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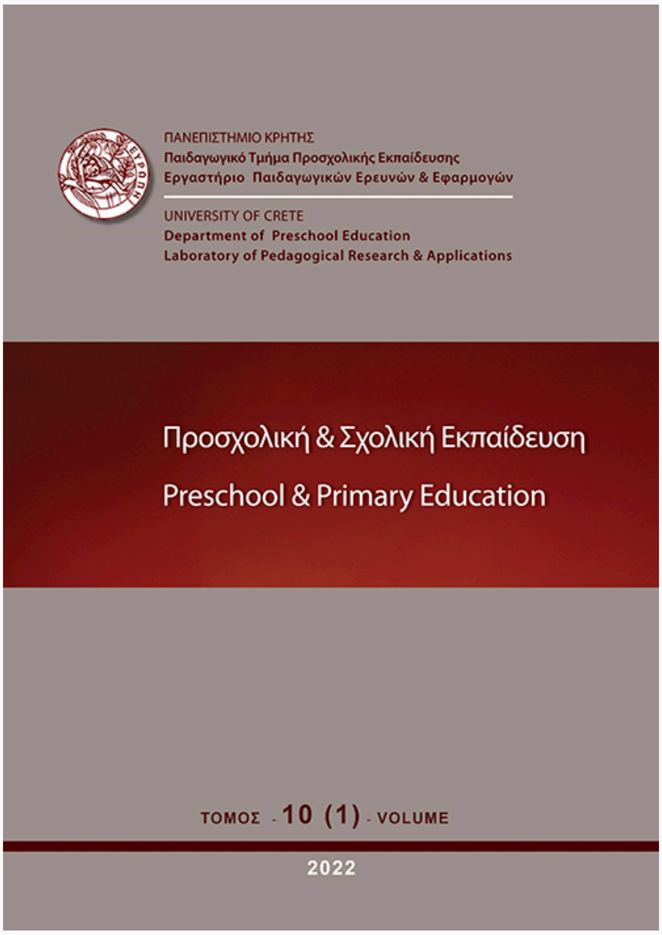

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Primary students' argumentation skills on evaporation: A teaching intervention

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Abstract. This paper reports the findings of a study exploring the possibilities of improving students' argumentation skills concerning evaporation process and factors affecting evaporation by implementing two teaching schemes, with and without the use of particle theory. The participants (ages 10/11, n = 77) were students of four fifth-grade classes of two Greek regular public primary schools. The research data were collected through an open-ended written test (pre- and post-intervention) and a semi-structured interview (post-intervention). Results revealed that the improvement of students' argumentation skills regarding the evaporation process and the factors affecting evaporation is feasible through an appropriate teaching intervention. This concerns mainly the components of claim and evidence, whereas the use of the particle theory seems to contribute further to this improvement, as well as to the improvement of the reasoning component. Implications for science education are also discussed.

Keywords: argumentation, evaporation, particle theory, primary education, teaching intervention.

Introduction

Over the last decades, a trend in science education seems to have shifted its focus from students' final ideas, where memorization of concepts, facts and principles is emphasized, to a science-as-practice vision, where students are engaged in science practices constructing understanding of the natural world (Cherbow et al., 2020; Duschl, 2007; McNeill & Berland, 2017). Argumentation is a typical form of scientific practice (Deng & Wang, 2017) and is regarded to be one of the most important processes in contemporary science education, incorporated in the curricula of many countries (McDonald & McRobbie, 2012). Students' engagement in scientific argumentation promotes critical thinking and reasoning skills (Jimenez-Aleixandre & Erduran, 2007; Kaya, 2013; Kuhn & Udell, 2007), enhances the understanding of scientific epistemology (Berland & Reiser 2010; Sampson & Blanchard, 2012), helps in adopting a positive attitude towards science (Jiminez-Aleixandre & Erduran, 2007; Hong et al., 2013; McNeill & Krajcik, 2006) and contributes to the development of conceptual understanding (Bell & Linn, 2000; Jiminez-Aleixandre & Erduran, 2007; Kaya, 2013; McNeill & Krajcik, 2007; Sampson & Clark 2009; Zohar & Nemet, 2002). Regarding the relationship between argumentation and conceptual understanding, there is evidence that the conceptual understanding of a topic influences the quality of relevant arguments and vice versa (Cetin, 2014; Garcia-Mila et al., 2013; Sadler, 2004; von

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Aufschnaiter et al., 2008). As Ogan-Bekiroglou and Eskin (2012) suggest, students engage in a scientific argumentation based on their prior knowledge. Thus, the conceptual understanding of major topics of science education is considered to be one of the main factors affecting the quality of students' arguments regarding these topics.

One of these major topics of science education is evaporation, which is taught from the primary school onwards (Canpolat, 2006; Coştu & Ayas, 2005). The conceptual understanding of evaporation is essential for understanding other important related concepts and helpful in explaining everyday phenomena (Coştu & Ayas, 2005; Kirbulut & Beeth, 2013). However, despite the importance of the evaporation concept, there is no research evidence concerning primary students' argumentation skills on this topic. Thus, the aim of this paper is to study the effect of a teaching intervention regarding evaporation on fifth-grade primary school students' argumentation skills about the evaporation process and the factors affecting evaporation.

Theoretical background

Arguments' structure and analytical frameworks

According to Toulmin's framework for argumentation structure (Toulmin, 1958, 2003), known as Toulmin's Argumentation Pattern (TAP), the components of an argument are: claim, data, warrant, backing, qualifier and rebuttal. Each of these components has its own role in a well-structured argument. The claim is an assertion that one tries to justify, the data are evidence providing support for the claim, the warrant explains the way in which the data support the claim, the backing strengthens the validity of the warrant, the qualifier indicates the conditions for the claim to be valid and the rebuttal represents the condition under which the claim could be undermined.

The analytical framework developed by Toulmin (1958, 2003) has had a wide appeal and has been employed by the majority of researchers in studies of argumentation in science education (Bağ & Çalik, 2017). However, this framework has often been criticized for being difficult to apply in the argument analysis of school students (Naylor et al., 2007), as the differentiation between the components of an argument appears to be difficult (e.g. difficulty in distinguishing between warrant and backing) (Erduran et al., 2004; Keith & Beard, 2008; Mcneill et al., 2006). Thus, some modified versions of the TAP have been proposed by a number of researchers, taking into account the particularities of students' arguments. As students' arguments are usually less complex than scientific ones (Mendonca & Justi, 2014), there is a need for simpler frameworks of analysis. In the recent literature one can find such analytical frameworks which take into consideration the common structure of students' arguments and usually include three or four components (e.g. Evagorou et al., 2011; Kulatunga et al., 2013; McNeill et al., 2006; McNeill and Krajcik, 2011). Among them, the most characteristic framework is that developed by Mcneill et al. (2006) and also McNeill and Krajcik (2011). According to this, a student's argument includes a claim, evidence (similar to Toulmin's data), reasoning and rebuttal. The component of 'reasoning' is a combination of Toulmin's warrant and backing, explaining the link between claim and evidence, based on scientific principles (Mcneill et al., 2006), whereas the 'rebuttal' component explains how or why an alternative claim is incorrect (McNeill & Krajcik, 2011).

Although the simplification of the analytical frameworks can be characterized as a positive step towards an effective methodology for analyzing students' arguments in science education, another issue is raised regarding the suitability of the components' content of an argument. As Sampson and Clark (2006) state, the majority of argumentation studies evaluate solely the quality of the students' arguments from a structural perspective, based on the presence or absence of a particular structural component, whereas there is little information on the suitability of the content of each one of the argument components. Thus, the need for an analytical framework evaluating the quality of both the structure and the content suitability of students' arguments has resulted in the development of new frameworks. The analytical framework of Chen et al. (2016), for instance, is such a framework, combining the evaluation of the quality of both the structure and the suitability of the content in students' arguments. For the purposes of their research, they developed a four-level scoring scale (0–3) evaluating the content suitability of each one of the four components of students' arguments (claims, evidence, warrants, rebuttals). The criteria for assigning a particular score on this scale were based on the completeness and correctness of the component.

Students' ideas for evaporation

To date, several studies (e.g. Bar & Galili, 1994; Bar & Travis, 1991; Canpolat, 2006; Coştu et al., 2010; Coştu & Ayas, 2005; Kirikkaya & Gulu, 2008; Osborne & Cosgrove, 1983; Russell et al., 1989; Tsikalas et al., 2014) have been conducted on students' ideas about evaporation, investigating a number of relevant issues such as the evaporation process or factors affecting evaporation. Findings indicated that students' ideas regarding these issues differ significantly from scientifically accepted views. With regard to the evaporation process, research evidence (Bar & Galili, 1994; Osborne & Cosgrove, 1983; Russell et al., 1989; Tsikalas et al., 2014) has shown that students often perceive this phenomenon as a 'disappearance' (evaporated substance disappears, e.g. the water does not exist anymore), as 'absorption' (evaporated substance is absorbed by materials or surfaces, such as a plate, or the floor, or even by the sun), or as 'transfer/displacement' (evaporated substance is transferred to another location, such as the ground, the clouds, the sun, or the ceiling).

As for the factors affecting evaporation, students' alternative conceptions and misconceptions have been recorded concerning temperature, the nature of the liquid substance, liquid surface and air current. For instance, heating seems to be necessary for the evaporation of a liquid according to students' rationale (Canpolat, 2006; Coştu et al., 2010; Johnson, 1998; Prain et al., 2009), as it is believed that the temperature of the liquid should be higher than the room temperature. Also, students have alternative conceptions concerning the nature of the evaporated substance, believing in some cases that only water and water solutions can evaporate, whereas in cases where they accept the evaporation of other liquids, they believe the rate is the same as that of water (Coştu et al., 2010; Coştu & Ayas, 2005; Tsikalas et al., 2014). Regarding the effect of air current (above the surface of the liquid) on evaporation, students erroneously often have the view that it decreases the evaporation of the liquid (Coştu et al., 2010; Coştu & Ayas, 2005). In addition, students' conceptions concerning the liquid surface are also different from the scientific view, as they do not recognize the effect of the liquid surface on the evaporation rate (Coştu et al., 2010).

As a number of researchers suggest (Gopal et al., 2004; Paik, 2015), the above misconceptions originate from the abstract nature of the evaporation process, where an invisible state of a substance is formed. The problem is bigger for primary students, where the concept of the substance itself is not clear. According to Johnson (1998), when the understanding of this concept is not clear, there no chance to understand the changes of a substance during a physical or chemical phenomenon. As a result, the process of evaporation is even more difficult, since, beyond the change of state of a substance (from liquid to gas), also mixing with air components takes place during the phenomenon (Johnson & Papageorgiou, 2010). Thus, in order for students to imagine this complex process, appropriate representational resources must be developed. As some researchers suggest (e.g., Johnson, 1998; Tytler et al. 2007; Wang & Tseng, 2018), such resources are based on particle ideas. Indeed, there is evidence supporting that a particle model enables students to visualize this 'invisible' phenomenon and to develop deep understanding of the whole evaporation process (Kirbulut & Beeth, 2013; Papageorgiou & Johnson, 2005). As a result, particle theory seems to play a critical role in understanding evaporation, and it could be a promising tool when used in teaching interventions.

Rationale

Although many studies have focused on the importance of students' argumentation skills in a number of physics and biology topics (Bağ & Çalik, 2017), limited attention has been paid to the investigation of such skills in evaporation topics. Evaporation is a fundamental concept of science and students' understanding at the submicroscopic level is important, as it is the basis for the understanding a number of everyday situations and other related concepts (Chang, 1999). However, argumentation on evaporation is not a stand-alone issue and, as noted above, many scientists suggest that students' prior knowledge and conceptual understanding of the arguments' subject matter is an important factor that affects the quality of students' arguments (Cetin, 2014; Faize et al., 2018; Garcia-Mila et al., 2013; Venville & Dawson, 2010). Taking also into account that there is no research focusing on primary students' argumentation on the evaporation phenomenon, it was considered important to focus on this phenomenon in relation to students' relevant prior content knowledge. In particular, the present research aims to study the effectiveness of a teaching intervention regarding evaporation, with and without the use of particle theory, on fifth-grade students' argumentation skills concerning the evaporation process and factors affecting evaporation. The following research questions were investigated in this study:

- What are the primary students' argumentation skills regarding the evaporation process and the factors affecting evaporation following a relevant teaching intervention? Are there any significant differences between pre- and post-intervention?
- What is the effect of using particle theory during the teaching intervention? Are there any significant differences between students who received the particle theory and those who did not, during the intervention?

Methodology

The sample

The research was conducted in two regular public primary schools, located in an urban area of central Greece in the 2019-2020 academic year. The total number of participants was 77, attending two fifth-grade classes of each school (age 10/11). All the four classes of the sample were of mixed academic abilities, with no significant differences in school academic performance according to their teachers' evaluation. Additionally, students' socioeconomic backgrounds in all the four classes were similar. To access the schools, permission from the Greek Ministry of Education was obtained. All students voluntarily participated in the study and parents' informed consent was also obtained. Participants were also informed about the aims of this study and its anonymity.

The procedure

A combination of quantitative and qualitative methods was implemented in the present study. In particular, to answer the first research question, a 'one-group pre-test post-test' pre-experimental design was implemented (Cohen et al., 2007) following the structure pre-test> teaching intervention> post-test (see Figure 1). In this design, the 'group' comprised all students of four classes (n = 77). Before the intervention, all classes had followed the National Science Curriculum for Greece (Plakitsi et al., 2014) using the same textbooks. Therefore, students' prior knowledge about the phenomenon of evaporation was similar for all students and very limited, since the concept of evaporation was approached only in the context of the water cycle during the second grade.

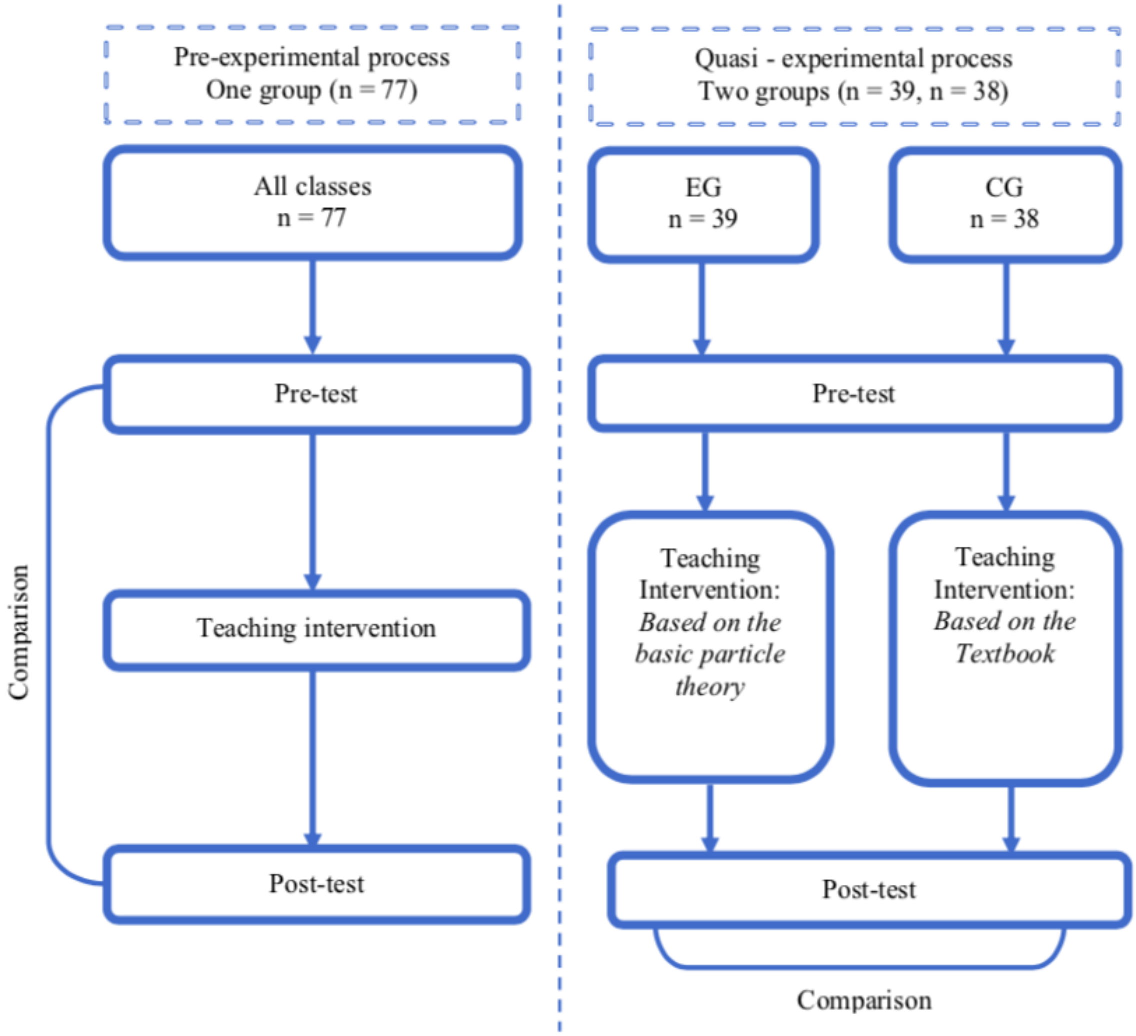

Figure 1 An overview of the whole procedure

In order to address the second research question, a quasi-experimental design was implemented, where two of the classes (randomly selected) comprised the experimental group (EG, n = 39) and the other two classes comprised the control group (CG, n = 38). During the teaching intervention, particle theory was used to teach evaporation only for the experimental group, as it is described in "The teaching intervention" section.

For both research questions, the same test was used pre- and post- intervention to measure students' argumentation skills. Furthermore, twenty-four students, twelve from each group (EG and CG), were selected on the basis of their science performance (four students from high, intermediate and low bands of performance in each group), to take part in a semi-structured individual interview.

Instruments

To assess students' argumentation skills, a written open-ended test was developed, based on relevant studies (Bar & Travis, 1991; Chen et al., 2016; Coştu et al., 2010; Papageorgiou et al., 2008; Prain et al., 2009). The test was administered to all students, one week before (pre-test) and three weeks after (post-test) the intervention.

The instrument consisted of two parts and took one hour to complete. The first part included three tasks concerning the evaporation process and the second part included four tasks regarding the factors affecting evaporation (Table 1).

Table 1 A description of the instrument

Part	Task	Description of the Task
	1	What happens to water spilled on the floor as it dries?
I	2	How can we smell a perfume when the lid of its bottle is opened?
	3	What happens to water as the laundry is drying?
	4	What happens to water left in two plates for some days, in a hot and a cold classroom, comparatively?
II	5	What happens to water left for some days, in a plate with a small surface and in another with a larger one, comparatively?
	6	What happens to alcohol left in a vessel for several hours, in front of a fan and in a cupboard, comparatively?
	7	What happens to small quantities of alcohol and water left in a vessel for several hours, comparatively?

In each task, students had to choose the correct one out of a number of proposed views and they were asked to answer the following questions:

a. Which student do you agree with? (Claim)
b. Why do you agree with this point of view? Please explain. (Evidence + Reasoning)
c. Why do you not agree with the other students? Please explain. (Rebuttal)

Additional data were collected through semi-structured interviews. The average duration of the interviews was approximately twenty minutes for each one of the twenty-four students. The interview's protocol was structured following exactly the same structure and content of the written test, but students had more opportunities to further express their arguments, especially at the microscopic level. It was considered that an 11-year-old student could more easily present an oral than a written argument referring to the microscopic level (using particle ideas). Therefore, when the students did not refer to particles spontaneously, the interviewer asked relevant questions, reminding the student of the existence of particles, e.g. '*Imagine that you could use a really powerful microscope and the beakers' content was magnified many times. What would you see*?' Furthermore, regarding the component 'reasoning' where a justification should provide evidence supporting the claim, students were asked to draw this 'magnified' picture in each task, as an additional method of evaluation (Kaya, 2018). Students thus had the chance to support their reasoning with drawings, something very when it was difficult for them to express it verbally.

The teaching intervention

The students attended a six-lesson course that lasted seven hours in total, for each group. Two teaching schemes on evaporation were developed for the two groups (EG and CG), respectively. Dealing with the same phenomena, the teaching schemes' contents differed only in relation to the submicroscopic level concepts and explanations. More specifically, one scheme included the *basic particle theory*, as introduced by Johnson and Papageorgiou (2010), whereas the other did not. The scheme with the particle ideas was implemented in the EG. In this case, the focus was on the idea of a substance as a collection of particles which can hold on to each other and are always moving in some way (Johnson & Papageorgiou, 2010). The scheme implemented in the CG was designed in accordance with the submicroscopic level topics in the conventional textbook. According to this scheme's design only some superficial explanations were given and no particular particle model was adopted (i.e., matter consists of molecules which consist of atoms, the basic components of which are protons, neutrons and electrons – in solids, liquids and gases the distances between molecules and their freedom of movement differ).

Both schemes were designed based on similar teaching schemes developed in previous studies (Papageorgiou et al., 2008, 2010; Papageorgiou & Johnson, 2005), where the concept of evaporation was adapted. An outline of the teaching schemes is presented in Table 2. All scheme units are common for both schemes, apart from unit 3, which was taught only in the EG. Furthermore, in the EG any explanation in units 4, 5 and 6 took place in terms of *basic particle theory* (Johnson & Papageorgiou, 2010), whereas in CG, explanations were given in the context of the textbook material.

Table 2 The teaching scheme

1. Studying materials and objects in terms of their properties. Distinguishing between the two.
2. Studying substances and mixtures. Substances have characteristic properties that can be used to differentiate them from mixtures and from each another.
3. Introducing a simple particle model (for EG only)
    - Substances are collections of particles. Empty space exists between particles.
    - The particles can hold on to each other. There is always motion among the particles.
    - All particles of a substance remain the same during changes of state.
4. A substance can exist in any of the three states (solid, liquid or gas) depending on the temperature. Different substances can exist in different states at the same room temperature.
5. Describing the evaporation process (a change from liquid to gas state). Mixing particles of the substance evaporated with those of the air.
6. Factors affecting evaporation (temperature, surface, breeze, the substance itself).

The instructional material was designed based on the teaching model 5E (Bybee et al., 2006), which combines a constructivist approach with an inquiry-based learning approach. The learning activities during the implementation of this teaching model required students to work in small groups and participate in a way that activated their pre-existing knowledge, as a prerequisite to build new knowledge.

Data analysis

To evaluate students' argumentation skills, their answers to written tests were analyzed. The quality of students' arguments was evaluated based on their structure and content. The structure of an argument depends on the number of the relevant components and the content of an argument relates to the suitability of its components when they are evaluated on the basis of school scientific knowledge (Skoumios & Hatzinikita, 2014).

Using a four-level scoring scheme (0-3), based on that developed by Chen et al. (2016), the arguments' content was analyzed to assess the suitability of each one of the three out the four components of their arguments, namely, the evidence, the reasoning and the rebuttal. Zero represents an irrelevant or wrong answer, 1 shows a low level suitability answer constituting a simple component, 2 indicates a moderate level constituting a partially complete component and 3 was assigned to a high level suitability answer constituting a clear and complete component. As far as the claim was concerned, a two-level scoring scheme was used, because students had to choose the correct one out of a number of proposed views. Therefore, for claims, 0 was assigned to an incorrect choice and 1 to the correct one. Apart from the assessment of the suitability of each component separately, the overall argumentation skill can be evaluated calculating the sum of the component scores (Chen et al., 2016). The absence of an answer-component was considered as a 'missing value' and affected the arguments' structure quality. Appendix 1 shows some examples of scoring students' answers per argument component.

Statistical analyses were performed by using the software SPSS applying a significance level of 5%. As far as the first research question is concerned, the Wilcoxon Signed Ranks Test was used to determine any differences in students' argumentation skills before and after the intervention. Addressing the second research question, any differences in students' argumentation skills between the EG and the CG, the non-parametric test of Mann-Whitney U was conducted.

Data collected from the interviews were analyzed using content theme analysis, identifying key themes and students' ideas referring to the microscopic level or not. In addition, these data were categorized using the same scoring scheme used for the quantitative analysis as described above. Finally, to assess students' drawings generated during the interviews, a second scoring scheme was developed especially for the needs of this study (Table 3).

Table 3 Scoring scheme for the evaluation of students' drawings

Score	Level	Description
0	-	Irrelevant content/ Microscopic ideas not depicted.
1	Low	Representation of particles of only one state (only in liquid or gaseous state).
2	Moderate	Representation of particles of both liquid and gaseous state, as well as representation of the evaporation process only one way (either due to movements of the particles of liquid state with increased energy or due to the collisions of air particles with the particles of the liquid state).
3	High	Representation of all particles and representation of the evaporation process both ways.

Results and discussion

The effectiveness of the intervention on students' argumentation skills

Table 4 presents an overview of students' scoring in pre- and post- tests.

Table 4 Frequencies (and percentages) of scores concerning students' argumentation skills pre- and post- teaching intervention. 'M' denotes 'missing values'.

Task	Score	Claim		Evidence		Reasoning		Rebuttal	
		Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
1	0	36 (46.8)	12 (15.6)	53 (68.8)	29 (37.7)	3 (3.9)	1 (1.3)	43 (55.8)	28 (36.4)
	1	41 (53.2)	65 (84.4)	15 (19.5)	37 (48)	2 (2.6)	19 (24.7)	23 (29.9)	39 (50.6)
	2				3 (3.9)		8 (10.4)		5 (6.5)
	3				2 (2.6)		1 (1.3)		
	M			9 (11.7)	6 (7.8)	72 (93.5)	48 (62.3)	11 (14.3)	5 (6.5)
2	0	21 (17.3)	12 (15.6)	47 (61)	32 (41.6)	1 (1.3)		47 (61)	42 (54.5)
	1	53 (68.8)	65 (84.4)	17 (22.1)	36 (46.8)	3 (5.9)	15 (19.5)	7 (9.1)	14 (18.2)
	2				4 (5.2)		3 (3.9)		4 (5.2)
	3				1 (1.3)				
	M	3 (3.9)		13 (16.9)	4 (5.2)	73 (94.8)	59 (76.6)	23 (29.9)	17 (22.1)
3	0	72 (93.5)	43 (55.8)	64 (83.1)	52 (67.5)	5 (6.5)	3 (3.9)	57 (74)	46 (59.7)
	1	5 (6.5)	34 (44.2)	2 (2.6)	20 (26)		14 (18.2)	1 (1.3)	15 (19.5)
	2						3 (3.9)		1 (1.3)
	3								
	M			11 (14.3)	5 (6.5)	72 (93.5)	57 (74)	19 (24.7)	15 (19.5)
4	0	34 (44.2)	17 (22.1)	50 (64.9)	32 (41.6)	2 (2.6)		50 (64.9)	39 (50.6)
	1	39 (50.6)	60 (77.9)	10 (13)	38 (49.4)	5 (6.5)	18 (23.4)	8 (10.4)	18 (23.4)
	2				3 (3.9)		3 (3.9)		2 (2.6)
	3				1 (1.3)				
	M	4 (5.2)		17 (22.1)	3 (3.9)	70 (90.9)	56 (72.7)	19 (24.7)	18 (23.4)
5	0	63 (81.8)	30 (39)	59 (76.6)	44 (57.1)	1 (1.3)	1 (1.3)	54 (70.1)	42 (54.5)
	1	13 (16.9)	47 (61)	2 (2.6)	24 (31.2)	1 (1.3)	7 (9.1)	3 (3.9)	12 (15.6)
	2				5 (6.5)		4 (5.2)		1 (1.3)
	3								
	M	1 (1.3)		16 (20.8)	4 (5.2)	75 (97.4)	65 (84.4)	20 (26)	22 (28.6)
6	0	49 (63.6)	20 (26)	56 (72.7)	39 (50.6)	3 (3.9)		42 (54.5)	38 (49.4)
	1	25 (32.5)	56 (72.7)	3 (3.9)	28 (26.4)	1 (1.3)	3 (3.9)	1 (1.3)	8 (10.4)
	2				3 (3.9)		2 (2.6)	1 (1.3)	1 (1.3)
	3						1 (1.3)		
	M	3 (3.9)	1 (1.3)	18 (23.4)	7 (9.1)	73 (94.8)	71 (92.2)	33 (42.9)	30 (39)
7	0	53 (68.8)	31 (40.3)	55 (71.4)	42 (54.5)	4 (5.2)		41 (53.2)	42 (54.5)
	1	20 (26)	45 (58.4)	1 (1.3)	22 (28.6)	2 (2.6)	11 (14.3)	4 (5.3)	8 (10.4)
	2						1 (1.3)		1 (1.3)
	3								
	M	4 (5.2)	1 (1.3)	21 (27.3)	13 (16.9)	71 (92.2)	65 (84.4)	32 (41.6)	26 (33.8)

On the basis of a general evaluation of data presented in Table 4 on the structure of students' arguments pre-intervention, a common characteristic in all tasks is that over two-thirds of students provided arguments with an evidence, over a half of them articulated a rebuttal and there were no missing values in claims for the vast majority. In contrast only a small minority of students articulated reasoning. This situation appears to be improved post-intervention, since the number of missing values in all components and almost all tasks decreased. However, the improvement is quite limited in cases of reasoning and rebuttal with percentages varying according to the task. These findings seem to be in line with other studies (Deng & Wang, 2017; Heng et al., 2015; Jiménez-Aleixandre et al., 2000; McNeill & Krajcik, 2008; Sandoval & Millwood, 2007; Skoumios & Balia, 2020), where students mainly construct simple arguments consisting of claim and evidence, struggling to provide reasoning and rebuttal.

As far as the content of students' arguments is concerned, it seems that their suitability pre- intervention was not satisfying since a significant number of students supported incorrect claims and their evidence, reasoning and rebuttal were scored 0 and 1 in almost all tasks. Post- intervention, the suitability of the content seems to have changed, although not dramatically. In particular, the majority of students' responses were scored 1, whereas those at score levels 2 and 3 were a small minority. As Table 4 shows, even though most of the students post- intervention were able to support a correct claim, they still had difficulties providing suitable evidence and reasoning compatible with the school level knowledge of science (Skoumios & Hatzinikita, 2014), as well as explaining why an alternative claim is incorrect (rebuttal). These findings support a number of suggestions found in literature according to which, students often fail to appropriately connect claims and evidence (Ryu & Sandoval, 2012) even after an argumentation-based intervention (McNeill & Krajcik's research, 2007). Student's difficulty in producing suitable rebuttals leads to the conclusion that this component may require higher order thinking skills (Christenson & Chang Rundgren, 2015).

Table 5 presents a clearer view of changes pre- and post- intervention, comparing students' scores on the basis of the Wilcoxon Signed Ranks Test. As mentioned above, the improvement reflects the structure of the arguments rather than the suitability of their content, which continues mainly to be scored at level 1, with only a few scored at levels 2 and 3. However, regarding the claims there is a remarkable increase of students who made the correct choices. Also, claim and evidence seem to be the most improvable components for almost all the tasks, regarding both the structure and the suitability of their content. This advocates other researchers' suggestions that claim is the most manageable component for students (McNeill & Krajcik, 2008) followed by the component of evidence (Heng et al., 2015). On the other hand, the components of reasoning and rebuttal appear to be the most difficult to improve across all the tasks for reasoning and tasks 2, 6 and 7 for rebuttal. Moreover, reasoning constitutes the most difficult component to improve as it is missing even after the intervention. Similarly, McNeill and Krajcik (2007) demonstrated that although students' reasoning improved after an intervention, its quality was lower in relation to other components. Also, according to some studies (Faize & Dahar, 2017; McNeill & Krajcik, 2007) both components are considered to be difficult for students to construct with suitable content. As far as the difficulty of tasks is concerned, it seems that students' performance was not satisfactory in task 3, pre- and post-intervention for all the components, as well as in tasks 5, 6 and 7 for the components of reasoning and rebuttal. This could be possibly explained by students' prior experiences of everyday situations related to the tasks. According to Ogan-Bekiroglu and Eskin (2012), when students are familiar with a task, it is more likely that they will engage in a relevant argumentation and construct its components.

The effectiveness of particle theory on students' argumentation skills

Results presented in Tables 6 and 7 concern the comparison of students' argumentation skills between the two groups EG and CG, post-intervention. It is apparent that there are differences in both the structure and the content of the arguments. As regards the structure, the main difference was detected in the component of reasoning, where the EG students used reasoning to a greater extent in their arguments compared to CG students, as shown by the percentages of missing values for this component. Regarding the content of the components, it seems that the EG students were able to construct arguments with more suitable content. Although most of the EGs' suitability of evidence, reasoning and rebuttal was still scored 1, post- intervention, there were also components at levels 2 and 3 – something that, for CG holds true only in two cases of score 2 (Table 6).

Table 5 Comparison of students' performance pre- and post- intervention.

		Claim		Evidence		Reasoning		Rebuttal	
Task		Mean Rank	z	Mean Rank	z	Mean Rank	z	Mean Rank	z
1	Pre-	17.5	-4.116*	15.5	-4.498*	0	-1.414	15	-3.588*
	Post-	17.5		18.32		1.5		16.85	
2	Pre-	13	-1.8	16	-3.642*	0	-	7	-2.209
	Post-	13		18.5		0		9	
3	Pre-	18	-4.902*	10.5	-3.578*	0	-	7.5	-3.3**
	Post-	18		10.5		1		8.04	
4	Pre-	16	-3.053*	13	-4.421*	0	-1.414	9.5	-3.3**
	Post-	16		14.62		1.5		9.5	
5	Pre-	18	-5.578*	12	-4.604*	0	-	5	-2.496***
	Post-	18		14.08		1		5.56	
6	Pre-	20	-4.644*	11	-4.327*	0	-1	5.5	-1.081
	Post-	20		12.57		1		3.1	
7	Pre-	20.5	-3.479*	10	-3.9*	0	-1.414	5	-1
	Post-	20.5		10		1.5		5	

Note: *p<0.001, **p<0.01, ***p<0.05

Table 7 can better highlight the significant differences between EG and CG in the suitability of the components' content using the Mann-Whitney U-test. Although EG students seem to have performed better than CG students, some difficulties are also present in this group. The construction of 'reasoning' appears to be the most difficult component for EG in tasks 5, 6, 7, whereas 'reasoning' in task 6 and 'rebuttal' in task 7 seem to be the most difficult components regarding their suitability of content. Some researchers have highlighted that these two components are the most difficult for the students, being usually absent from their arguments (Faize & Dahar, 2017; McNeill & Krajcik, 2007), as students tend to focus on their own position without considering it necessary to support it or to defend it against others' views (Felton & Kuhn, 2001). On the other hand, apart from 'claim', which is generally considered the most improvable component (Krajcik & McNeill, 2008), 'evidence' also appears to be an improvable component for EG students, both structurally (in all the tasks) and as to the suitability of its content (in tasks 1 and 2). As for the evaluation of the EG students' performance across the tasks, it can be inferred that two tasks, namely task 6 and 7, were more difficult for them, especially the components of 'reasoning' and 'rebuttal'. This advocates again the view, that the task itself can somehow influence students' argumentation (Deng & Wang, 2017).

Table 6 Frequencies (and percentages) of scores concerning students' argumentation skills of EG and CG, post- intervention ('M' indicates 'missing values').

Task	Score	Claim		Evidence		Reasoning		Rebuttal	
		CG	EG	CG	EG	CG	EG	CG	EG
	0	10 (26.3)	2 (5.1)	22 (57.9)	7 (17.9)		1 (2.6)	21 (55.3)	7 (17.9)
	1	28 (73.7)	37 (94.9)	14 (36.8)	23 (59)	4 (10.5)	15 (38.5)	14 (36.8)	25 (64.1)
1	2				3 (7.7)	1 (2.6)	7 (17.92)		5 (12.8)
	3				2 (5.1)		1 (2.6)		
	M			2 (5.3)	4 (10.3)	33 (86.8)	15 (38.5)	3 (7.9)	2 (5.1)
	0	7 (18.4)	5 (12.8)	20 (52.6)	12 (30.8)			23 (60.5)	19 (48.7)
	1	31(81.6)	34 (87.2)	16 (42.1)	20 (51.3)	2 (5.3)	13 (33.3)	4 (10.5)	10 (25.6)
2	2				4 (10.3)		3 (7.7)		4 (10.3)
	3				1 (2.6)				
	M			2 (5.3)	2 (5.1)	36 (94.7)	23 (59)	11 (28.9)	6 (15.4)
	0	25 (65.8)	18 (46.2)	34 (89.5)	18 (46.2)	2 (5.3)	1 (2.6)	26 (68.4)	20 (51.3)
	1	13 (34.2)	21 (53.8)	2 (5.3)	18 (46.2)		14 (35.9)	3 (7.9)	12 (30.8)
3	2						3 (7.7)		1 (2.6)
	3								
	M			2 (5.3)	3 (7.7)	36 (94.7)	21 (53.8)	9 (23.7)	6 (15.4)
	0	8 (21.1)	9 (23.1)	21 (55.3)	11 (28.2)			25 (65.8)	14 (35.9)
	1	30 (78.9)	30 (76.9)	14 (36.8)	24 (61.5)	5 (13.2)	13 (33.3)	3 (7.9)	15 (38.5)
4	2				3 (7.7)	1 (2.6)	2 (5.1)		2 (5.1)
	3				1 (2.6)				
	M			3 (7.9)		32 (84.2)	24 (61.5)	10 (26.3)	8 (20.5)
	0	16 (42.1)	14 (35.9)	25 (65.8)	19 (48,7)	1 (2.6)		24 (63.2)	18 (46.2)
	1	22 (57.9)	25 (64.1)	11 (28.9)	13 (33.3)	1 (2.6)	6 (15.4)	2 (5.3)	10 (25.6)
5	2				5 (12.8)		4 (10.3)		1 (2.6)
	3								
	M			2 (5.3)	2 (5.1)	36 (94.7)	29 (74.4)	12 (31.6)	10 (25.6)
	0	15 (39.5)	5 (12.8)	24 (63.2)	15 (38.5)			22 (57.9)	16 (41)
	1	23 (60.5)	33 (84.6)	10 (26.3)	18 (46.2)	1 (2.6)	2 (5.1)		8 (20.5)
6	2				3 (7.7)		2 (5.1)		1 (2.6)
	3						1 (2.6)		
	M		1 (2.6)	4 (10.5)	3 (7.7)	37 (97.4)	34 (87.2)	16 (42.1)	14 (35.9)
	0	15 (39.5)	16 (41)	23 (60.5)	19 (48.7)			23 (60.5)	19 (48.7)
	1	22 (57.9)	23 (59)	7 (18.4)	15 (38.5)	3 (7.9)	8 (20.5)	2 (5.3)	6 (15.4)
7	2						1 (2.6)		1 (2.6)
	3								
	M	1 (2.6)		8 (21.1)	5 (12.8)	35 (92.1)	30 (76.9)	13 (34.2)	13 (33.3)

A clearer view of the effect of teaching the particle theory on the improvement of the suitability of content can be seen in the of their responses during the interview process. Table 8 presents an overview of students' scoring in the interviews. The scoring scale is the same as that used in the written tests. Additionally, in the same Table, there are data regarding the students' drawings, designed in order to clarify and/or to complement what was verbally mentioned as 'reasoning'. To assess students' drawings, the scoring scale described in 'Methodology' was used. Some examples of such student drawings are presented in Appendix 2.

Table 7 Comparison of students' performance between the two groups EG and CG, post-intervention.

Task		Claim Mean Rank	Claim z	Evidence Mean Rank	Evidence z	Reasoning Mean Rank	Reasoning Z	Rebuttal Mean Rank	Rebuttal Z
1	CG	34.87	-2.546***	27.83	-3.803*	13.7	-0.449	27.9	-3.835*
	EG	43.03		44.4		15.27		44.64	
2	CG	37.91	-0.673	31.61	-2.399***	8	-0.652	25.65	-2.425***
	EG	40.06		42.24		9.69		34.47	
3	CG	35.17	-1.723	28.5	-4.181*	2	-2.653**	26.66	-2.608**
	EG	42.75		44.5		11.44		35.76	
4	CG	39.39	-0.213	30.5	-2.996**	11.25	-0.192	23.05	-3.573*
	EG	38.62		43.78		10.9		36.27	
5	CG	37.79	-0.555	32.89	-1.892	3	-1.715	23.58	-2.627**
	EG	40.18		41		7.2		31.97	
6	CG	33.5	-2.588***	29.85	-2.583***	2	-0.949	19.5	-3.089**
	EG	43.5		40.83		3.8		27.96	
7	CG	38.59	-0.043	28.97	-1.733	6	-0.577	23.5	-1.78
	EG	38.41		35.62		6.67		28.4	

Note: *$p<0.001$, **$p<0.01$, ***$p<0.05$

As Table 8 shows, more EG students articulated arguments with suitability content scoring level 2 compared to CG, whereas only EG students achieved score 3. Although there were also CG students who used particle ideas in their argument, it is apparent that the achievement of scores 2 and 3 by EG students is generally in line with a wider use of the particle theory, which was also present in their reasoning-related drawings. This use of particle ideas can be seen almost exclusively in 'evidence' and 'reasoning', whereas in 'rebuttals' it is present only in few cases. Some examples of students' 'evidence' and 'reasoning' using particle ideas can be seen in Appendix 3. It should be noted that using particle ideas, even by the CG students to a certain degree, is not something usual and could be considered a consequence of the corresponding teaching intervention. As Coştu and Ayas (2005) suggest, students do not often use particle ideas to explain phenomena like evaporation, whereas, although they are able to construct 'reasoning', they do not often use scientific principles (McNeill et al., 2006). As for differences found among the tasks, they are also present in interviews, being generally in line with those recorded during the written tests.

When contrasting students' performance in the interviews and the written tests, it is quite obvious that scientific knowledge is more often obvious in the content of the arguments constructed during the interviews, especially in 'evidence' and 'reasoning'. This is possibly due to the general context of an interview, which can be seen as a kind of a 'social' context, where students have the chance to argue more explicitly about their own position during a discussion with another person. As Heng et al. (2015) suggested, students involved in group argumentations can construct arguments of better quality, with more scientific elements at the macro- and submicro- levels. As for the 'rebuttal', although there is a slightly better performance in interviews, it seems that generally it is a quite problematic component, where both EG and CG students have difficulties in articulating the possibility and suitability of content. It might be possible that when students use school scientific knowledge in their 'evidence' and 'reasoning', they feel confident about their arguments and do not consider it necessary to rebut an opposite claim.

Table 8 Students' performance in the interviews: Frequencies of EG and CG students ('M' denotes 'Missing values').

Task	Score	Claim		Evidence		Reasoning: Verbal		Reasoning: Drawing		Rebuttal	
		EG	CG	EG	CG	EG	CG	EG	CG	EG	CG
1	0		1		1		1		2	7	4
	1	12	11	3/1*/2**	5/2**	1/1*/1**	2/2*		2*	3	6
	2			1/2*/3**	1/2**	5*/3**	1/2*/2**	5*	7*	2	1
	3					1*		6*			
	M				1		1	1	1		1
2	0	1			1				1	2	1
	1	11	12	1/1**	4/1**	1/1**	2*/3**		2*	4	6
	2			1/2*/7**	1/5**	2*/4**	1*/4**	5*	7*	3	
	3					2*/1**		6*			
	M					1	2	1	2	3	5
3	0		2		3		1		2	2	4
	1	12	10	2/1*/3**	3/1*	2/1*/2**	1		2*	5	3
	2			1/2*/3**	1/2*/2**	1*/6**	2*/5**	5*	7*	3	2
	3			1				6*			
	M						3	1	1	2	3
4	0				1		1	1	3	1	4
	1	12	12	1*/2**	5	3*/1**	3*/1**		2*	3	1
	2			1/1*/5**	1/2*/3**	3*/4*	3*/3**	4*	6*	1	1
	3			2**		1**		6*		1*	
	M						1	1	1	6	6
5	0		1		1		1		3	1	2
	1	12	11	1**	1	1**		2*	2*	1	1
	2			7**	1/1*/7**	10**	1*/7**	3*	6*	2/2**	3
	3			4**				6*			
	M				1	1	3	1	1	6	6
6	0	1	1	4	5	5	5	4	6	2	3
	1	11	11	1/2**	1/1*/1**	2**	1/2**	1*	2*		1
	2			1*/4**	1/2**	1**	2**	4*	3*	1/2**	1**
	3					1**		2*			
	M					3	2	1	1	7	7
7	0	1	1	1	4	4	3	6	6		3
	1	11	11	6	4/1*	1/1*	2/2*/1**		1*	1	1
	2			2**	1/1**	1/1**		2*	4*		
	3			1*				3*			
	M			2	1	4	4	1	1	11	8

Note: The slashes (/) are used to separate the number of students' responses without any use of particle theory (without any asterisk) from those responses spontaneously using particle theory (two asterisks **) and those using particle theory after prompting (one asterisk *).

Conclusions and implications for science education

The findings of this study suggest that the improvement of students' argumentation skills regarding the evaporation process and the factors affecting evaporation is feasible through the implementation of a relevant teaching intervention. This improvement concerns mainly claim and evidence, which seem to be the most improvable components (whether using or not using particle theory), whereas reasoning and rebuttal appear to be the most difficult to improve. However, when using particle theory, it can be argued that considerable progress was made, even in the case of the reasoning component, whereas further improvement was recorded in relation to the claim and evidence components.

As a result, some conclusions can be drawn concerning the relationship between argumentation skills and both prior knowledge and conceptual understanding. As teaching interventions enriched students' prior knowledge on evaporation, they could also produce arguments of better quality, advocating the view that any enhancement of students' prior knowledge affects their argumentation skills (Cetin, 2014; Ogan-Bekiroglu & Eskin, 2012). However, the EG students' performance in argumentation was better, where the teaching of particle theory appears to have contributed to a deeper conceptual understanding of the evaporation concept (Kirbulut & Beeth, 2013). This rather implies that a conceptual understanding of a topic can lead to better argumentation skills concerning this topic.

On the other hand, students' performance was not satisfying in two tasks, even after the teaching of particle theory. The students' difficulty in arguing about the factors of 'breezes' and the 'nature of the liquid' may be related to their (alternative) ideas and the lack of a deeper understanding of these factors during the interventions. As reported in the study of Costu et al. (2010), both of these factors are part of the students' alternative conceptions' about evaporation and thus, these ideas are highly robust and extremely resistant to change even after instruction (Canpolat, 2006; Subramaniam & Harrell, 2013). In particular, the first cases of alternative conceptions (concerning breezes) could possibly be attributed to students' everyday experiences, where breezes are related to making something cold. Thus, when students try to explain the impact of the breeze on the evaporation of a liquid, they transfer this experience to the microscopic level, believing that in the same way breezes cool down liquids, so evaporation decreases (Coştu & Ayas, 2005). In the same study (Coştu & Ayas, 2005) the second case of alternative conceptions (concerning nature of the liquid) is attributed to the almost exclusive use of water by teachers and textbooks in teaching about evaporation.

Evaluating all the above, some practical implications emerge concerning the method of presenting and analyzing the topics in the school curriculum, as well as the methodology of teaching these concepts in the classroom. As for the former, the better results of the EG seems to suggest that particle theory and the interpretation of phenomena at the microscopic level (along with an analysis at the macroscopic one) can lead to a deeper understanding, which is connected to better argumentation skills. Many studies stress the importance of such multiple representations for students' deeper understanding regarding many concepts of science (Ainsworth, 1999; Kirbulut & Beeth, 2013), including the evaporation concept (Tytler et al., 2007). In such representations, using particle theory appears to have a critical role, especially in the case of evaporation (Johnson, 1998; Johnson and Papageorgiou, 2010), since it is about a change of state, where the distribution of energy across the particles of the liquid state plays a significant role, whereas the particles of the air components are also involved. Besides, as Prain et al. (2009) explain, without particulate ideas the notion of change from a liquid to a gas cannot be successfully imagined.

As for the teaching methodology, the integration of some technological tools could help students to understand better the relevant concepts. For instance the study of Papageorgiou et al. (2008) found that using a software package which included a particle simulation of evaporation helped students understand particulate explanations of this phenomenon. In addition, a collaborative effort, providing students with the opportunity to work in groups, might also enhance students' understanding of scientific concepts (Kulatunga et al., 2013; Osborne, 2010), since they can help each other change alternative ideas in order to reach a consensus (Berland & Lee, 2012). Moreover, collaborative learning contexts, where students can substantively interact with peers and actively participate in discussion activities, could further support the improvement of their arguments' quality (Chen et al., 2016; González-Howard & McNeill, 2019; McNeill & Berland, 2017).

However, it should be taken into account that the students of the sample were not used to argumentation engagements at the time of the study. As a number of researchers suggest (Ogan-Bekiroglu & Eskin, 2012; Venville & Dawson, 2010; Zohar & Nemet, 2002), 'cultivation of argumentation' in the classroom could lead to an even better improvement of the argumentation components, especially those that seem to have been already improved (claim, evidence and reasoning). Thus, an effort to develop argumentation in the classroom could be a good idea. This could be implemented through the explicit teaching of argumentation, which includes practices such as focusing on an argument's structure, developing criteria to distinguish between good and bad arguments and, creating many opportunities for students to practice their argumentation skills (Zohar & Nemet, 2002). The improvement of students' argumentation skills on the basis of such practices has also been highlighted by a number of researchers (e.g. Chen et al. 2016, Mastrogiorgaki & Skoumios, 2018; McNeill & Krajcik, 2008; Skoumios & Balia, 2020). However, any change in students' practice of argumentation presupposes a change in the culture of the classroom by designing an environment in which argumentation skills are embedded in the learning tasks (Jiménez-Aleixandre, 2007; Ryu & Sandoval, 2012; Sandoval et al., 2019).

As Cross et al. (2008) stated, engagement in argumentation can be more safely developed in a context of understanding prerequisite concepts and, at the same time, when students argue in groups, they have the chance to discover other students' ideas, increasing their knowledge and correcting their alternative ideas. Taking these together, the suggestion seems to be that any effort to improve students' argumentation skills regarding evaporation contributes to a deeper understanding of this topic and vice versa, the enhancement of a conceptual understanding of evaporation, especially when using the particle theory, leads to the development of relevant argumentation skills.

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References

Ainsworth, S. (1999). The functions of multiple representations. *Computers & Education*, *33*(2-3), 131-152. https://doi.org/10.1016/s0360-1315(99)00029-9

Bağ, H., & Çalik, M. (2017). A thematic review of argumentation studies at the K-8 level. *Egitim ve Bilim*, *42*(190), 281–303. https://doi.org/10.15390/EB.2017.6845

Bar, V., & Galili, I. (1994). Stages of children's views about evaporation. *International Journal of Science Education*, *16*(2), 157–174. https://doi.org/10.1080/0950069940160205

Bar, V., & Travis, A. S. (1991). Children's views concerning phase changes. *Journal of Research in Science Teaching*, *28*(4), 363–382. https://doi.org/10.1002/tea.3660280409

Bell, P., & Linn, M. C. (2000). Scientific arguments as learning artifacts: Designing for learning from the web with KIE. *International journal of science education*, *22*(8), 797-817. https://doi.org/10.1080/095006900412284

Berland, L. K., & Lee, V. R. (2012). In Pursuit of Consensus: Disagreement and legitimization during small-group argumentation. *International Journal of Science Education*, *34*(12), 1857–1882. https://doi.org/10.1080/09500693.2011.645086

Berland, L. K., & Reiser, B. J. (2010). Classroom communities' adaptations of the practice of scientific argumentation. *Science Education*, *95*(2), 191-216. doi:10.1002/sce.20420

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). The BSCS 5E instructional model: Origins and effectiveness. *Colorado Springs, Co: Biological Sciences Curriculum Study, 5*, 88-98.

Canpolat, N. (2006). Turkish undergraduates' misconceptions of evaporation, evaporation rate, and vapour pressure. *International Journal of Science Education*, *28*(15), 1757–1770. https://doi.org/10.1080/09500690600779957

Cetin, P. S. (2014). Explicit argumentation instruction to facilitate conceptual understanding and argumentation skills. *Research in Science and Technological Education*, *32*(1), 1–20. https://doi.org/10.1080/02635143.2013.850071

Chang, J. Y. (1999). Teachers college students' conceptions about evaporation, condensation, and boiling. *Science education, 83*(5), 511-526.

Chen, H. T., Wang, H. H., Lu, Y. Y., Lin, H. S., & Hong, Z. R. (2016). Using a modified argument-driven inquiry to promote elementary school students' engagement in learning science and argumentation. *International Journal of Science Education*, *38*(2), 170–191. https://doi.org/10.1080/09500693.2015.1134849

Cherbow, K., McKinley, M. T., McNeill, K. L., & Lowenhaupt, R. (2020). An analysis of science instruction for the science practices: Examining coherence across system levels and components in current systems of science education in K-8 schools. *Science Education*, *104*(3), 446-478.

Christenson, N., & Chang Rundgren, S. N. (2015). A framework for teachers' assessment of socio-scientific argumentation: An example using the GMO issue. *Journal of Biological Education*, *49*(2), 204–212. https://doi.org/10.1080/00219266.2014.923486

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education*, 6th edition. Routledge. doi:10.4324/9780203029053

Coştu, B., & Ayas, A. (2005). Evaporation in different liquids: Secondary students' conceptions. *Research in Science and Technological Education*, *23*(1), 75–97. https://doi.org/10.1080/02635140500068476

Coştu, B., Ayas, A., & Niaz, M. (2010). Promoting conceptual change in first year students' understanding of evaporation. *Chemistry Education Research and Practice*, *11*(1), 5–16. https://doi.org/10.1039/c001041n

Cross, D., Taasoobshirazi, G., Hendricks, S., Hickey, D. T., Cross, D., Taasoobshirazi, G., Hendricks, S., Hickey, D. T., Cross, D., Taasoobshirazi, G., & Hendricks, S. (2008). Argumentation: A strategy for improving achievement and revealing scientific identities. *International Journal of Science Education*, *30*(6), 837–861. https://doi.org/10.1080/09500690701411567

Deng, Y., & Wang, H. (2017). Research on evaluation of Chinese students' competence in written scientific argumentation in the context of chemistry. *Chemistry Education Research and Practice*, *18*(1), 127–150. https://doi.org/10.1039/c6rp00076b

Duschl, R. (2007). Quality argumentation and epistemic criteria. In S. Erduran & M. Jimenez-Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 159–175). Springer.

Erduran, S., Simon, S., & Osborne, J. (2004). TAPing into argumentation: Developments in the application of Toulmin's Argument Pattern for studying science discourse. *Science Education*, *88*(6), 915–933. https://doi.org/10.1002/sce.20012

Evagorou, M., Papanastasiou, E., & Osborne, J. (2011). *The case of designing and validating a tool to assess 11–14 year old students written argumentation*. European Science Education Research Association (ESERA).

Faize, F. A., Husain, W., & Nisar, F. (2018). A critical review of scientific argumentation in science education. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(1), 475–483. https://doi.org/10.12973/ejmste/80353

Faize, F. A., & Dahar, M. A. (2017). Developing argumentation skills among undergraduate students using inquiry led argument framework. *Pakistan Journal of Education*, *34*(2), 37–54.

Felton, M., & Kuhn, D. (2001). The development of argumentative discourse skill. *Discourse Processes, 32,* 135–153. doi:10.1080/0163853x.2001.9651595.

Garcia-Mila, M., Gilabert, S., Erduran, S., & Felton, M. (2013). The effect of argumentative task goal on the quality of argumentative discourse. *Science Education*, *97*(4), 497–523. https://doi.org/10.1002/sce.21057

González-Howard, M., & McNeill, K. L. (2019). Supporting linguistically diverse students in scientific argumentation across writing and talking. In Spycher, P. & Haynes, E. (Eds.), *Culturally and linguistically diverse learners and STEAM: Teachers and researchers working in partnership to build a better path forward* (pp. 77-94). Information Age Publishing.

Gopal, H., Kleinsmidt, J., Case, J., & Musonge, P. (2004). An investigation of tertiary students' understanding of evaporation, condensation and vapour pressure. *International Journal of Science Education*, *26*(13), 1597–1620. https://doi.org/10.1080/09500690410001673829

Heng, L. L., Surif, J., & Seng, C. H. (2015). Malaysian students' scientific argumentation: Do groups perform better than individuals? *International Journal of Science Education*, *37*(3), 505–528. https://doi.org/10.1080/09500693.2014.995147

Hong, Z. R., Lin, H. S., Wang, H. H., Chen, H. T., & Yang, K. K. (2013). Promoting and scaffolding elementary school students' attitudes toward science and argumentation through a science and society intervention. *International Journal of Science Education, 35*(10), 1625-1648. 1625-1648. doi:10.1080/09500693.2012.734935

Jiménez-Aleixandre, M. P. (2007). Designing argumentation learning environments. In S. Erduran & M. P. Jiménez-Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp.91-116). Springer.

Jiménez-Aleixandre, M. P., Bugallo Rodríguez, A., & Duschl, R. A. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. *Science Education*, *84*(6), 757–792. https://doi.org/10.1002/1098-237X(200011)84:6<757: AID-SCE5>3.0.CO;2-F

Jimenez-Aleixandre, M. P., & Erduran, S. (2007). Argumentation in science education: An overview. In S. Erduran & M. P. Jimenez-Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 3 – 27). Springer.

Johnson, P. (1998). Children's understanding of changes of state involving the gas state, Part 2: Evaporation and condensation below boiling point. *International Journal of Science Education*, *20*(6), 695–709. https://doi.org/10.1080/0950069980200607

Johnson, P., & Papageorgiou, G. (2010). Rethinking the introduction of particle theory: A substance-based framework. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 47*(2), 130-150. https://doi.org/10.1002/tea.20296

Kaya, E. (2013). Argumentation practices in classroom: Pre-service teachers' conceptual understanding of chemical equilibrium. *International Journal of Science Education*, *35*(7), 1139-1158. doi:10.1080/09500693.2013.770935

Kaya, E. (2018). Argumentation in elementary science education: addressing methodological issues and conceptual understanding. *Cultural Studies of Science Education*, *13*(4), 1087–1090. https://doi.org/10.1007/s11422-017-9848-7

Keith, W., & Beard, D. (2008). Toulmin' s Rhetorical Logic: What' s the Warrant for Warrants? *Philosophy & Rhetoric, 41*(1), 22–50. doi:10.1353/par.2008.0003

Kirbulut, Z. D., & Beeth, M. E. (2013). Consistency of students' ideas across evaporation, condensation, and boiling. *Research in Science Education*, *43*(1), 209–232. https://doi.org/10.1007/s11165-011-9264-z

Kirikkaya, E. B., & Gulu, D. (2008). Fifth grade students' misconceptions about heat - temperature and evaporation – boiling. *Elementary Education Online*, *7*(1), 15–27.

Kuhn, D., & Udell, W. (2007). Coordinating own and other perspectives in argument. *Thinking & Reasoning, 13*(2), 90-104. doi:10.1080/13546780600625447

Kulatunga, U., Moog, R. S., & Lewis, J. E. (2013). Argumentation and participation patterns in general chemistry peer-led sessions. *Journal of Research in Science Teaching*, *50*(10), 1207-1231.

Mastrogiorgaki, M., & Skoumios, M. (2018). Improving the structure of students' arguments through a teaching-learning sequence on Newton's 2nd Law. *European Journal of Education Studies, 5*(5), 1-10.

McDonald, C. V., & McRobbie, C. J. (2012). Utilising argumentation to teach nature of science. In B. J. Fraser, K. G. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education* (pp. 969–986). Springer.

McNeill, K. L., & Berland, L. (2017). What is (or should be) scientific evidence use in k-12 classrooms? *Journal of Research in Science Teaching, 54*(5), 672-689.

McNeill, K.L., & Krajcik, J.S. (2006). *Supporting students' construction of scientific explanation through generic versus context– specific written scaffolds*. Paper presented at the American Educational Research Association annual meeting, San Francisco, CA. Retrieved from: https://www.researchgate.net/profile/Katherine_Mcneill/publication/228850868_Supporting _students'_construction_of_scientific_explanation_through_generic_versus_context-specific_written_scaffolds/links/02bfe50d0b95446aad000000.pdf

McNeill, K. L., & Krajcik, J. (2007). Middle school students' use of appropriate and inappropriate evidence in writing scientific explanations. In M. Lovett & P. Shah (Eds.), *Thinking with data* (pp. 233 – 265). Taylor & Francis.

McNeill, K. L., & Krajcik, J. S. (2008). Assessing middle school students' content knowledge and reasoning through written scientific explanations. In J. Coffey, R. Douglas, & C. Stearns (Eds.), *Assessing science learning: Perspectives from research and practice* (pp. 101–116). NSTA Press.

McNeill, K. L., & Krajcik, J. S. (2011). *Supporting grade 5-8 students in constructing explanations in science: The claim, evidence, and reasoning framework for talk and writing.* Pearson Allyn & Bacon.

Mcneill, K. L., Lizotte, D. J., Krajcik, J., & Marx, R. W. (2006). Supporting students' construction of scientific explanations by fading scaffolds in instructional materials. *The Journal of the Learning Sciences*, *15*(2), 153–191. doi:10.1207/s15327809jls1502_1

Mendonca, P., & Justi, R. (2014). An instrument for analyzing arguments produced in modeling-based chemistry lessons. *Journal of Research in Science Teaching*, *51*(2), 192–218. https://doi.org/10.1002/tea.21133

Naylor, S., Keogh, B., & Downing, B. (2007). Argumentation and primary science. *Research in Science Education*, *37*(1), 17–39. https://doi.org/10.1007/s11165-005-9002-5

Ogan-Bekiroglu, F., & Eskin, H. (2012). Examination of the relationship between engagement in scientific argumentation and conceptual knowledge. *International*

Journal of Science and Mathematics Education, *10*, 1415–1443. https://doi.org/10.1007/s10763-012-9346-z
Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science*, *328*, 463–466. https://doi.org/10.1126/science.1183944
Osborne, R. J., & Cosgrove, M. M. (1983). Children's conceptions of the changes of state of water. *Journal of Research in Science Teaching*, *20*(9), 825–838. https://doi.org/10.1002/tea.3660200905
Paik, S. H. (2015). Exploring the role of a discrepant event in changing the conceptions of evaporation and boiling in elementary school students. *Chemistry Education Research and Practice*, *16*(3), 670-679.
Papageorgiou, G., Grammaticopoulou, M., & Johnson, P. M. (2010). Should we teach primary pupils about chemical change? *International Journal of Science Education*, *32*(12), 1647–1664. https://doi.org/10.1080/09500690903173650
Papageorgiou, G., & Johnson, P. (2005). Do particle ideas help or hinder pupils' understanding of phenomena? *International Journal of Science Education*, *27*(11), 1299–1317. https://doi.org/10.1080/09500690500102698
Papageorgiou, G., Johnson, P., & Fotiades, F. (2008). Explaining melting and evaporation below boiling point. Can software help with particle ideas? *Research in Science and Technological Education*, *26*(2), 165–183. https://doi.org/10.1080/02635140802037336
Plakitsi, K., Perraki, V., & Klonari, K. (2014). *Programma Spoudon Fysikon Epistimon Dimotikou gia to 'Neo Scholio'* (Curriculum for Elementary Science Education for the 'New School'). Institute of Educational Policy, Ministry of Education.]
Prain, V., Tytler, R., & Peterson, S. (2009). Multiple representation in learning about evaporation. *International Journal of Science Education*, *31*(6), 787–808. https://doi.org/10.1080/09500690701824249
Russell, T., Harlen, W., & Watt, D. (1989). Children's ideas about evaporation. *International Journal of Science Education*, *11*(5), 566–576. https://doi.org/10.1080/0950069890110508
Ryu, S., & Sandoval, W. A. (2012). Improvements to elementary children's epistemic understanding from sustained argumentation. *Science Education*, *96*(3), 488–526. https://doi.org/10.1002/sce.21006
Sadler, T. D. (2004). Informal reasoning regarding socioscientific issues: A critical review of research. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 41*(5), 513-536. doi:10.1002/tea.20009
Sampson, V., & Blanchard, M. R. (2012). Science teachers and scientific argumentation: Trends in views and practice. *Journal of Research in Science Teaching, 49*(9), 1122-1148.
Sampson, V., & Clark, D. (2006). Assessment of argument in science education: A critical review of the literature. In S. A. Barab, K. E. Hay, & D. T. Hickey (Eds.), *Proceedings of the 7th International Conference of the Learning Sciences* (Issue 1958, pp. 655–661). International Society of the Learning Sciences.
Sampson, V., & Clark, D. (2009). The impact of collaboration on the outcomes of scientific argumentation. *Science education, 93*(3), 448-484. doi:10.1002/sce.20306
doi:10.1002/tea.21037
Sandoval, W. A., Enyedy, N., Redman, E. H., & Xiao, S. (2019). Organising a culture of argumentation in elementary science. *International Journal of Science Education*, *41*(13), 1848–1869. https://doi.org/10.1080/09500693.2019.1641856
Sandoval, W. A., & Millwood, K. A. (2007). What can argumentation tell us about epistemology? In S. Erduran & M. P. Jimenez-Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 71–88). Springer.
Skoumios, M., & Balia, C. (2020). Studying the structure of primary school students' written arguments on electric circuits. *Science Education International*, *31*(3), 304–312. https://doi.org/10.33828/sei.v31.i3.9

Skoumios, M., & Hatzinikita, V. (2014). Axiologontas tis graptes eksigisis ton mathiton stis Fysikes Epistimes (Assessing students' science written explanations). *Natural Sciences in Education*, *3*, 9–19.

Subramaniam, K., & Harrell, P. E. (2013). Framing prospective elementary teachers' conceptions of dissolving as a ladder of explanations. *Journal of Science Teacher Education*, *24*(7), 1177–1199. https://doi.org/10.1007/s10972-013-9356-x

Toulmin, S. E. (1958). *The uses of argument*. Cambridge University Press.

Toulmin, S. E. (2003). *The uses of argument (Updated ed.)*. Cambridge University Press.

Tsikalas, T., Stamovlasis, D., & Papageorgiou, G. (2014). Mental representations of 12 year-old children about boiling and evaporation: A probabilistic association with convergent and divergent thinking. *Preschool and Primary Education*, *2*, 17–26. https://doi.org/http://dx.doi.org/10.12681/ppej.87

Tytler, R., Prain, V., & Peterson, S. (2007). Representational issues in students learning about evaporation. *Research in Science Education*, *37*(3), 313–331. https://doi.org/10.1007/s11165-006-9028-3

Venville, G. J., & Dawson, V. M. (2010). The impact of a classroom intervention on grade 10 students' argumentation skills, informal reasoning, and conceptual understanding of science. *Journal of Research in Science Teaching, 47*(8), 952-977.https://doi.org/10.1002/tea.20358

Von Aufschnaiter, C., Erduran, S., Osborne, J., & Simon, S. (2008). Arguing to learn and learning to argue: Case studies of how students' argumentation relates to their scientific knowledge. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 45*(1), 101-131.

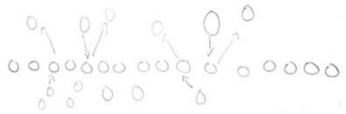
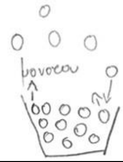
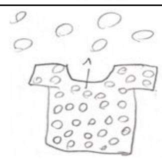
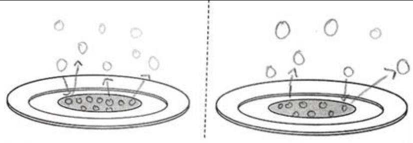
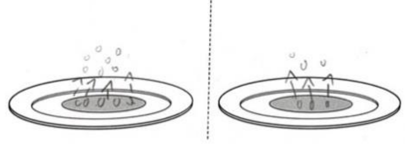
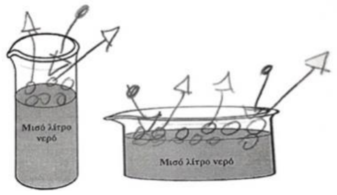
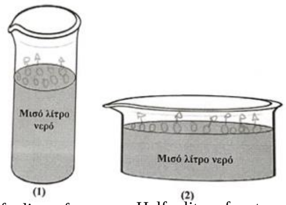
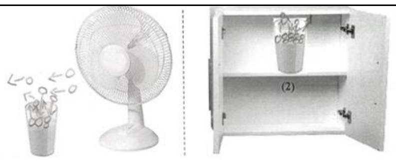
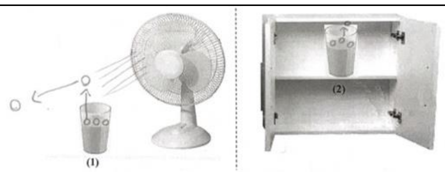
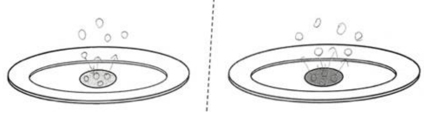
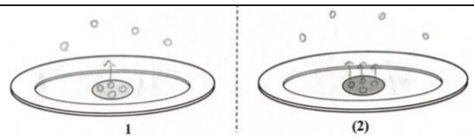
Wang, T. L., & Tseng, Y. K. (2018). The comparative effectiveness of physical, virtual, and virtual-physical manipulatives on third-grade students' science achievement and conceptual understanding of evaporation and condensation. *International Journal of Science and Mathematics Education, 16*(2), 203-219. doi:10.1007/s10763-016-9774-2

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching, 39*(1), 35–62. https://doi.org/10.1002/tea.10008

Appendix 1 Some examples of scoring students' answers per argument component.

Component	Example of student answer	Score
Claim	I agree with Vasilis who believes that the water disappeared and doesn't exist anymore.	0
	I agree with Aris who believes that the water dispersed into the air and exists there (in the air).	1
Evidence	The water and the alcohol are the same and they will evaporate at the same time.	0
	The water has dried; it has gone into the air.	1
	The second container has a larger surface, so more air particles can ~~go~~ proceed and collide with liquid particles.	2
	Both substances are liquids, so they will evaporate, but the one with the larger surface will evaporate faster, because it has more particles on its surface.	3
Reasoning	When there is a breeze the liquid cannot evaporate, because its temperature decreases.	0
	Air particles help water particles evaporate.	1
	Evaporation takes place only from the surface of the liquid and the larger it (the surface) is, the more particles it has and the faster the liquid evaporates.	2
	The air particles collide with the perfume particles, and they go into a gaseous state. They (air particles) give energy to liquid particles and so they defeat the attraction from the other liquid particles and leave the liquate state.	3
Rebuttal	I don't agree with this point of view because it is wrong.	0
	I don't agree because both substances will evaporate.	1
	I don't agree with them because we did an experiment and we saw that both substances (water and alcohol) evaporate, but the alcohol evaporates more quickly, under the same circumstances.	2
	I don't agree with them because: All liquids evaporate. The only difference is the rate at which the evaporation occurs. Also, it is not possible for the liquid to evaporate faster in the cold class because at 5 °C there is little energy in the particles, thus little holding energy that is more difficult to overcome.	3

Appendix 2 Examples of EG and CG students' drawings (where there is use of particle ideas).

Task	EG	CG
1		
2		
3		
4	 Classroom at 30 degrees; Classroom at 5 degrees	 Classroom at 30 degrees; Classroom at 5 degrees
5	 Half a litre of water; Half a litre of water	 Half a litre of water; Half a litre of water
6		
7	 Plate with water; Plate with alcohol	 Plate with water; Plate with alcohol

Appendix 3 Examples of EG and CG students' 'evidence' and 'reasoning' using particle ideas in interviews.

Task	Component	Group	Example	Score
2	evidence	EG	The perfume is a liquid and it evaporates. Its particles leave the bottle and disperse into the air we breathe and thus we smell it.	2

Task	Component	Group	Example	Score
		CG	The perfume particles evaporate, they go from the liquid to the gaseous state and so they reach our nose.	2
2	reasoning	EG	The air particles collide with the particles in the liquid state. So, the particles in the liquid state take energy, defeat the forces of attraction and leave, pass from the liquid to the gaseous state, or some perfume particles remain alone, because they have increased energy due to movements of the particles in the liquid state. Everything that is in the gaseous state can come into our nose when we breathe and so we can smell it.	3
		CG	The particles of the liquid state that are at the surface evaporate and go into the air. Then, these particles move freely in the air and can come into our nose.	2
4	evidence	EG	There is the same amount of water in both plates, but the temperature is different. Water that is at 30 °C will evaporate faster because its particles have more energy.	3
		CG	Here (at 30 °C), the water particles will receive more heat and they will evaporate faster.	2
4	reasoning	EG	When the temperature is high, the particles in the liquid state overcome the holding energy more easily and they can go to a gaseous state faster.	3
		CG	The higher the temperature is, the more heat the water particles receive, and they evaporate faster.	2
5	evidence	EG	The two plates contain the same liquid substance (water) but the water in the plate with a larger surface will evaporate faster, because it has more particles on its surface.	3
		CG	The second plate has larger surface, so more particles can evaporate.	2
5	reasoning	EG	All liquids evaporate. […] Evaporation takes place only from the surface of the liquid. The larger the surface is, the more particles it has and so, the faster the liquid evaporates.	2
		CG	Only the particles that are on the surface of a liquid evaporate. If the surface is large, it has more particles that can evaporate.	2

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