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Investigating the effectiveness of a POE-based teaching activity on students' understanding of condensation

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Abstract This article reports on the development of a Predict–Observe–Explain, POE-based teaching strategy to facilitate conceptual change and its effectiveness on student understanding of condensation. The sample consisted of 52 first-year students in primary science education department. Students' ideas were elicited using a test consisting of five probe questions and semi-structured interviews. A teaching activity composed of three Predict–Discuss–Explain–Observe–Discuss–Explain (PDEODE) tasks was employed, based on students' preconceptions identified with the test. Conceptual change in students' understanding of condensation was evaluated via a pre-, post-, and delayed post-test approach and students' interviews. Test scores were analyzed using both qualitative and quantitative methods. The findings suggested that the strategy helps students to achieve better conceptual understanding for the concept of condensation and enables students to retain these new conceptions in their long-term memory.

Keywords Predict–Discuss–Explain–Observe–Discuss–Explain (PDEODE) teaching strategy · Conceptual change · Alternative conceptions · Condensation

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Introduction

A plethora of science education research studies have focused on identifying student alternative conceptions for a variety of subject areas (Duit 2009) including the subject of this study—physical changes associated with condensation. A large body of knowledge reveals numerous students' alternative conceptions and learning difficulties for properties of condensation. This included a variety of topics, such as changes of phase (e.g., Chang 1999), evaporation and condensation (e.g., Lee et al. 1993), conservation of matter during evaporation and condensation (e.g., Hatzinikita and Koulaidis 1997), changes of state associated with real life events like the weather (e.g., Henriques 2000), vapor pressure (e.g., Gopal et al. 2004), conditions for changes of state (e.g., Paik et al. 2004), conceptions of the nature of matter and its phases (e.g., Johnson 2005), student's conceptual progression in their understanding of phase changes (e.g., Varelas et al. 2006), condensation in open systems (e.g., Paik et al. 2004), condensation in closed systems (e.g., Coştu 2006), and finally condensation and heat transformations (e.g., Coştu 2002). This represents a substantial body of literature, and affords insights into common alternative conceptions and learning difficulties. This study also covers a variety of grade levels from elementary to university level, and diverse cultural backgrounds pointing to the ubiquitous nature of student alternative conceptions for chemistry topics, but remarkably few solutions for teaching.

Focusing on the literature review, specifically on the condensation concept, several researchers (Bar and Gaglili 1994; Bar and Travis 1991; Chang 1999; Coştu 2002, 2006; Coştu and Ayas 2005; Ewings and Mills 1994; Gopal et al. 2004; Hatzinikita and Koulaidis 1997; Henriques 2000; Johnson 1998, 2005; Kruger and Summers 1989; Lee et al. 1993; Osborne and Cosgrove 1983; Paik et al. 2004; Papageorgiou and Johnson 2005; Stavy 1990a, b; Tytler 2000; Varelas et al. 2006; You and Schallert 1992) have investigated students' conceptions at a range of grade levels and have unveiled a wide variety of SAC (students' alternative conceptions). Condensation is considered a sophisticated topic necessitating cognitive differentiations that students in different stages may not be ready for and may not be able to construct (Varelas et al. 2006). Hence, this topic is usually organized not for middle grades, but for upper grades. Also, research has most often studied primary school children's conceptions and the progression of the phenomena of evaporation and condensation (e.g., Bar and Gaglili 1994; Bar and Travis 1991; Tytler 2000; Varelas et al. 2006). As Tytler (2000) pointed out "…there is some developing agreement concerning the fundamental ontological shifts that drive children's growing understanding of evaporation and condensation phenomena…" (p. 451). Tytler (2000) compared conceptions of Year 1 and 6 children and found "…substantial overlap between the conceptions used…also substantial differences in the patterns of conceptions, the epistemological sophistication, and the structure of their explanations…" (p. 463). On the contrary, over the last decade, a few science education researchers have focused on older students' conceptions (e.g., Coştu 2006; Chang 1999; Gopal et al. 2004). Also, Chang (1999) focused on trainee teachers and suggested that the misconceptions that students have are not limited to school children. This view was corroborated in other studies conducted on teachers, and prospective teachers (e.g., Kruger and Summers 1989; Coştu 2006) since the mechanism of condensation with respect to the particulate nature of matter is covered extensively both in secondary and during undergraduate science courses. Hence, studying freshman students offered us a fruitful exercise in the present study to explore the conceptions of condensation students held and to provide strategies for conceptual change.

Condensation is an abstract concept that even older students confronted great difficulties to learn, since it mainly requires an awareness of the existence of water vapor in the air at all times (not when water is heated or not when water boiled) to take into account for visible formation of droplets on a cold surface. As explained by Taber (2001), some of the particular difficulties that chemistry concepts present, among which is the need to be able to change between microscopic and macroscopic levels, and also the abstract nature. These two issues are very relevant to the condensation concept. Bar and Travis (1991) indicated that children do not capture the nature of water vapor, its formation in air, and its transformation as water droplet. Similarly, Chang (1999) and Coştu (2006) also found that even student teachers, referred to air and gases in the air rather than water vapor as the substance that condenses.

The main reason researchers and teachers are interested in student alternative conceptions is that, research suggests, they interfere with subsequent learning. This often means that new knowledge cannot be integrated appropriately into students' cognitive structures (Taber 2000). In order to develop conceptual understanding in a manner acceptable to scientists and teachers, student alternative conceptions and existing knowledge structures may need modification in a process known as conceptual change. There have been many conceptual change models (e.g., Chi and Roscoe 2002; Hewson and Hewson 1983; Hynd et al. 1994; Nussbaum and Novick 1982; Posner et al. 1982; Thagard 1992) that have been developed based on developmental and cognitive psychology (Piaget's study) and philosophy of science (Kuhn 1970; Lakatos 1970). These models claim that shifting misconceptions (named with different terms, such as preconceptions, alternative frameworks, children's science, naive conceptions, and so forth) toward more scientific ones is the role of conceptual change learning. Contrary to these models, Marton (1981) presented a more radical view of conceptual change model, *Variation Theory of Learning* named as Phenomenography. Based on the phenomenography (Marton and Booth 1997; Marton and Tsui 2004), Ebenezer et al. (2010) have recently proposed a conceptual change model as *Common Knowledge Construction Model* (CKCM). This model is situated at the intersection of two theories, namely, conceptual change theory rooted in Piaget and phenomenography. The model consists of four interactive phases of teaching and learning: Exploring and categorizing; constructing and negotiating; translating and extending; and reflecting and assessing (for detailed information see Ebenezer et al. 2010). Moreover; Ebenezer et al. (2010) stated that

> Regardless of theoretical suppositions, the hallmarks of teaching and learning for conceptual change include: Exploration of students' conceptions about a natural phenomenon; students becoming consciously aware of their own conceptions; sharing personal conceptions within a learning community for appraisal; testing and comparing personal conceptions with scientific models and explanations for plausibility; and through a social process, refining, reconstructing, reconciling or rejecting personal conceptions to align with the scientifically sound and agreed upon conception. These hallmarks of teaching may be adopted by those who understand conceptual change as undoing misconceptions or altering naive conceptions as well as by those who value variations in students' conceptions… (p. 2)

As stated above, there are many hallmarks of teaching and learning for conceptual change represented with many different models previously stated. Whenever you select one of the conceptual change models, you should serve the mentioned hallmarks. In the present study, we utilized the conceptual change model proposed by Posner et al. (1982). The above model has been widely used for the last two decades in the science education literature (e.g., Anderson et al. 1990; Basili and Stanford 1991; Coştu et al. 2010; Çalık et al. 2007a, b; Jensen and Finley 1996; Özmen 2009; Pınarbaşı et al. 2007), although it has been exposed to several criticisms (e.g., Caravita and Halden 1994; Ebenezer et al. 2010; Smith et al. 1993; Vosniadou and Verschaffel 2004). Posner et al. (1982) suggest that conceptual change necessitates creating dissatisfaction with existing alternative conceptions followed by a strengthening of the status of the preferred scientific conceptions. Posner et al. (1982) propose four conditions that need to be met before conceptual change likely occurs:

(a) The learners must become dissatisfied with their existing concepts (dissatisfaction),
(b) The new conception must be intelligible (intelligibility),
(c) The new conception must be plausible (plausibility), and
(d) The new conception must be fruitful (fruitfulness).

There are a number of specific instructional strategies based on this conceptual change model and these include things, such as concrete or physical activities, conceptual change text, hands-on activities, concept mapping, Prediction Observation Explanation (POE) tasks, computer-aided instruction, and so on. Conceptual change researches are reported for many of the concepts in science but are very limited for the topic of condensation. In this study, we utilized, a variant of the classical POE activity, the *Predict–Discuss–Explain–Observe–Discuss–Explain* (PDEODE) teaching strategy to facilitate conceptual change for the subject of condensation.

PDEODE teaching strategy

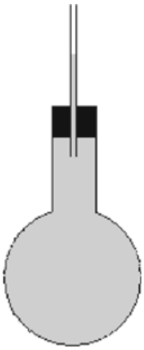
The PDEODE strategy was initially proposed by Savander-Ranne and Kolari (2003). As noted, the POE or primary version of the PDEODE has been used extensively as a vehicle to investigate students' understanding of science concepts. We describe POE first and then show how the PDEODE activity differs from this.

The POE technique probes student understanding by requiring students to carry out three tasks. First, students must predict the outcome of some event or situation and must justify their prediction (*P: Predict*). Second, they describe what they see happen (*O: Observe*). Finally, they must reconcile any discrepancy between prediction and observation (*E: Explain*). An example of a POE task is given in Fig. 1.

As noted above the POE technique has been used extensively to investigate student understanding of a variety of concepts (Gunstone and White 1981; Kearney and Treagust 2000, 2001; Kearney et al. 2001; Liew 1995; Liew and Treagust 1998; Palmer 1995). As well as helping teachers or researchers to identify student alternative conceptions, POE activities also may serve as an instructional strategy, with a particular teaching/learning sequence (Kearney et al. 2001; Liew and Treagust 1998). White and Gunstone (1992) note that the discussions are a key part of using POE (see also, Searle and Gunstone 1990; Tao and Gunstone 1999). Recently, Ebenezer et al. (2010) used the Predict–Explanation–Observation–Explanation (PEOE) strategy rooted in POE as assessment tool integrated in the CKCM of conceptual change.

The PDEODE teaching strategy, as noted above, is a modification of POE suggested by Savander-Ranne and Kolari (2003) and has been used in several studies (e.g., Coştu 2008; Coştu et al. 2010; Kolari and Savander-Ranne 2004). The key difference is the added emphasis on enhancing its value as teaching activity by creating an atmosphere that supports discussion, and a diversity of views. The PDEODE teaching strategy as used in the present study consisted of six steps. In the first step (*P: Prediction*), the teacher

POE Task*



Predict (P)
Predict what will happen to the water level in the glass tubing if the round bottomed flask is plunged into the hot water from the initial moment and onwards? State and explain the reason(s) for your prediction.

……………………………………………………………………………………

……………………………………………………………………………………

Observe (O)
What happened to the water level in the glass tubing when the flask is immersed into the hot water from the initial moment and onwards? State and explain the reason(s) for your observation.

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……………………………………………………………………………………

Explain (E)
Compare your observation with your prediction. Are they in agreement or disagreement? Explain with your reason(s).

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* Derived from Liew & Treagust (1998).

Fig. 1 An example of POE a task. *Derived from Liew and Treagust (1998)

presented a phenomenon about condensation to students using an activity sheet and asked them to make a prediction individually as to what will happen, and to justify their reasoning. In the second step (*D: Discuss*), the intention was that the students would discuss and share their ideas in their groups. In the third step (*E: Explain*), students in each group were asked to reach a consensus and conclusion about phenomenon, and to present their ideas to other groups through whole-class discussions. Afterward, the students again worked in groups to perform a hands-on experiment and individually recorded their observations about what happened. In this step (*O: Observe*), the students observed changes in the phenomenon and the teacher guided them to focus on observations relevant to target concepts. In the fifth step (*D: Discuss*), the students were asked to reconcile their predictions with the actual observations made in the earlier step. Here, the students were asked to analyze, compare, contrast, and criticize their classmates in the groups. In the last step (*E: Explain*), the students confronted all discrepancies between observations and predictions. Here, the students had to try and resolve any contradictions. The role of the teacher in this teaching strategy was to challenge students and to facilitate discussions. Moreover, the teacher asked probing questions, and worked to make sure students did observations carefully (i.e., in the fourth step) correctly and tried to ascertain if they reached the target concepts.

The relationship between the PDEODE teaching strategy and conceptual change approach is shown in Fig. 2, and this shows how eliciting students' alternative conceptions occurred before teaching—something deemed crucial for conceptual change (Savander-Ranne and Kolari 2003).

As seen in Fig. 2, the PDEODE teaching strategy starts with elicitation of prior ideas, followed by the students reexamining their ideas in their groups and in whole-class discussions. Finally, the sequence ends by trying to resolve any contradictions between their prior beliefs and observations. This process is thus consistent with the four conditions suggested by Posner et al. (1982), meaning it should lead to conceptual change and enhanced conceptual understanding (Coştu et al. 2010; Savander-Ranne and Kolari 2003).

A teaching activity sheet composed of three PDEODE tasks containing the six steps mentioned above is presented as shown in Fig. 3.

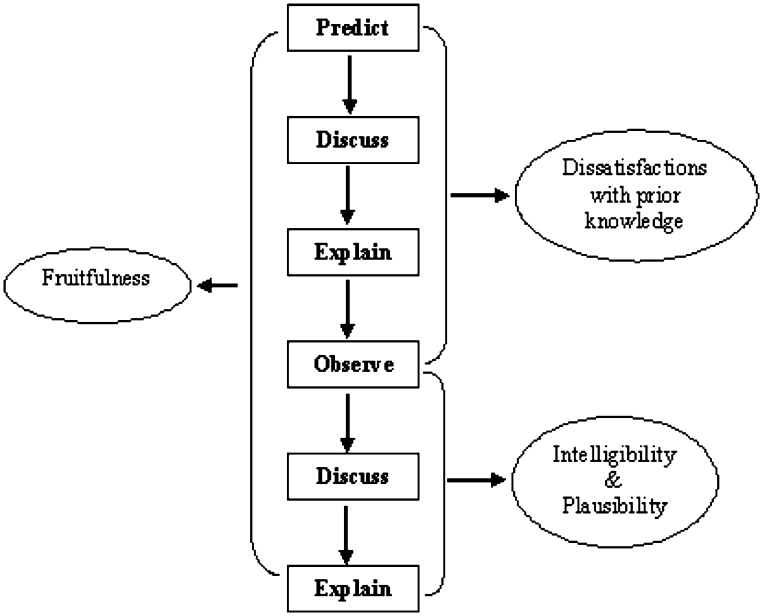


Fig. 2 The relationship between PDEODE teaching strategy and the conceptual change model

Research purpose and research questions

The purpose of this study was to develop a teaching activity composed of three PDEODE tasks to facilitate conceptual change and evaluate its effectiveness on student understanding of condensation. The following specific research questions were addressed:

1. Does the teaching activity composed of three PDEODE tasks help students to change their alternative conceptions toward more scientific ones for the topic of condensation? To what degree does any conceptual change take place?
2. Does the teaching activity as used here enable students to store any new conceptions in their long-term memory?

Methods

Sample

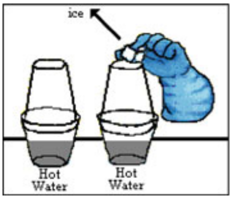
The participants in this study were 52 students who originated from different cities in Turkey. All were enrolled in the same introductory chemistry courses at the same university, referred to here as *Technical University* (a pseudonym). One of the students had left the university by the time the delayed post-test was administered. Thus, there is a full data set for 51 students. Students in Turkey have to pass an entrance examination (OSS), to pursue their education in the university. Passing this quite stringent examination means that all students should have achieved a certain level of understanding in chemistry, and would have been exposed to instruction in basic chemistry topics including physical properties such as condensation, evaporation, and the like.

Teaching Activity

Name and Surname: **Group Number:**

- When you are breathing in a cold day, you have noticed vapors rising from your mouth. Actually, do vapors rise? Although you noticed vapors on a cold day, they did not appear on a warm day. Why do you think this happen?
……..

In this activity, you will answer the above questions. Follow the steps below and discuss questions in your groups.



✓ *Have a total four plastic cup, two of which is wide and two tall.*
✓ *Fill in the wide cups with the same amount of hot water.*

- What happens to the hot water and interior surface of each tall plastics cup, after a tall plastics cup placed upside down over each of the wide cups and then a cube of ice as shown in the left figure. Predict and discuss your predictions in your group. Then explain your reasons in detail.
……………………………………………………………………………………………
- Observe changes in water and interior surface of each tall plastics cup. What happened? Do you notice any difference between them? Why do you think these happen? Discuss in your group.
……………………………………………………………………………………………
- Explain in detail what would happen? What did you deduce from the above experiences? Please write your deduction below.
……………………………………………………………………………………………
- Are there any differences in weights of each cup before and after? Predict and discuss your predictions in your group. Then explain reasons in detail.
……………………………………………………………………………………………
- Measure them with a balance. Record their weights. Do you notice any difference between them? Why? Discuss in your group.
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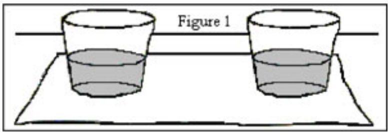
- Explain in detail? What did deduce? Please write your deduction below.
……………………………………………………………………………………………



✓ Have two clear plastic cups
✓ Pour same amount of tap water into each cup as figure 1.After then; place these cups on a paper towel
✓ Wait a few minutes

- What happens to the outside of each plastics cup, a few minutes later? Predict and discuss your prediction in your group. Then explain your reasons in detail.
……………………………………………………………………………
- Observe changes in the outside of each plastics cup. What happened? Do you notice any difference between them? Why do you think these happen? Discuss in your group.
……………………………………………………………………………………………
- Explain in detail what would happen? What did deduce from the above experiences? Please write your deduction below.
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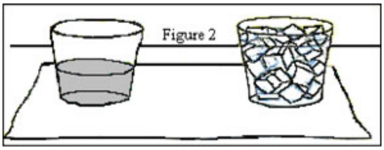

✓ Have two clear plastic cups
✓ Fill in the one of the plastic cup with lots of ice cubes. Do not add any ice to the other cup. Place the cups on a paper towel.
✓ Wait a few minutes

- What happens to the outside of each plastics cup, a few minutes later? Predict and discuss your prediction in your group. Then explain your reasons in detail.
……………………………………………………………………………
- Observe changes in the outside of each plastics cup. What happened? Do you notice any difference between them? Why do you think these happen? Discuss in your group.
……………………………………………………………………………………………
- Explain in detail what would happen? What did deduce from the above experiences? Please write your deduction below.
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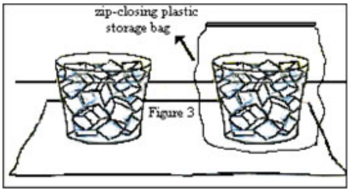


✓ Have two clear plastic cups
✓ Fill in the cups with lots of ice cubes.
✓ Put one of the cups in a zip-closing plastic storage bag. Place both cup on a paper towel.
✓ Wait a few minutes.

- What happens to the outside of each plastics cup and plastic storage bag, a few minutes later? Predict and discuss your prediction in your group. Then explain your reasons in detail.
……………………………………………………………………………
- Observe changes in the outside of each plastics cup and plastic storage bag. What happened? Do you notice any difference between them? Why do you think these happen? Discuss in your group. ……………………………………………………………
- Explain in detail what would happen? What did deduce from the above experiences? Please write your deduction below.
……………………………………………………………………………………………

Answer the questions below using their experiences gained from the activity

- When you are breathing in a cold day, you have noticed smokes rising from your mouth. Actually, do smokes rise? Although you noticed smokes in a cold day, they did not see in a warm day. Why do you think this happen? ………………
……………………………………………………………………………………………
- (Compare their beliefs before and after the activity). Please write a brief paragraph that states the changes in their mind before and after the activity? ……………………………………………………………

Fig. 3 The teaching activity composed of three PDEODE tasks used in the study

Data collection

To assess students' conceptual change subsequent to the intervention, a purpose-designed test, the *Condensation Conceptual Test* (CCT), consisting of five items, was developed based on the alternative conceptions derived from the literature. The items comprised three formats: one two-tier multiple-choice-test item (Item 3b), two true/false two-tiered test items (Items 1 and 2), and two open-ended test items (Items 3a, 4, and 5). All the test items are presented in Fig. 4.

The first type of two-tier item (Item 3b) is multiple-choice in format, and requires respondents to select a response and to subsequently justify this selection (Mulford and Robinson 2002). For this type of item, there is one correct answer, and the distracters reflect common alternative conceptions as discerned from the literature. Respondents also are able to write different reasons from those presented to them as test item choices if they wish. In the second type of two-tier item (Item 1 and 2), the first tier consists of a true/false response, followed by a second tier consisting of a set of reasons for selecting the true or false response (Mike and Treagust 1998). For this type of item, again the distracters reflect likely alternative conceptions, and again respondents are also able to write reasons different from those presented. The third type of test items (test Items 3a, 4, and 5) is open-ended, and respondents are required to write their own ideas in spaces provided.

All items were piloted with 31 students who were excepted from the original 52 participants, and the test was validated by a panel of experts, consisting of three chemistry teachers and two teacher educators. The final form of the test was administered to the sample 1 month before (pre-test) and after the intervention (post-test). It was also administered 3 months later (i.e., as a delayed post-test) to the sample, who had subsequently gone on to study primary science education. It is assumed that duration between application of the same test as pre-, post-, and delayed post-tests is sufficient to see if the students had forgotten the items quickly.

Changes in students' performance as a measure of conceptual change were determined from (i) any gain in scores, (ii) changes in the responses/explanation choices from pre-test to post- and delayed post-tests, and (iii) changes in students' alternative conceptions from pre-test to post-test and delayed post-test.

Also, semi-structured interviews were conducted with three students [one average (S19), one below average (S6), and one above average (S50)]. These students were selected based on their scores in the pre-test. That is, above-average students showed the best performance on the pre-test, whilst below-average ones showed the least performance on the pre-test. In the interviews; initially, the situations about condensation were presented to the students by depicting them on two cards (see Fig. 5) and, then, asked a few questions related to the condensation (as in Osborne and Cosgrove 1983).

Based on the students' responses to main questions in the cards, follow-up questions were then asked to provide students an opportunity to elaborate. The interviews were of 25–30 min in duration and conducted just after the intervention.

Teaching intervention

Of many potential conceptual change teaching strategies, we decided to use the PDEODE teaching strategy, based on our perception of its appropriateness for the educational context in this study. We developed the activity about condensation (see Fig. 3) detailed in Table 1.

Item1
Water vapors turn into water when cooled

□ **True** □ **False**

Because;

a) When water evaporates, it scatters into air and disappears.
b) Water vapors only change as water in clouds
c) Water vapors only change as water when the weather is raining
d) Water vapors are composed of water molecules
e) ……………………………………………………………………………

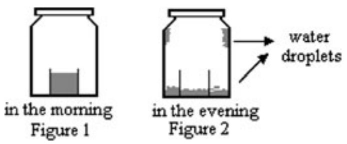
Item2
There is water vapor in air at all times.

□ **True** □ **False**

Because;

a) There are water vapors in air only when there is a boiling kettle.
b) There are water vapors in air only in winter when it is cold.
c) Water vapor is one of the components of air. Therefore, there is always vapor in the air.
d) There are hydrogen and oxygen gases in the air instead of water vapor.
e) There are only nitrogen and oxygen gases in the air.
f) ……………………………………………………………………………………………………..

Item3
a)



A jar in which there is a small beaker filled with a little water placed on a table in the morning (Figure 1). The lid of jar is screwed tightly and it is left undisturbed until the evening (Figure 2). At the end of this period, many tiny water droplets appeared on the inner surface and bottom of the jar. Why does this event happen? Please explain.
……………………………………………………………………………………………

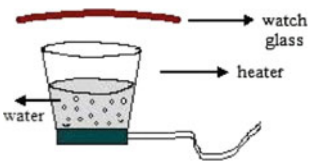
b) Before and after water droplets appeared inside the jar, how will the weight of the water inside the beaker change?

a) Decreases
b) Increases
c) No change

Because;

a) Became lighter because water evaporated
b) Became heavier because water vapor made of evaporated water exerts pressure and it causes the weight to increase.
c) Became lighter due to evaporation. Water vapor weighs less than liquid water.
d) No change because water molecules changed into water vapor, which is a physical change.
e) ……..

Item4



A watch glass is carefully placed on an electrical heater in which there is a small amount of boiling water. A few minutes later, many tiny water droplets appeared on the watch glass surface. Why does this event occur? Please explain in detail.

……………………………………………………………………..

Item5
A small bottle is taken out of a refrigerator for not too long. A few minutes later, it was seen that there are many water droplets on the surface of the bottle. Where do water droplets (wetness) come from? Explain your reasons in detail?
……

Fig. 4 The CCT used in the study to evaluate students' conceptions for condensation

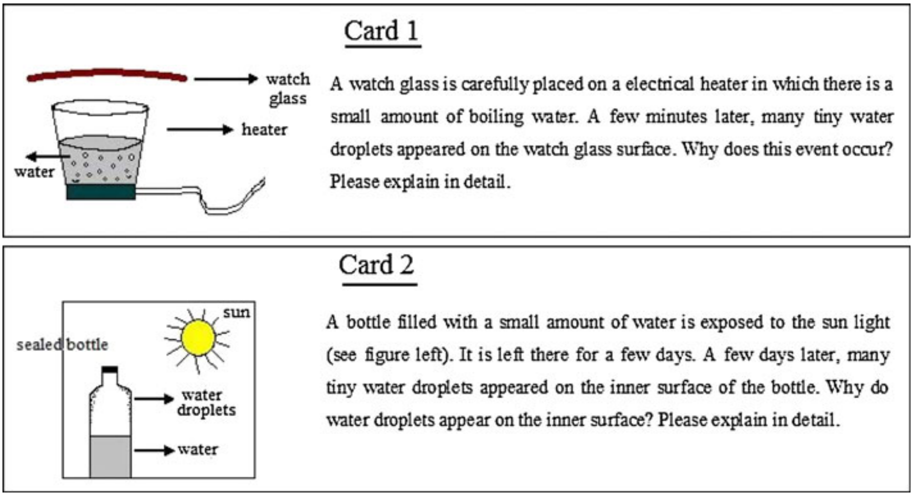


Fig. 5 Interview cards used in the study to evaluate students' conceptual change about condensation

Table 1 Teaching activity composed of three PDEODE tasks developed in the study

Condensation in closed systems (condensation of water vapor rising from the hot water) (PDEODE Task 1)
Condensation at a room temperature
Condensation on a cold surface
Conservation of matter during condensation
Condensation in open systems (PDEODE Task 2)
Condensation on a beaker filled with water at room temperature
Condensation on a beaker filled with ice
Condensation in open systems (PDEODE Task 3)
Condensation on a beaker filled with ice
Condensation on plastic bag in which there is a beaker filled with ice

Before the three PDEODE tasks, a question was presented to students to draw their attention to the main idea of the activity (i.e., condensation). After completing the tasks, the question was then re-visited to see if the students now understood the concept correctly. The teaching intervention was administered to groups of students (a total eight groups: 4 of 7 students, and 4 groups of 6 students). At the beginning of each teaching activity, the activity sheet on which students would write down their explanations was handed out to each group. Students worked collaboratively in groups, and they filled in each activity sheet individually.

The teaching activity was introduced during a normal scheduled class of 60-min duration—the language of the instruction was Turkish. The instruction was given by the first author; hence we assumed that he expertly employed the teaching strategy. The lecturer can interact with the groups, especially discussions steps (the second and the fifth steps). In other words, discussions were completed under the guidance of the teacher. While students were discussing in their small groups, the teacher visited all the groups and asked some guiding questions to lead students in an appropriate direction.

Table 2 Criteria for analyzing the two-tiered test items

Categories First tier–second tier	Marks
True response–true reason (T–T)	3
False response–true reason (F–T)	2
True response–no reason (T–N)	2
True response–false reason (T–F)	1
False response–no reason (F–N)	0
False response–false reason (F–F)	0
No response–no reason (N–N)	0

Data analysis procedure

Two-tiered test items were analyzed with criteria presented in Table 2. A review of the literature shows that two-tiered test items have been analyzed differently, depending on research aims and scope of the study. Some studies (e.g., Chandrasegaran et al. 2007) consider the two-tiered test item as correct answer if both content and reason parts were correctly answered. Some (e.g., Tsai and Chou 2002) use categories as follows: incorrect (incorrect in both two tiers, awarded as 1 point), partially correct (correct in one and only one tier, awarded as 2 points) and correct (correct in both two tiers, awarded as 3 points). On the other hand, some (e.g., Özmen et al. 2009) also use extended category systems in which there are different point scales, and the present study used these criteria, as presented in the Table 2.

In analyzing open-ended test items in the test, first, student responses were examined thematically, and the following criteria were used to classify the responses. *Sound Understanding* (SU) (3 points), *Partial Understanding* (PU) (2 points), *Specific Misconception* (SM) (1 point), *No Understanding* (NU) (0 point), and *No Response* (NR) (0 point). These are the same criteria used by Coştu et al. (2007) to analyze similar open-ended test items. Validation of students' responses to the open-ended items (Items 3a, 4 and 5) employed the following steps. Students' responses to the test items were classified by the first and second authors of the article (the third author is excluded for categorizations since he is not Turkish and lives out of Turkey) separately, as SU, PU, SM, or NU. This resulted in about 90% agreement and any differences were resolved by negotiation.

For the two-tiered test items, each question and reason had one correct answer, and the others were deemed alternative conceptions. Hence, students' responses were analyzed to define their conceptions based on pre-, post-, and delayed post-test responses. Changes in student responses are presented in tables below to show students' conceptual change after the teaching activity. The total number of points for each student was computed and used to make statistical comparisons and statistical analyses via general linear model repeated measures and Tukey post-hoc test.

Interview data were analyzed qualitatively, in which we analyzed student responses thematically seeking to identify similarities and differences as suggested by Yin (1994) and Merriam (1988).

Findings

We first present students' responses to test items, and this is followed by a summary of the interview data.

Findings from the CCT

The results from the two-tiered test items are given as follows: Most of the students' gave responses that fell into "*T–T*" category after the teaching intervention (Items 1, 2, and 3b). These responses were generally the highest in the delayed post-test. For example, the proportion of students' responses in "*T–T*" category for Item 1 changed from 90%, to 98%, and to 100% for the pre-, to post-, and to delayed post-test scores, respectively. However, for test Item 3b, although most of the students gave responses that fell into "*T–T*" category after the teaching intervention, a few of the students changed their responses in the delayed post-test. Nevertheless, the number of the students' who gave responses that fell into "*T–T*" category in the delayed post-test was still more than for the pre-test. In a similar manner, students' responses that fell into the "*F–F*" category for this item decreased from pre-test to delayed post-test. For example, the proportion of responses in the "*F–F*" category for Item 2 changed from 6%, to 0%, and to 0% for pre-, to post-, and to delayed post-test scores, respectively. However, for test Item 3b, students' responses in the "*F–F*" category reduced after the teaching intervention, even though again a few changed their responses in the delayed post-test. Nevertheless, overall, the number of the students' who gave responses that fell into "*F–F*" category in the delayed post-test was less than for the pre-test.

The results from the open-ended test items and some examples from the given responses are presented in Table 3.

As can be seen from Table 3, more students gave responses classified as sound understanding (SU) after the intervention. This increase, however, decreased slightly in the delayed post-test. For example, the proportion of students' responses in this category for Item 5 changed from 29%, to 77% and then to 70% for the pre-, post-, and delayed post-test scores, respectively. Hence, although most of the students' responses were classified as having sound understanding (SU) after the teaching intervention, a small number changed in the delayed post-test. Nevertheless, the number of the students' who gave responses that were classified in the sound understanding (SU) category in the delayed post-test was still more than for the pre-test. In a similar manner, responses classified as specific misconceptions (SM) decreased from pre-test to post-test, but this was not sustained in the delayed post-test. For example, the proportion of students' responses in this category for Item 4 changed from 15%, to 0% and 4% for pre-, post-, and delayed post-test scores, respectively. Again, although there has been some attrition in the delayed post-test, it is still a considerable improvement over the pre-test.

Students' responses were also analyzed to determine specific alternative conceptions or difficulties based on pre-, post-, and delayed post-test (see Table 4).

As can be seen from Table 4, students' alternative conceptions changed from the pre-test, with improvement noted in the post-, and delayed post-test scores. That is, most students experienced conceptual change. This suggests that these students' alternative conceptions were reduced as a result of the intervention. For example, for the 2nd SAC the proportion decreased from 31 to 2% for the pre- and post-tests (i.e., +29%). Additionally, the data were examined to see whether or not this conceptual change was maintained. If the proportion of SAC in the delayed post-test was lower or equal to the post-test scores, conceptual change was deemed to be maintained. When comparing students' alternative conceptions for the post-test and delayed post-test, all of the SAC, except for three students (SAC #4 and 6), were found to be maintained.

Table 3 Proportion and examples of students' responses for open-ended test items for categories of understanding

Test item	Category	Example of students' responses	Pre-test ($N = 52$) (%)	Post-test ($N = 52$) (%)	Delayed test ($N = 51$) (%)
3a	SU	Evaporation and condensation occurred in this jar. Water in the jar evaporated time passing and then turned into water vapors. These vapors encountered more cool space on top of the jar. Therefore, they lost heat and turned into liquid form as water. Small part of the condensed water falls down and the other constitutes water droplets on the wall of the jar (S18; post-test)	4	83	84
	PU	Water in the jar evaporated with sunlight in the morning. In the evening, condensation occurred in the jar. Thus, water droplets appeared on the inner surface of the jar (S2; pre-test)	75	17	14
	SM	Water evaporated because of two reasons. One is that there is air in the jar before screwing lid of the jar. Second is that sunlight effects the jar resulting in evaporation. In the evening, water vapors changed into water because air in the jar decreased. H_2 and O_2 gases in the air combined with each other and constituted water droplets (S33; pre-test)	15	–	2
	NU	Water evaporated and then, stacked on to inner surface of the jar as water droplets (S34; pre-test)	2	–	–
	NR	No response (S29; pre-test)	4	–	–
4	SU	Water in the electrical heater evaporated and turned into water vapor. Since these water vapors came across to cooler surface such as water glass, they lost heat and then, condensed on the water glass first as dampness and afterwards as water droplets (S46; post-test)	21	92	86
	PU	Since water in the electrical heater boiled, the water evaporated in gaseous form as water vapors. Then, water vapors constituted water droplets (give no reasons) (S29; delayed test)	54	8	10
	SM	Water molecules in the heater separated from each other as water vapors. After that, water vapors came across to the water glass in which there was more pressure. With the effect of pressure, water vapors (gaseous form) changed as water (liquid from) (S40; delayed test)	15	–	4
	NU	Water in gaseous state changed into water droplets with effect of the surrounding (S49; pre-test)	8	–	–
	NR	No response (S23; pre-test)	2	–	–

Table 3 continued

Test item	Category	Example of students' responses	Pre-test ($N = 52$) (%)	Post-test ($N = 52$) (%)	Delayed test ($N = 51$) (%)
5	SU	In the air, there are many gases, namely, oxygen, nitrogen, water vapors and other gases. Since the bottle was taken from the refrigerator, it is very cold. Only water vapors, by losing heat, first as dampness and afterwards as water droplets (S47; delayed test)	29	77	70
	PU	The bottle is colder than the surrounding because it was taken from the refrigerator. Water vapors came across the bottle and condensed as water droplets on the bottle (S11; post-test)	15	13	16
	SM	Since the bottle was taken from the refrigerator, there were ice particles on the bottle. These ice particles first evaporated and afterwards condensed as water droplets on the bottle (S21; delayed test)	46	10	14
	NU	Since the bottle was closed, water droplets appeared on it with the effect of condensation (S16; post-test)	8	–	–
	NR	No response (S23; pre-test)	2	–	–

Note: S1, S2… refer to the particular students in the study

SU Sound understanding (3 points), *PU* partial understanding (2 points), *SM* specific misconception (1 point), *NU* no understanding (0 point), *NR* no response (0 point)

Findings from the students' interviews

Based on the test findings, it was well understood that students changed their alternative conceptions and difficulties about condensation toward scientific ones. In order to explicitly see the students' conceptual change after the intervention, we present the three (below average, average, and above average, respectively) students' understanding about condensation in detail.

The below-average student (S6) has three alternative conceptions and difficulties in the pre-test (see Table 4, namely, SAC # 4, 5 and 6). She changed her views in an affirmative manner in the post- and delayed post-tests. This change was followed by the interviews conducted after the post-test as indicated below.

R A watch glass is carefully placed on an electrical heater in which there is a small amount of boiling water (showing Card 1, see Fig. 5). A few minutes later, many tiny water droplets appeared on the watch glass surface. Why does this event occur? Please explain in detail

S6 Water evaporated since it was heated. Water vapors in gaseous phase reached the watch glass and heat exchange occurred between water vapors and the watch glass. Therefore, they condensed as water on the watch glass

R Please explain how heat exchange occurred?

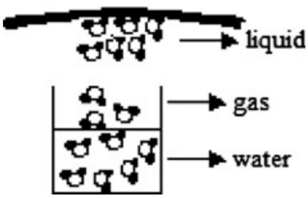
Table 4 Conceptual changes and retentions about students' alternative conceptions (SAC) and difficulties through each test

Students' alternative conceptions and difficulties (SAC)	Pre-test (%)	Post-test (%)	Conceptual changes (%)	Delayed post-test (%)	Retention
1. Water vapor can not be changed into water	10	0	+10	0	R
2. Water vapor can not exist in air at all times	31	2	+29	0	R
3. Hydrogen and oxygen gases, components of water vapor, exist in air instead of water vapor itself	10	0	+10	0	R
4. Water vapor molecules weigh less than liquid water molecules	31	4	+27	8	NR
5. Air condensed as water	13	8	+5	4	R
6. Condensation occurs because of increasing vapor pressure	15	2	+13	4	NR
7. There is water vapor in air only in the winter when it is cold	10	0	+10	0	R
8. Ice on the cold surface melts and forms drops of water (condensation in open systems)	11	2	+9	2	R

"+" Shows positive conceptual change; "R" shows conceptual change is retentive; "NR" shows conceptual change is not retentive

S6 Heat transferred from water vapors to watch glass because it is very hot. Thus, they condensed as water droplets

R Please draw microscopically this process that you have stated. And explain your drawing



In the liquid form, water molecules move closer together. Water evaporates as times goes and re-form as water vapors. That is, water molecules are far from each other. In this period, water molecules do not break down as gases of H_2 and O_2 although water is composed of those gases. And then, water vapors lose heat and come close to each other, therefore, they formed tiny water droplets…

....

R A bottle filled with a small amount of water is exposed to the sun light (showing Card 2, see Fig. 5). It is left there for a few days. A few days later, many tiny water droplets appeared on the inner surface of the bottle. Why do water droplets appear? Please explain in detail

S6 Condensation occurred in this event. Since the bottle was exposed to sun light, the water in the bottle heated and, thus, a little part of the water evaporated. Because of decreasing effects of the sunlight in afternoon and evening times, evaporated water in the bottle reformed as water droplets on the inner surface

R Imagine that the bottle is left somewhere in which there is no sunlight. Again, do water droplets appear on the inner surface of the bottle?

S6 Yes, water droplets again appear. However; less water droplets would form as compared to the first place where there is sun light

R Why?

S6 … the water was less heated and less water vapor was formed because there was no sun light in there. Therefore, there was less condensed water vapor on the inner surface of the bottle

R (showing the Card 2, see Fig. 5)… Is there any difference in weight of the bottle between the first and the last form (a few days later) of the bottle?

S6 There is no difference in weights

R Why?

S6 Changes in water is a physical change and not a chemical change. The water only changed its form as water vapors. There is no weight change. Moreover, it is a closed system because of tightly capped bottle…

R You are right, however; the bottle contained both water and water vapors. Again, is there any difference in weight of the bottle or not?

S6 Yes. There is no difference since water vapor and water are the same matter

………………

The average student (S19) had one alternative conception in the pre-test (see Table 4, namely, SAC # 5). He changed his views in an affirmative manner in the post- and delayed post-tests. This change was followed by the interviews as indicated below.

R In a cold day, you have noticed that dampness occurs on the windows surface of a house or a car. Why? Please explain

S19 Interior of a house is warmer than exterior of a house…thus, inner surface of the window is warmer than the outer surface. Water vapors in the house collided with windows, lost heat and condensed as water since they encountered the colder surface. Therefore, dampness occurs on the windows of the house

R What condensed on the window?

S19 Water vapors

R In a house, there are many gases, such as; oxygen, nitrogen, hydrogen and other gases. Why did these gases not condense as water vapors do?

S19 The situations are only suitable for water vapors not the other gases

R Right. Could other gases also condense?

S19 Yes, if all requirements are provided…

………………

The above-average student (S50) had no alternative conceptions in the pre-test. He empowered his scientific views from pre-test toward post- and delayed post-tests. This powerful construction was followed by the interviews as indicated below.

R A bottle filled with a small amount of water is exposed to the sun light (showing Card 2, see Fig. 5). It is left there for a few days. A few days later, many tiny water droplets appeared on the inner surface of the bottle. Why do water droplets appear on the inner surface? Please explain in detail

S50 Water in the container evaporated and scattered into empty space of the bottle as water vapors. The water vapors hitting interior wall of the bottle transfer heat since the temperature of that surface is cooler than the temperature of the water vapor. They, hence, condensed first as dampness and then water droplets

R Imagine that the bottle is left somewhere in which there is no sunlight. Again, do water droplets appear on the inner surface of the bottle?

S50 Yes, water droplets again appear. This process takes more time as compared to the first situation where there is sun light, since heat accelerates evaporation rates. Evaporation takes place without heating, however; it takes more time and only a few particles evaporate

………………

R You have noticed smoke rising from a huge ice cube taken out from a refrigerator. Actually ice cube also produce smoke. How does smoke take place? Please explain

S50 Actually, it does not give off smoke. The reason why the ice cube gives off smoke is that water vapor condensed into liquid, that is, water after making contact with the surface of a cold ice cube

Discussion and conclusions

The major purpose of this study was to investigate the effectiveness of a teaching activity composed of three PDEODE tasks in bringing about conceptual change for student understanding of condensation. The research findings presented here suggest that PDEODE teaching strategies are an effective means of reducing the number of alternative conceptions students hold about condensation. The research findings suggest that after the intervention, students' understanding improved as measured by the test items and students' interviews. Moreover, the students' alternative conceptions (as seen in the responses to all test items, Table 4) were reduced from pre-test to post-test. Interestingly, the most frequently observed changes were those in which alternative conceptions were detected in the pre-test and these were removed and replaced by conceptual understanding for both the post- and the delayed post-tests. Besides the test results, interview findings also showed that students at three different levels (below average, average, and above average) improved their understanding about condensation. The below-average and average students' alternative conceptions and difficulties elicited based on the pre-test were remediated after the intervention. Also, the above-average student had no alternative conceptions in the pre-test and showed sound understanding about condensation especially in explaining daily life events related to the topic. These findings are similar to other studies on conceptual change for a variety of topics such as solution (e.g., Çalık et al. 2007b; Pınarbaşı et al. 2007), mole (e.g., Case and Fraser 1999), chemical equilibrium (e.g., Canpolat et al. 2006), evaporation (e.g., Coştu et al. 2010), boiling (e.g., Coştu et al. 2007) and electrochemistry (e.g., Niaz 2002). We suggest here that the success of these students stems from the fact that the PDEODE tasks helped them to *evaluate* their prior knowledge and to reexamine their ideas within their groups and in whole-class discussions. As a consequence of the PDEODE, the students, became *dissatisfied* with their existing knowledge through their direct observations that occurred in the tasks, and it seems this helped them to accept better, more scientific, explanations to the problems presented (i.e., fruitful explanations). Finally, they modified their ideas toward the scientific view, and subsequently enhanced their newly structured knowledge about condensation from discussions after the observations.

It is important to note at this point that although predominantly positive changes were seen in terms of student conceptual understanding, a few students retained alternative conceptions after the teaching intervention (see Table 4). Some maintained their alternative conceptions throughout the study, and others maintained their scientific conceptions (Table 4). The fact that some students retained alternative conceptions has also been reported in other studies of conceptual change (e.g., Case and Fraser 1999; Coştu et al. 2010; Ebenezer 2001; Hewson and Hewson 1983), and it may be that this occurred as a result of interaction with students who adhered strongly to their prior alternative conceptions.

This study identified three prevalent student alternative conceptions (namely 1, 2 and 4, Table 4). For alternative conception # 4—students' belief about the weight of water vapor in comparison with the liquid phase—a decrease was seen from pre-test (31%) to post-test (4%), representing a positive conceptual change (+27). Interestingly, however, the prevalence of this belief increased somewhat in the delayed post-test (8%, see Table 4). This is perhaps an indication of the robustness of some students' alternative conceptions. Likewise for student alternative conception #1—involving water vapor changing into liquid water—the prevalence of alternative conceptions decreased from pre-test (10%) to post-test (0%). and this was maintained, in the delayed post-test (Table 4). In the case of alternative conception # 2—about the existence of water vapor in air—the prevalence of this alternative conception again decreased markedly between the pre-test (31%) and post-test (2%), and decreased further in the delayed post-test (to 0, Table 4).

The second research question concerned whether or not any conceptual change was retained in students' long-term memory. The research findings revealed that prevalence of students' alternative conceptions decreased (Table 4) in all cases, except for alternative conception # 4 and 6, suggesting that the activity developed in this study, helped students to retain their conceptions in their long-term memory (Coştu 2006; Coştu et al. 2007, 2010; Çalık et al. 2007b; Glynn and Takahashi 1998; Hynd et al. 1997; Palmer 2003; Tsai 1999).

In summary, this study provides some evidence that teaching activity composed of PDEODE tasks as used in the present study can be an effective means of conceptual change and help shift students' alternative conceptions and enhance conceptual understanding for condensation. Readers may wish to consider such an approach in their own classrooms, for this topic and perhaps other related topics.

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