Teaching*, 47(1), 25-46.

Ebenezer, J.V., & Fraser, D.M. (2001). First year chemical engineering students' conceptions of energy in solution processes: Phenomenographic categories for common knowledge construction. *Science Education*, 85, 509-535.

Ercan, F., Taşdere, A., & Ercan, N. (2010). Observation of cognitive structure and conceptual changes through word associations tests. *Journal of Turkish Science Education*, 7(2), 136-154.

Gianino, C. (2008). Microcomputer-based laboratory for Archimedes' principle and density of liquids. *The Physics Teacher*, 46(1), 52-54.

Hardy, I., Jonen, A., Möller, K., & Stern, E. (2006). Effects of instructional support within constructivist learning environments for elementary school students' understanding of "floating and sinking". *Journal of Educational Psychology*, 98(2), 307-326.

Harrell, P.E., & Subramaniam, K. (2014). Teachers need to be smarter than a 5th grader: What pre-service teachers know about density. *The Electronic Journal for Research in Science and Mathematics Education*, 18(6), 1-23.

Harrell, P.E., Kirby, B., Subramaniam, K., & Long, C. (2022). Are elementary preservice teachers floating or sinking in their understanding of buoyancy? *International Journal of Science and Mathematics Education*, 20(2), 299-320.

İyibil, Ü. (2011). A new approach for teaching 'energy' concept: The common knowledge construction model. *Western Anatolia Journal of Educational Sciences*, Special Issue: Selected papers presented at WCNTSE, 1-8.

Jang, S.J., & Chen, K.C. (2010). From PCK to TPACK: Developing a transformative model for pre-service science teachers. *Journal of Science Education and Technology*, 19(6), 553-564.

Johnstone, A.H., Bahar, M., & Hansell, M.H. (2000). Structural communication grids: A valuable assessment and diagnostic tool for science teachers. *Journal of Biological Education*, 34(2), 87-89.

Karakaya Cirit, D. (2020). Global environmental problems based on common knowledge construction model: Evaluation of "exploring and categorizing" stage. *International Online Journal of Educational Sciences*, 12(3), 212-229.

Karslı, F., & Yiğit, M. (2015). Effect of context-based learning approach on 12 grade students' conceptual understanding about alkanes. *Inonu University Journal of the Faculty of Education*, 16(1), 43-62.

Kılınç, S. (2017). *Fen Bilgisi Öğretmen Adaylarının Yoğunluk Konusundaki Kavram Yanılgılarının Dört Aşamalı Tani Testi ile Belirlenmesi* [*Determining Preservice Science Teachers' Misconceptions about Density Subject with Four Tier Diagnoctic Test*]. Yayınlanmamış Yüksek Lisans Tezi. Konya: Necmettin Erbakan Üniversitesi.

King, D., Winner, E., & Ginns, I. (2011). Outcomes and implications of one teacher's approach to context-based science in the middle years. *Teaching Science*, 57(2), 15-30.

King, S.J. (2013). *Overcoming Misconceptions in Religious Education: The Effects of Text Structure and Topic Interest on Conceptual Change*. United States: Utah State University.

Kıray, S.A., Aktan, F., Kaynar, H., Kilinc, S., & Gorkemli, T. (2015). A descriptive study of pre-service science teachers' misconceptions about sinking-floating. *Asia-Pacific Forum on Science Learning and Teaching*, 16, 1-28.

Kıryak, Z. (2013). *Ortak Bilgi Yapılandırma Modelinin 7. Sınıf Öğrencilerinin su Kirliliği Konusundaki Kavramsal Anlamalarına Etkisi*. (Yayımlanmamış Yüksek Lisans Tezi). Trabzon: Karadeniz Teknik Üniversitesi.

Kıryak, Z., & Çalık, M. (2018). Improving grade 7 students' conceptual understanding of water pollution via common knowledge construction model. *International Journal of Science and Mathematics Education*, 16(2), 1025-1046.

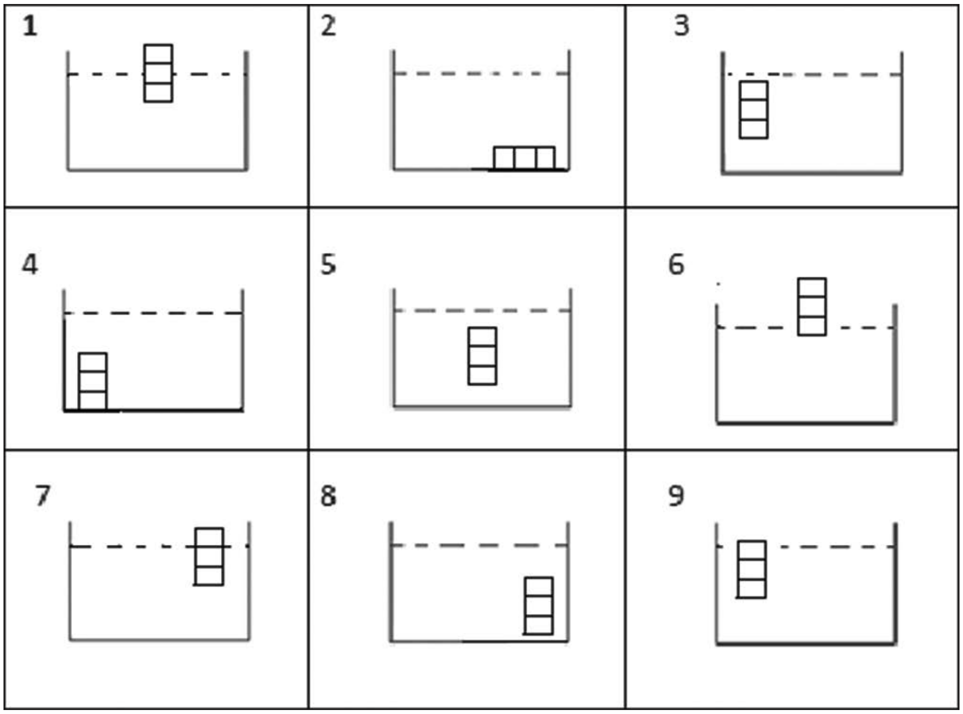
Kwak, S.W., & Choi, B.S. (2012). The level of secondary school science teachers' PCK on density and the characteristics of eight aspects of CoRe by the level of PCK. *Journal of the Korean Chemical Society*, 56(1), 128-136.

Loverude, M.E., Kautz, C.H., & Heron, P.R.L. (2003). Helping students

develop an understanding of Archimedes' principle. I. Research on student understanding. *American Journal of Physics*, 71(11), 1178-1187.
Nakiboglu, C. (2008). Using word associations for assessing non major science students' knowledge structure before and after general chemistry instruction: The case of atomic structure. *Chemistry Education Research and Practice*, 9(4), 309-322.
Özsevgeç, T., & Çepni, S. (2006). Farklı siniflardaki öğrencilerin yüzme ve batma kavramlarini anlama düzeyleri [The level of understanding of the concepts of floating and sinking of students in different classes]. *Milli Eğitim Dergisi*, 172, 297-311.
Paik, S., Song, G., Kim, S., & Ha, M. (2017). Developing a four-level learning progression and assessment for the concept of buoyancy. *Eurasia Journal of Mathematics, Science and Technology Education*, 13(8), 4965-4986.
Posner, G.J., Strike, K.A., Hewson, P.W., & Gertzog, W.A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, 66(2), 211-227.
Potvin, P., & Cyr, G. (2017). Toward a durable prevalence of scientific conceptions: Tracking the effects of two interfering misconceptions about buoyancy from preschoolers to science teachers. *Journal of Research in Science Teaching*, 54(9), 1121-1142.
Radovanović, J., & Sliško, J. (2013). Applying a predict-observe-explain sequence in teaching of buoyant force. *Physics Education*, 48(1), 28.
Sadler, I. (2009). *Development of New Teachers in Higher Education: Interactions with Students and Other Influences upon Approach to Teaching.* (Unpublished PhD Thesis). Edinburgh: University of Edinburgh.
Shaker, Z. (2012). The use of concept maps as a tool for understanding conceptual change in pre-service elementary teachers on the concept of density. *International Review of Contemporary Learning Research*, 1(1), 9-22.
She, H.C. (2002). Concepts of a higher hierarchical level require more dual situated learning events for conceptual change: A study of air pressure and buoyancy. *International Journal of Science Education*, 24(9), 981-996.
She, H.C. (2005). Enhancing eighth grade students' learning of buoyancy: The interaction of teachers' instructional approach and students' learning preference styles. *International Journal of Science and Mathematics Education*, 3(4), 609-624.
Skoumios, M. (2009). The effect of sociocognitive conflict on students' dialogic argumentation about floating and sinking. *International Journal of Environmental and Science Education*, 4(4), 381-399.
Sungur Alhan, S. (2022). The effect of common knowledge construction model based instruction on pre-service science teachers' lesson planning. *Cukurova University Faculty of Education Journal*, 51(1), 1-41.
Tasdere, A., & Ercan, F. (2011). An alternative method in identifying misconceptions: Structured communication grid. *Procedia-Social and Behavioral Sciences*, 15, 2699-2703.
Trochim, W.M., & Donnelly, J.P. (2001). *The Research Methods Knowledge Base*. Cincinnati, OH: Atomic Dog Pub.
Ünal, S. (2008). Changing students' misconceptions of floating and sinking using hands-on activities. *Journal of Baltic Science Education*, 7(3), 134-146.
Uzunkaya, M. (2019). *The Influence Effect of the Common Knowledge Construction Model Basic Teaching Students' Academic Success: A Case of Sound Unit* (Master's Thesis). Konya, Turkey: Necmettin Erbakan University.
Vural, S. (2016). *Ortak Bilgi Yapılandırma Modeline Uygun Geliştirilen Öğretim Materyalinin Üstün Yetenekli Öğrencilerin Asit-baz Kavramlarını Anlamaları Üzerine Etkisi* [*The Effect of teaching material based on the common Knowledge Construction Model on the Gifted Students' Understanding of Concepts: "Acid-base"*]. (Unpublished Doctoral Dissertation). Trabzon, Turkey: Karadeniz Technical University.
Wong, D., Lim, C., Munirah, S., & Foong, S.K. (2010). Student and Teacher Understanding of Buoyancy. In: *Physics Education Research Conference*. Available from: https://www.per-central.org/perc/2010/files/perc2010_buoyancy_final.pdf [Last accessed on 2023 Mar 27].
Wood, L.C. (2012). *Conceptual Change and Science Achievement Related to a Lesson Sequence on Acids and Bases among African American Alternative High School Students: A Teacher's Practical Arguments and the Voice of the "Other"*. Unpublished Ph.D. Dissertation, Wayne State University.
Yıldızbaş, H. (2017). *Ortak Bilgi Yapılandırma Modeline Dayalı Öğretimin Öğrencilerin Akademik Başarılarına ve Eleştirel Düşünme Becerilerine Etkisi* (Yayımlanmamış Yüksek Lisans Tezi). Konya: Necmettin Erbakan Üniversitesi.
Yurtbakan, E., Çalık, M., & Güler, T. (2021). *Investigating fourth grade students' conceptual growth of the 'organic and nonorganic foods' subject: A case of common knowledge construction model.* Hacettepe Üniversitesi Eğitim Fakültesi Dergisi, 36, 544-561.
Zoupidis, A., Spyrtou, A., Pnevmatikos, D., & Kariotoglou, P. (2021). Teaching and learning floating and sinking: Didactic transformation in a density-based approach. *Fluids*, 6(4), 158.

APPENDIX 1

The grid below contains samples regarding various situations about buoyancy and density of liquids. Please answer the questions using the box numbers. You can use the same box number as an answer to more than one question.



Objects are released in the same liquid in the above boxes. According to the box;

1. In which boxes the density of the object and liquid are the same?
2. In which boxes the density of the object is larger than the density of the liquid?
3. a. In which boxes the density of the objects in the liquid is smaller than the density of the liquid?
   b. Please order the densities for the objects from the smallest to the largest.
4. In which boxes the buoyancy exerted on objects is equal to the weight of the object?
5. In which boxes the buoyancy exerted on objects smaller than the weight of the object?