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Primary and Secondary Students' Understanding of the Rainfall Phenomenon and Related Water Systems: a Comparative Study of Two Methodological Approaches

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Abstract

Rainfall is a key process in the water cycle, the most structured scientific knowledge about water movement on Earth. Nevertheless, despite being a common topic covered in school science, it entails several cognitive difficulties for young children. This study uses a pictorial task and semi-opened questions to examine primary (11/12 years old) and secondary (12/13 years old) students' understanding of the elements and processes involved in the hydrologic cycle and how they are integrated into their explanations regarding the rainfall phenomenon. Overall, we have found that the studied children's ($n = 246$) conceptual knowledge increases with age. However, they have an incomplete perception of the mechanism of rainfall and its integration into the water cycle. In fact, not all the students have a cyclic notion of water dynamics; they also miss the inclusion and role of groundwater in water systems and present misconceptions regarding key processes, such as condensation and evaporation. Regarding the two diagnostic tools (drawings and questionnaires) used to study children's understanding, although questionnaires seem more appropriate for assessing lower conceptual levels, each methodological approach is useful for detecting different key concepts and misconceptions related to the rainfall phenomenon and related water cycle. Consequently, a mixed research design using different methods is advised for a comprehensive study of students' conceptions.

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Introduction

Understanding the dynamic of water systems is becoming increasingly important as it is linked to major environmental and social issues such as climate change or drinkable water scarcity (Sadler et al. 2017). Although water has the potential to serve as an interdisciplinary theme for multiple areas of the school curriculum, it tends to be exclusively addressed in science classes. In fact, the idea of the water cycle is one of the earliest abstract scientific concepts to be taught at school (Vinisha and Ramadas 2013). Moreover, the components and processes involved in this natural phenomenon are highly complex and a comprehensive understanding unfolds only gradually, throughout the school years and beyond (Vinisha and Ramadas 2013). In order for students to understand it meaningfully, they must comprehend several relationships between the Earth's spheres and the related physical processes (e.g., hydrosphere-atmospheric relationships and processes such as evaporation, condensation, and precipitation), but also the dynamic and cyclic nature of natural phenomena (Assaraf and Orion 2005). Rainfall is a key component of how water moves through the water cycle, connecting the main Earth's systems (i.e., hydrosphere, geosphere, atmosphere, and biosphere). Precipitation, the source of virtually all freshwater in the hydrologic cycle, is in fact a commonly used resource in primary and secondary education of Earth's sciences as it is linked with numerous physical, chemical, and biological processes integrated within the water cycle in nature (Assaraf and Orion 2005; Assaraf et al. 2012). Thus, the flawless understanding of the mechanisms and elements of rainwater is linked to an appropriate comprehension of the notion of the entire water cycle (Henriques 2002; Saçkes et al. 2010; Villarroel and Ros 2013).

A plethora of studies into student knowledge and understanding in science education suggests that students commonly hold conceptions—also labeled as misconceptions, alternative conceptions, and alternative conceptual frameworks—that may overlap only partially or may even be completely at odds with the target knowledge set out in the curriculum (Taber 2015). According to the constructivist approach, students' ideas should be the starting point of the meaningful teaching and learning of science in schools (Driver et al. 1985; Taylor 2015). Therefore, quite a lot of studies conducted on science education nowadays focus on students' understanding of science and their misconceptions, because this knowledge shapes the ways in which students interact with presentations of science topics.

In this regard, drawings have been pointed out as simple research tools for exploring students' ideas of various topics in science education (Ainsworth et al. 2011), including the water cycle (e.g., Assaraf and Orion 2005; Cardak 2009) and rainfall mechanisms (Saçkes et al. 2010; Savva 2014; Villarroel and Ros 2013). This technique has the added advantage that some ideas and processes can be more easily communicated by students (Ainsworth et al. 2011), while also enabling easy comparisons at an international level. However, previous studies have also recognized the importance of multiple data collection techniques in order to conduct comprehensive research in this field (Saçkes et al. 2010; Villarroel and Ros 2013). Thus, experimental designs involving both semi-open questionnaires and drawing techniques can be used as complementary and useful methods to explore children's ideas about scientific concepts (Villarroel and Ros 2013).

Although perceptions of the water cycle have already been thoroughly studied (e.g., Assaraf and Orion 2005; Cardak 2009; Lee et al. 2017), the phenomenon of rainfall has received relatively less attention (Malleus et al. 2017; Saçkes et al. 2010; Savva 2014; Villarroel and Ros 2013). Some studies have reported that students often over-simplify the water cycle by representing only evaporation and/or condensation (i.e., reciprocating the course of water from clouds to sea, and back to clouds) (Assaraf and Orion 2005). Moreover, many everyday and common natural phenomena related to the mechanism of rainfall (e.g., evaporation, condensation, and precipitation), which are experienced from early childhood, are frequently misinterpreted by students, due to the level of abstraction that is needed to recognize and understand hidden or invisible phenomena and processes (Agelidou et al. 2001; Assaraf and Orion 2005). Previous studies have also highlighted that many students have a partial understanding of the water cycle, lacking important components such as groundwater, water in the atmosphere, and water in living organisms (Agelidou et al. 2001), even after extensive formal learning (Assaraf and Orion 2005). Moreover, students often hold different misconceptions relative to the water cycle that can interfere with their understanding of accurate explanations for the cycling of water into and out of the atmosphere (Romine et al. 2015).

The most frequent educational target of studies specifically dealing with students' conceptions about rainfall, and how students relate this phenomenon with the concepts and processes of the water cycle, has been during early childhood (Malleus et al. 2016, 2017; Saçkes et al. 2010; Savva 2014; Villarroel and Ros 2013). However, few scientific educational studies, involving primary and secondary students, explicitly deal with students' understandings of precipitation formation and posterior water movement within the hydrologic cycle.

Thus, and in contrast to most previous research, the main goal of this study is to examine the conceptual understanding and misconceptions of the mechanisms of rainfall and its integration into the water cycle of students enrolled in the final course of primary education (11/12 years old) and the first course of secondary education (12/13 years old) school students by means of two different experimental procedures (semi-opened questions and drawings) as previously used in similar studies (Saçkes et al. 2010; Savva 2014; Villarroel and Ros 2013). Moreover, we aim to compare the effectiveness of these two different methodologies in order to mirror children's scientific model of the phenomena involved. Additionally, we aim to analyze educational and gender level–related differences in terms of the utilization of the key elements and processes of the hydrologic cycle and how they are integrated into students' explanations regarding rainfall mechanism.

Methodology

Participants

This research was conducted in the Autonomous Community of the Basque Country, located in northeastern Spain. The climate is temperate oceanic, with a total rainfall of around 1200–1400 mm.

The sample study was comprised of 246 children studying compulsory education, 168 of them attending the final course of primary education (age 11/12) and 75 enrolled in the first course of secondary education (age 12/13). Age distribution of educational levels prior to university studies in the Autonomous Community of the Basque Country is as follows: 2–6 years old (non-compulsory preschool education), 6–12 years old (compulsory primary education), 12–16 years old (compulsory secondary education), 16–18 years old (non-compulsory high school and vocational training).

The two age groups were selected on the basis of cognitive development and school curricula. Although close in age, the teenagers studied were leaving behind the concrete operational stage (till approximately age 11) and entering the Piagetian formal operational stage (at approximately age 12). In this transition, children start gaining the ability to think in an abstract manner, without any dependence on concrete manipulation (Piaget 1970). Thus, older students should have a higher capacity for the comprehension of hidden and/or abstract phenomena involving the water cycle (such as condensation, or evaporation). From the curricular perspective, the first group, that at the end of primary school, was chosen to examine concepts developed after finishing elementary studies. According to the education curriculum of the Basque Country (Basque Government 2007), these students should know and recognize different weather phenomena and water cycle–related key ideas. In fact, meteorological variables, such as precipitation, and the early idea of water cycle together with the physical states of water, are taught during the second cycle of primary education, that is, when children are 8–10 years old. At the end of primary education (10/11 and 11/12 years old), students start learning about the effect of energy (especially heat), or different forces, on the change of state of matter. Thus, by the end of primary education, students should also have a basic knowledge about states of matter and phase change. All these topics are covered in more depth during their first year of secondary school, since students focus on states of aggregation of matter (solid, liquid, gas) and their knowledge of the different Earth systems (atmosphere, geosphere, and biosphere) broadens. When it comes to the comprehension of hydrosphere elements and processes, the curriculum emphasizes the study of water's states of matter, the key role of the sun on water cycle (as a source of energy), and fresh water reservoirs. So, students acquire more significant information in relation to water cycle elements and processes.

Regarding gender of the participants, 125 were females and 121 males (primary: $n = 90$ female and $n = 81$ male; secondary, $n = 35$ female and $n = 40$ male). This sample was obtained from 4 educational centers, each was located in a different city of the Autonomous Community of the Basque Country (all of them with a population of 15,000–30,000). These schools were visited during April and May 2014. Permissions to conduct the questionnaires were obtained from the administrators of each school prior to parents' authorization, and the activities took place at the schools during normal classroom time. The language used was Basque.

Data Collection

The methodology of this research was influenced by certain recommendations by Saçkes et al. (2010), who suggest that more multiple data collection techniques should be used in research of this nature. Thus, two different ways of gathering data to reveal children's understanding of the mechanisms of rainfall were used for this study (similar to Villarroel and Ros, 2013), in order to test the children's consistency and coherence of their ideas: drawings (aided by explicative text) and semi-opened questions.

To conduct both tasks, children were provided with a sheet containing two confined empty spaces (one for the drawing and the other to include its explicative text), and printed questions followed by blank spaces to write their answers on. At the beginning of the sheet, children themselves had to record the year they were born, their gender, name of their hometown, the school they were enrolled in, the academic year, and the date the interview was conducted. After appropriate explanations, children performed the task for 30 min.

Regarding the pictorial task, children were encouraged to draw all they know about rainfall. Children had some pens at their disposal to choose from, but no colored pens were made available in order to not make the activity too long. The explicative text was added to the drawing in order to identify children's previous ideas and mental models, and afterwards properly assess their understanding level (Gómez Llombart and Gavidia Catalán 2015).

The second part of the study consisted of a questionnaire, which was comprised of the following questions*: (Q1) What is rain? (Q2) Where does rain come from? (Q3) How do you think rain is made? (Q4) Where does rain go after it falls to the ground? (Q5) What happens to water of puddles, when puddles disappear? (Q6) Where does water go when puddles disappear?* By questioning children about these ideas, we aimed to understand their notions on (a) establishing the relationship between the phenomenon of rain, clouds, and the water cycle; (b) grasping what happens to the passage of rainwater when it falls to the Earth's surface or when puddles disappear; and (c) determining the explanations children express to make sense of the cause of the rain. A very similar set of questions was used in the studies developed by Saçkes et al. (2010), Savva (2014), and Villarroel and Ros (2013) in order to examine young children's understanding of the precipitation phenomena. These studies employed questions based on key concepts identified by Miner (1992).

During the interviews no photos or voice or video recordings were made. This research protocol earned the support of the advisory team of the Centre for the Support of Educational Innovation and Training for non-university learning within the Department of Education of the Basque Government, and it was also agreed on and approved by the principal of each of the schools involved in this study.

Additionally, the parents and caretakers of the children who were involved in the research were informed in writing by the direction board of each school regarding the objectives and methods of the study and also concerning the procedure for expressing the wish not to participate in the research. None of the families whose children were to take part in the study refused to cooperate with the research project.

Data Analysis and Statistical Procedures

To discover patterns of the participants' understanding of the rainfall phenomenon in relation to the water cycle, both the responses to the drawings and semi-opened questions were independently analyzed. At first, items appearing in each drawing (with its explicative text) and on each question response were recorded. The children's responses were coded by two different researchers in a standardized way, using established coding instructions based on previous works and existing theory. In order to obtain the range of possible answers, a pilot study was conducted with 30 students before the development of the coding system. Examples of responses from previous studies were discussed and divided into novel categories next to the results of the pilot study. Items appearing were afterwards separated into key "elements" (rain, clouds, mountains, sea/oceans, streams/rivers, lakes/wetlands, snow/ice, puddles, reservoirs, unidentified surface water, groundwater, plants, animals, humans, gutters, houses, and factories) and "processes" (precipitation, evaporation, condensation, infiltration, transpiration/evapotranspiration, phase change, and states of matter—solid, liquid, and gas) related to rainfall phenomenon and water systems. Ultimately, elements were categorized into the Earth's natural systems: biosphere, hydrosphere, geosphere, and atmosphere. Detected misconceptions in drawings and questionaries' answers were also recorded in parallel.

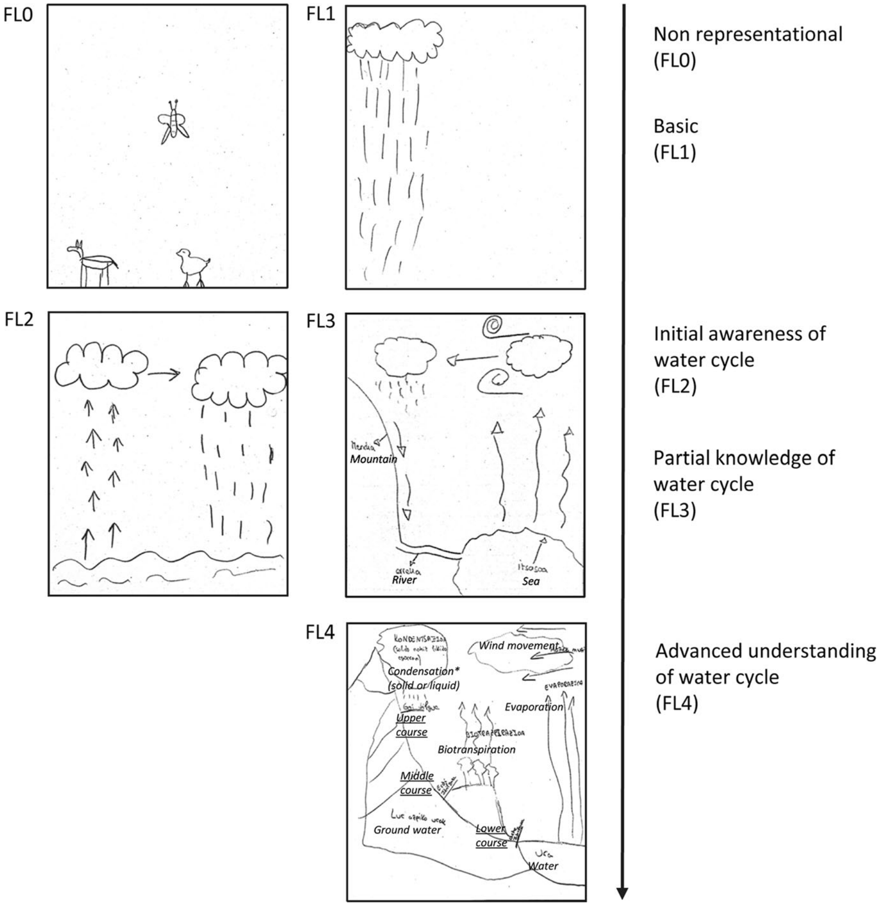

Fig. 1 Examples of drawings corresponding to the different formulation levels (FL) established from non-representational drawings (FL0) to advanced understanding of rainfall in relation to water cycle (FL4). Asterisk denotes mislabeling of precipitation as condensation

Finally, data collected by means of these two techniques was analyzed and categorized into different levels of conceptual understanding based on previous works (Cardak 2009; Köse 2008) and reformulating each category for the purpose of our analysis. The 5 categories that emerged from the data were of increasing complexity in students' conceptions of the explored phenomena (see some examples in Fig. 1) and proved to be useful for classifying students' responses in this study. Details of the formulation levels are disclosed in Table 1.

For the comparison of the frequency of the elements and processes of the hydrological cycle appearing on drawings at each educational level (11/12- and 12/13-year-old students), the chi-square test was performed. The corresponding effect size was estimated by Cramer's V (Kline 2004), and when the value of this parameter was higher than 0.35, a large effect was considered, that is, a strong association between studied variables. When Cramer's V value was within the range of 0.21–0.35, a medium effect was interpreted; that is, an intermediate relationship between the variables was considered (Sun et al. 2010). The same tests (chi-square

Table 1 Formulation levels (F.L.) defined to categorize students' responses about rainfall and its inclusion into the water cycle

F.L.	Categorization	No. of elements/ processes	Meaning
0	No drawing/no answer or non-representational	0/0	Students had not drawn nor written anything, or elements drawn or written by the students do not have any connection with what has been asked.
1	Basic	1/1	Basic elements and processes related to rainfall are mentioned, i.e., clouds and precipitation, always reflecting a lineal conception of water flux.
2	Initial awareness of the water cycle	2/2	Apart from clouds and precipitation, more elements (i.e., water masses such as the sea) and processes (evaporation or condensation) appear as part of rainfall mechanisms, reflecting an initial awareness of a cyclic process.
3	Partial knowledge of water cycle	3–4/3–4	More processes and elements related to surface water or groundwater appear (mostly runoff, rivers, lakes, or mountains), but not simultaneously. Students show an understanding of the water cycle, although they still show an incomplete knowledge of elements and processes involved in the entire cycle.
4	Advanced understanding	≥ 5/≥ 5	Students' representations and answers are the most competent and realistic. Students showing this conceptual level include more complex processes such as condensation, infiltration, evapotranspiration, or melting together with elements like surface and ground water masses.

and Cramer's V) were used to study the differences in students' responses to the questionnaire, and also to check whether the frequency of male and female students' responses (both in drawings and questionnaires) at each educational level fit to a random distribution (Muijs 2010).

Students' drawings' and answers' categorization as mentioned above was independently analyzed by two researchers and redefined until the Cohen kappa reliability coefficient indicated a very good concordance (0.91 and 0.90 for drawings and answers, respectively).

In order to study the existence of significant differences within the results obtained from the categorizations performed, the homogeneity of the samples was first verified according to the Kolmogorov-Smirnov test, which discarded the adjustment of the data to a normal distribution. The Kruskal-Wallis rank test was then applied to determine if there were significant differences in the formulation levels obtained by students of all ages (11/12 and 12/13). The effect size was calculated from the "Eta-squared (η^2)" (Morse 1999; Prajapati et al. 2010). The interpretation of coefficient η^2 is as follows: $r = 0.01$, weak effect size; $r = 0.06$, moderate effect size; and from $r = 0.14$ onward strong effect size.

Subsequently, the Mann-Whitney U test was used to verify whether there were significant differences between the inferred formulation levels using the two diagnostic tools (drawing vs. questionnaire), and between the formulation levels obtained by each of the gender groups. The effect size was calculated from the Pearson's correlation coefficient parameter r (Morse 1999; Ferrar et al. 2012). The interpretation of coefficient r is as follows: $r = 0.10$, weak effect size; $r = 0.30$, moderate effect size; and from $r = 0.50$ onward strong effect size (the values of r lie between 0 and 1).

Finally, to study the differences in the frequency of formulation levels obtained by each diagnostic tool (drawings and questionnaire) and educational stage, a chi-square test was performed with its corresponding Cramer's V (Kline 2004) for effect size estimation.

Results

The results of this research are presented by addressing, firstly, the analysis of the data related to children's drawings, subsequently those extracted from the semi-open questionnaire, and, finally, the assessment and comparison of the conceptual level of students' understanding inferred from both techniques are presented. Only statistically significant results with medium or high effect sizes are displayed. When effect size is low, it is stated.

Drawings

The results of children's drawings were analyzed with regard to their content, number, and type of pictorial elements and processes drawn (some examples of the drawings analyzed are presented in Fig. 1). Consequently, all the features displayed in each drawing were registered and classified in accordance with the categories that emerged from the examination of all the pictures ($n = 246$).

Rainfall and Water Cycle Key Pictorial Elements Classified by Earth Natural Systems

Figure 2 shows the frequency of the main pictorial elements of children's drawings linked to water cycle classified by means of the Earth's different natural systems (i.e., hydrosphere, geosphere, atmosphere, and biosphere) and depicted by the different educational levels analyzed. Students from both educational levels showed similar results with regard to the representation of the main components of the atmosphere related to the mechanism of rainfall (i.e., clouds and rain) that were present in nearly all of the drawings analyzed (ca. 97%). In contrast, the frequency of geosphere and hydrosphere main elements were higher in secondary students (Fig. 2). For instance, one of the key components of the geosphere, the mountains, was represented by 57% of 12/13 age group, while this element was less frequent in 11/12-year-old students' drawings (27%) ($p < 0.001$). The most frequent hydrosphere elements were seas-oceans and rivers and/or streams (ca. > 40%). However, these elements appeared in lower frequency in primary students' drawings than in those of secondary ones (sea-ocean 46% vs. 64%, $p < 0.01$); streams 37% vs. 60%, $p < 0.001$), although the effect size for sea/ocean was low (Cramer's V = 0.17). Other hydrosphere elements were mainly underrepresented in both educational-level students' drawings (< 20%). Groundwater was ignored by nearly all 11/12-year-old students (1%) but it was present at a higher frequency (15%) on 12/13 age students' drawings ($p < 0.001$). Less than 20% of both level students included components of the biosphere (humans, animals, and plants) and elements related to anthropic environments, such as houses and factories, although the presence of the latter elements was significantly higher in secondary students' drawings ($p < 0.05$; Cramer's V = 0.131). Thirty percent of the students highlighted in their drawings and/or text the importance of the rain for life on Earth (primary 16% vs secondary 9%) (e.g., "rain is good for nature," "we

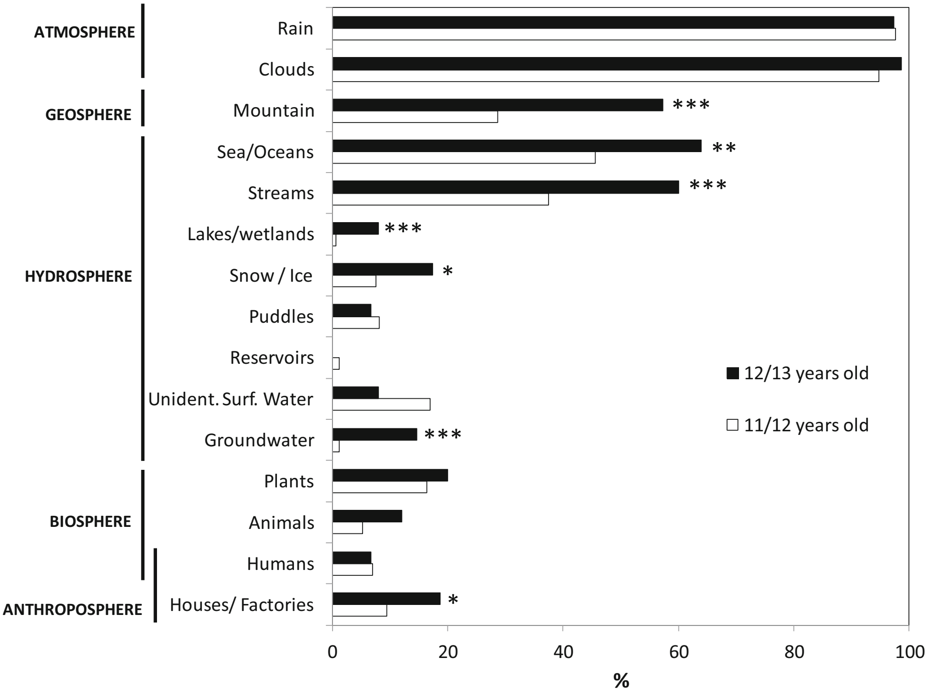

Fig. 2 Elements of the hydrologic cycle represented on drawings divided by the Earth's natural systems. Asterisks denote significant differences in the frequency of drawn elements between 11/12- and 12/13-year-old students (*$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$)

all need rain, animals, plants and humans, everything is related," "we cannot live without rain"). Additionally, 16% of secondary students spontaneously reported acid rain formation in their drawings. While only 2% of primary students included any citation to this phenomenon. Some students mixed the natural phenomena and the anthropogenic process of air pollution responsible for acid rain (e.g., "rain is made from the contaminated smog in factories," "our contamination creates the rain," "factories create the clouds").

Regarding gender, main differences were observed among primary education students, since girls included more biosphere components, such as plants or animals, than boys did in their drawings and attached explanations ($p < 0.01$). The only significant gender difference observed among secondary education students was the greater presence of "snow" in boys' pictorial tasks ($p < 0.05$).

The Sun

Children at an upper educational level showed a more significant tendency (primary 29% vs. secondary 43%) to include the sun as a rainwater-related element ($p < 0.01$), although effect size was relatively low (Cramer's V = 0.175). Moreover, among those drawings showing the sun, only 19% of primary students represented the sun as the main driver of water evaporation, while 39% of secondary student acknowledged this causal effect. With respect to gender, the inclusion of the sun was more significant in primary education boys' drawings in comparison to girls' drawings ($p < 0.05$), as well as the ascription of water evaporation to this star ($p < 0.01$).

It is noteworthy that some children from both educational stages attributed human characteristics to the sun and/or clouds drawings (primary 4%, secondary 6%).

Rainfall and Water Cycle Connection: the Cyclic Effect that Makes Rain

With regard to the notion of a cycle, primary and secondary students represented a cyclic phenomenon in their drawings, by the use of arrows, and/or by explicitly mentioning the cyclic nature of the process and/or by the use of explanations that aimed to describe a cyclic process (e.g., "this process is repeated again and again"; "…and begins again") with a similar frequency of 43% and 49%, respectively. However, the complexity of the represented cycles differed notably between the educational levels (see Formulation levels section). Similarly, the percentages of 11/12 and 12/13 age groups that spontaneously cited the water cycle, when asked to draw everything they knew about rainfall, were 18% and 20%, respectively.

Labeling

Interestingly, only 7% of primary student's drawings showed labeling of the elements' processes, while 28% of the secondary students used labeled drawings ($p < 0.01$) (see some examples on Fig. 1, formulation levels 3 and 4). The only gender differences were observed among primary students, since boys' drawings presented more labels than did girls' at this level ($p < 0.05$).

Physical Processes

Regarding the physical processes represented in students' drawings, we evidenced the same bias towards the processes that take place in the atmosphere (Fig. 3), but exclusively driven by precipitation and evaporation, and ignored the condensation process, as exemplified in Fig. 1 (see formulation levels 3 and 4). Other complex processes involving geosphere-hydrosphere (e.g., infiltration or runoff) and geosphere-hydrosphere-biosphere (transpiration and/or evapotranspiration) relationships were drawn by less than 11% of both level students. Water infiltration was included in more drawings in the 12/13 age group than in the 11/12 group (11% vs. 2%; $p < 0.01$; Cramer's V = 0.2; Fig. 3).

As expected, nearly all the students' drawings represented precipitation (97%, Fig. 3). A significant number of children's drawings reflected that precipitation only occurs over the mountains, the frequency being higher in secondary school students' representations (primary 25% vs. secondary 48%; $p < 0.01$). Evaporation was drawn by 77% of secondary students but only by 53% of primary students ($p < 0.001$). Similarly, secondary students showed a higher frequency of including the condensation process (37%) in their drawings and/or the attached explanatory text, in comparison to primary students, who only acknowledged this process in 4% of the sample ($p < 0.001$), which is a strong effect (Cramer's V = 0.426). Only 32% of the students correctly used both terms when explaining the phenomena (primary 3% vs. secondary 26%; $p < 0.01$). However, 30% of the students citing condensation erroneously referred to the evaporation process (see an example in FL4 from Fig. 1). Another frequent misconception identified in children's drawings was the fact that evaporation only takes place at sea level (primary 33% vs secondary 61%). Finally, only a few secondary students (5%) used the states of matter (gas, liquid, and gas) when explaining the phase changes described (i.e., condensation and/or evaporation). When it comes to gender analysis, we only detected differences regarding 11/12-year-old students' pictorial task, in which the frequency of the inclusion of "evaporation" and "condensation" was higher in boy's representations ($p < 0.001$ and $p < 0.05$, respectively), although effect size for condensation was low (Cramer's V = 0.159).

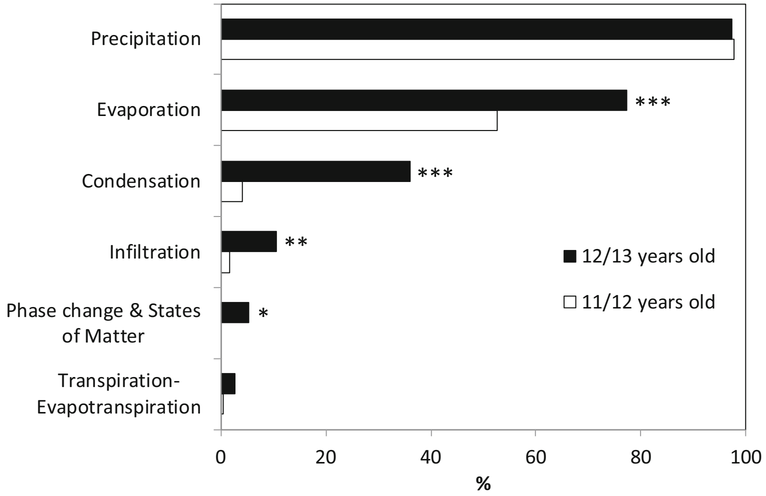

Fig. 3 Physical processes of the hydrologic cycle represented on students' drawings. Asterisks denote significant differences in the frequency of drawn processes between 11/12- and 12/13-year-old students (*$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$)

Questionnaires

Nature of Rain

When children were asked "What is rain?" (Fig. 4, Q1), most of them (77%), both from primary and secondary schools, affirmed that rain is "water." Moreover, many of the responses of students (ranging from 4 to 11%) referred to water phases (e.g., "liquid," "evaporated water"). However, it was remarkable that a higher percentage of secondary students defined rain as a phenomena/process or a kind of precipitation in comparison to primary students (primary 3% and 1% vs. secondary 9 and 8%, respectively; $p < 0.05$), although statistical analysis showed very weak effect sizes (Cramer's $V = 0.137$ and 0.177, respectively).

Source of Rain

With regard to the origin of rain (Fig. 4, Q2), most of the children, both from primary and secondary school, responded that it comes from "clouds" (70%). However, many students mentioned (some of them together with clouds) water masses such as "sea/ocean" (27%), "streams" (9%), or "lakes: (4%) as the source of rain. It must be noted that the latter responses were much more usual in secondary school children ($p < 0.001$).

Mechanisms of Rainfall

Regarding how rain is made (Fig. 4, Q3), more than a half of the studied children at all ages mentioned "evaporation" as the main process involved in rainfall mechanisms. Some of them (22%), mainly older children, even remarked that the sun was the agent of this physical transformation of water. In any case, it must be mentioned that some students showed difficulties in conceiving the nature of evaporation and remarked that "clouds/sun take in/

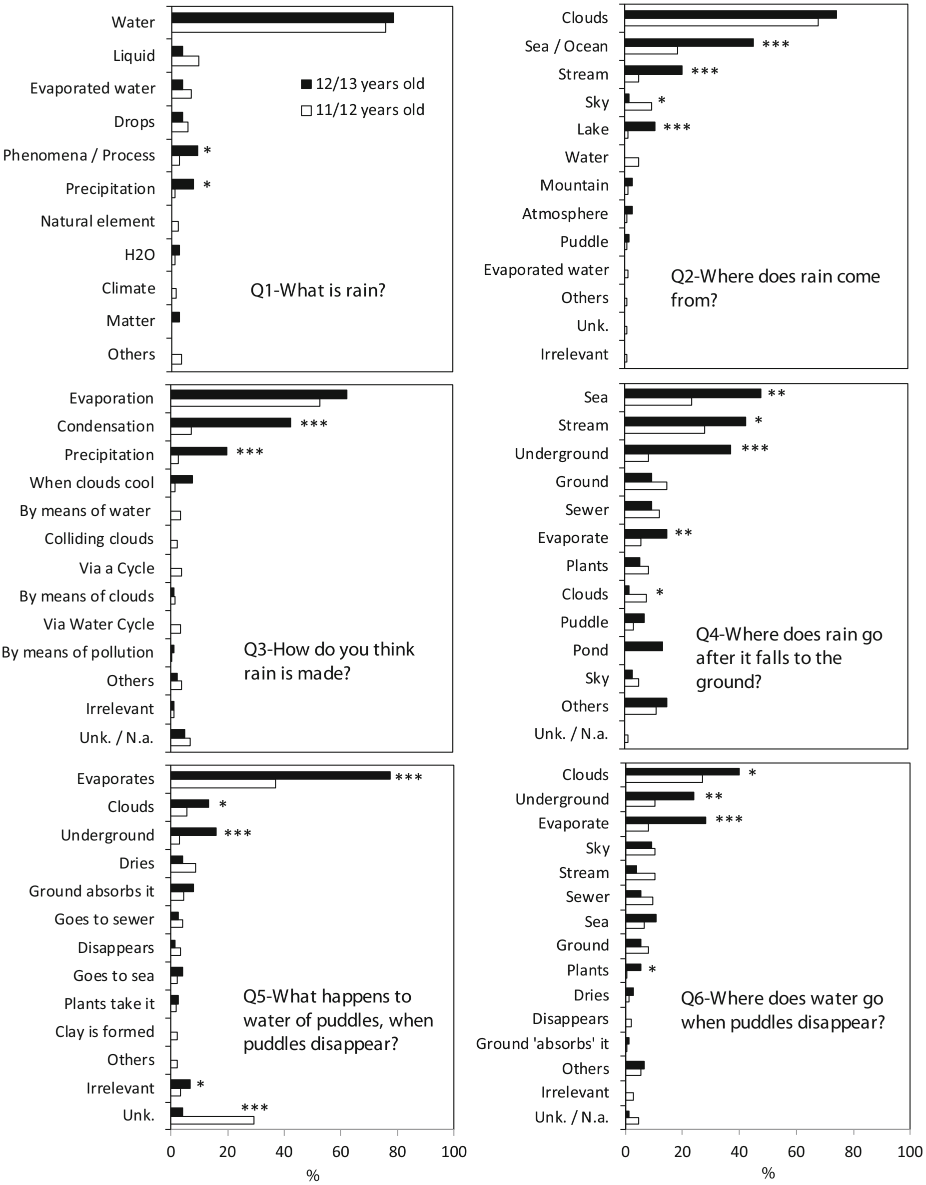

Fig. 4 The most frequent responses by students to each question related to the rainfall phenomenon. Q1, nature of rain; Q2, source of rain; Q3, mechanisms of rainfall; and Q4–Q6, displacement of rain water. Unk. = unknown; N.a. = No answer. Asterisks denote significant differences in the recorded responses between 11/12- and 12/13-year-old students (*$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$)

absorb water” (3% from each educational level), or simply that water “goes up” from water masses towards the sky/clouds (2% of primary education students).

An higher percentage of secondary school students also mentioned other processes as rainfall mechanisms, such as “condensation” or “precipitation” (42% and 20%, respectively). However, many students did not properly distinguish the evaporation and condensation processes (6% and 11% of primary and secondary students, respectively). Concerning precipitation, children from both educational levels responded that rain falls “When clouds are completely filled up with water or are too heavy” (3% and 8% of 11/12 and 12/13 years old, respectively), or that “pollution” is the trigger for rain (approximately 1% of children from each educational level). Younger students also argued that “colliding clouds” provoke rain (2.3%), or that “clouds colliding into mountains” or “clouds crying” result in rain (0.6% in both cases).

Displacement of Rain Water

When it comes to rainfall (Fig. 4, Q4), students were asked “Where does rain go after it falls to the ground?”, and the most usual responses obtained from both educational levels’ students were “stream’ (32%) and “sea” (30%). The mention of these two water masses was more frequent in secondary students’ responses ($p < 0.01$ and $p < 0.05$ for “sea” and “stream,” respectively), but the effect size was low (Cramer’s V = 0.187 and 0.119, respectively) and thus these results can be considered minimally acceptable. These older students also mentioned “underground” as a place where rainwater goes, whereas this response was much less frequent in primary students (primary 8% vs. secondary 37%, $p < 0.001$), and the effect size in this case was very high, reflecting a strong level of association between both variables, i.e., educational level and type of response (Cramer’s V = 0.374). In any case, few of these students explicitly mentioned water masses or channels beneath the surface (2.4%). That is, although many students mentioned that water or rain goes below ground, few of them seemed to know the existence of groundwater.

With respect to the understanding of what happens to rainwater in puddles (Fig. 4, Q5—“*What happens to water of puddles, when puddles disappear?*”), most children indicated that water “evaporates,” especially those from secondary school (primary 37% vs. secondary 77%, $p < 0.001$; Cramer’s V = 0.366, a very strong association level). Secondarily, most answers, especially those from secondary school students, specified that water goes “underground” (i.e., infiltrates, primary 3% vs. secondary 16%, $p < 0.001$) or that it ends up in “clouds” (i.e., evaporates, primary 6% vs. secondary 13%, $p < 0.05$), although the effect size was too low for the final answer to be accepted as a strong correlation (Cramer’s V = 0.126).

The abovementioned responses were quite similar to the ones obtained when children were asked “Where does water go when puddles disappear?” (Fig. 4, Q6), since “clouds,” “underground,” and “evaporates” were the most common responses recorded and their frequency was again higher in secondary students’ explanations ($p < 0.05$ for “clouds,” $p < 0.01$ for “underground,” and $p < 0.001$ for “evaporate”), although the effect size for “clouds” and “underground” was low (Cramer’s V = 0.131 and 0.175, respectively).

Elements and Processes

In analyzing children’s responses to the abovementioned questions, altogether (Q1–Q6), it stands out that secondary students mentioned more hydrosphere-related elements than did primary students (see Appendix Table 2, $p < 0.01$), and the inclusion of the processes of the hydrologic cycle, such as evaporation, condensation, or infiltration, was also higher in the older students’ responses (see Appendix Table 3, $p < 0.01$). Differences regarding gender wre not remarkable.

Formulation Levels

Overall, children aged 12/13 showed a higher conceptual understanding about rainfall and its inclusion in the water cycle than 11/12-year-olds (Fig. 5; $p < 0.001$) using both approaches (Cramer's V = 0.289 and 0.298 for drawings and questionnaires, respectively). It is worth noting that no differences in the results inferred from drawings and questionnaires were observed within the 12/13-year-old students' age range, while in the younger ones, a higher formulation level was inferred from data extracted from questionnaire responses than from drawings ($p < 0.05$), although eta-squared revealed a weak effect size ($r = 0.107$).

Regarding gender, the only differences were observed between formulation levels inferred from drawings of 11/12-year-old students, since boys showed a higher conceptual understanding of the water cycle according to these results ($p < 0.001$), with the correlation between these two variables was moderate (Pearson's $r = 0.257$).

Figure 6 breaks down the frequencies of the formulation levels obtained by each student group using both assessment techniques. According to data extracted from the drawings' analysis, most of the younger children studied (age 11/12) showed a basic conceptual understanding of the mechanism of rainfall (formulation level 1), whereas the majority of older children (12/13 years old) showed a higher knowledge of the water cycle (formulation level 3) (Fig. 6). Moreover, most of the children showing an advanced understanding of the water cycle corresponded to secondary school students (12/13 years old). Results obtained from questionnaires were quite similar. Overall, conceptual understanding was higher in secondary students, although in this case most children's formulation level, both from primary and secondary school, corresponded to the second level (i.e., basic understanding) (Fig. 6).

When comparing the distribution of students' categorization obtained by each method by the chi-square test, it is noteworthy that, at both the age ranges (11/12 and 12/13), significant differences were observed for F.L.1 and F.L.2 assessment ($p < 0.01$), but this is not for the case

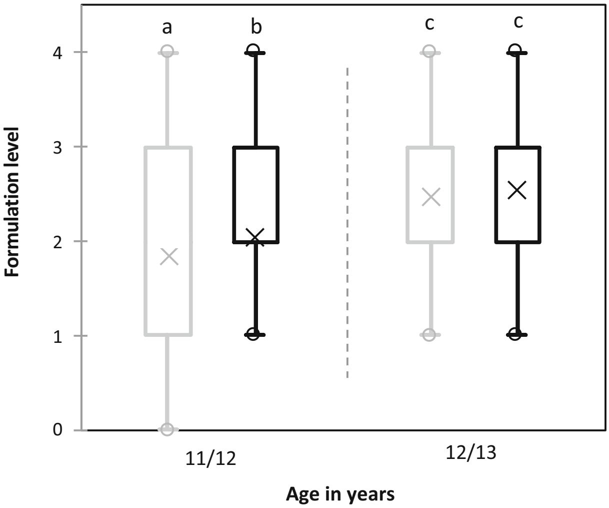

Fig. 5 Children formulation level about rainfall and water cycle inferred from drawings (gray) and questionnaires (black). Each box plot illustrates the median (*X*), minimum, and maximum (circles), as well as 25–75 percentile ranges of students' formulation level. Different letters indicate statistically significant differences between groups ("a" vs. "b" $p < 0.05$; "a" vs. "c" and "b" vs. "c" $p < 0.001$)

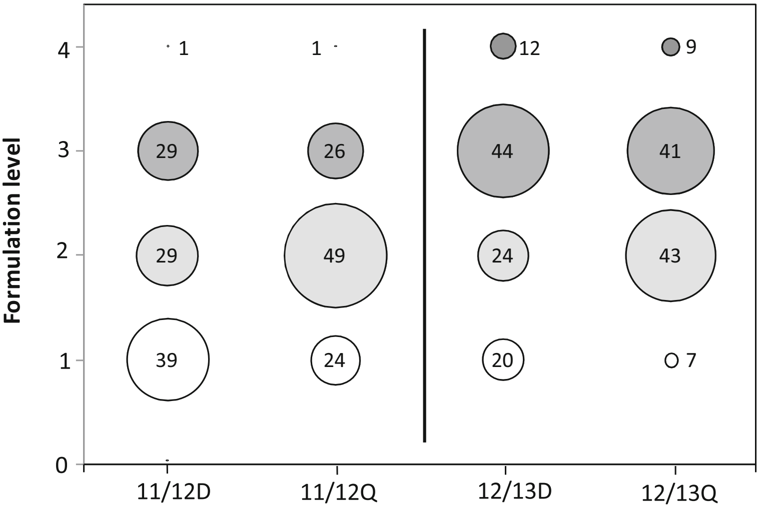

Fig. 6 Percentage of students' (aged 11/12 and 12/13) responses categorized into each formulation levels (1 to 4, axis *X*) using drawings (D) and questionnaires (Q) as diagnostic methods

for higher conceptual levels (F.L.3 and F.L.4). That is, when analyzing drawings, there were more students categorized into F.L.1 at both age ranges and, in contrast, when inferring formulation levels from the answers to the questionnaire, more students were categorized into F.L.2. Having collected data of each student in response to both diagnostic methods (drawings and questionnaire) allowed us to study this phenomenon deeply. We observed that a significant proportion of students whose mental model deduced from drawings was basic (F.L.1) changed to F.L.2 (initial awareness of the water cycle) in regard to their responses to the questionnaire (39% and 60% for 11/12- and 12/13-year-old students, respectively). However, students, whose level of understanding was categorized as F.L.2 (or beyond) when using drawings as an assessment tool, scarcely changed to another formulation level when analyzing their responses to the questionnaire.

Discussion

Our study gives an overview of children's conceptual understanding of rainfall and water cycle by means of drawings and questionnaires, along with the comparison of the effectiveness of these two methodologies to mirror children's scientific model of the phenomena involved. We found children's conceptual knowledge increases with age and that both primary and secondary school students had difficulties explaining the process of rainfall and identifying some key elements of the Earth's natural systems involved. Moreover, different misconceptions surfaced in their pictorial and text descriptions.

Students' Knowledge of Rainfall and Water Cycle Elements

In our study, when children were encouraged to draw a depiction of as many elements as possible related to rainfall, children at an upper educational level showed a more significant tendency to include a better representation of the different Earth systems involved in the water cycle. According to a recent overview (Sadler et al. 2017) framework of water systems understanding should include the physical dimensions (where water and substances therein exist) and other aspects of understanding, such as processes and mechanisms, energy, scale, representation, and dependency and human agency. Physical dimensions of water systems should comprise surface water, groundwater, atmospheric water, water in biotic systems, and water in engineered systems. In this research, while representation of atmosphere elements was similar in all students' drawings, the frequency of geosphere and hydrosphere elements was higher in secondary students' drawings. Similar results were obtained through the responses to the questionnaires, in which elements associated with the hydrosphere were more frequently mentioned by secondary school students than by primary ones. In our particular case, this might be in part explained by the fact that, in addition to the contents of the primary education that included the water cycle, the physical and chemical changes of matter, and nature protection or its exploitation, in secondary education, more abstract concepts are incorporated and Earth sciences are approached from a greater compartmentalization (atmosphere, hydrosphere, geosphere, biosphere) along with a detailed study of their complex interrelationships (Basque Government 2007).

Most of the elements drawn or mentioned by students at both age ranges corresponded to surface water systems, the most easily understood dimension of water systems (Sadler et al. 2017). However, the rainfall river and/or sea connection was only partially acknowledged by both age group students and was especially underrepresented in primary students.

Groundwater was ignored by nearly all primary students and included by few of the secondary students, in drawings (15%) or their questionnaire responses (5%). This is in agreement with previous studies showing that students tend to focus only on surface water system, which is likely the most easily understood dimension of water systems because it represents the dimension that students can most easily access and interact with, whereas a considerable abstraction level is needed to understand hidden phenomena and processes that take place underground (Assaraf and Orion 2005, Assaraf et al. 2012; Sadler et al. 2017).

Regarding atmosphere elements, secondary school students acknowledged more frequently than primary students, the sun as the main source of water evaporation. In this sense, Villarroel and Ros (2013) showed that between the final course of preschool education, 5–6 years old, and the end of the first course of primary education, 6–7 (60%), children achieve an understanding of the key, but non-obvious, role that the sun plays in the water cycle. However, our results suggested that this process could be further delayed, up to the transition between primary and secondary education.

Additionally, when students were asked about the source of rain, although both age groups of students indicated "clouds" as the main source, "sea/oceans" was a more common response for secondary students, reflecting a deeper knowledge of the cycle, i.e., how water moves from one part of the system to another.

In accordance with previous studies, we also found that students omit components of the biosphere such as humans, plants, and animals when describing the phenomena, suggesting that most young learners do not contemplate the role of water in biotic systems (Assaraf and Orion 2005, Assaraf et al. 2012; Sammel and McMartin 2014).

Processes of the Water Cycle

Rainfall is a significant process of the so-called water cycle, that is, the most highly structured scientific understanding regarding the movement of water substance on the Earth (Bennet

2008). The water cycle is a common topic covered in school science, and water in the atmospheric system receives a fair amount of attention in elementary grades (Sadler et al. 2017). In fact, school treatment of the water cycle often focusses on precipitation, leaving aside the cyclic nature of rain (Shepardson et al. 2009). In this regard, less than a half of the students who participated in this study (both from primary or secondary education) reflected a cyclic process when drawing. The study by Assaraf and Orion (2005) also evidenced that most of the 12–15-year students in Israel have difficulties in perceiving the cyclical notion of the system. Additionally, more secondary students used labeling in their drawings to distinguish its constituent parts or processes, providing additional and concise information, thus suggesting a better ability to synthesize the components into a coherent system (Vinisha and Ramadas 2013).

Although rainfall is an observable phenomenon, there are many non-observable mechanisms that underlie the atmospheric water phenomena (e.g., the role of sun in the movement of water between different reservoirs or the permanence of water as a substance despite its changes in appearance) that require some developmental steps that do not seem easily covered by young children (Shepardson et al. 2009; Villarroel 2012). When it comes to mentioning the physical phenomena taking place in the hydrologic cycle, precipitation was a physical process known by both primary and secondary students, but more complex phenomena such as evaporation or condensation were much more frequently reflected in secondary students' drawings, and also in their responses to the questionnaire. On a previous study conducted on the 5–15 age group (Miner 1992), it was concluded that concepts like condensation and evaporation may be perceived by 11-year-olds. Henriques (2002) also found that, despite instruction, many children towards the end of the elementary school year, still have difficulty understanding and explaining the role of evaporation and condensation in the formation of rain and clouds and in the processes of the water cycle. Thus, the higher presence of both processes identified in secondary students responses, could be related to a better level of abstraction of the phase change concepts by the older students (i.e., 12/13) in this study. Moreover, a lot of research has pointed out that the lack of understanding of the major concepts of the water cycle (i.e., evaporation and condensation) could be the main reason behind student's inability to explain the mechanism of rainfall (e.g., Bar 1989; Bar and Travis 1991; Henriques 2002).

Similar to the results reported by Malleus et al. (2017) in a previous study with 5–11-year-old students, both our study age group students identified the evaporation process as the main source of cloud formation and precipitation. Moreover, only a few secondary school students properly depicted and/or explained the role of evaporation and condensation. This is quite a common result since, although cloud formationis properly taught at school (in terms of condensation and evaporation), as the second process (evaporation) is more easily understood, children tend to think that water (vapor) goes up and stays there in the form of clouds (Malleus et al. 2017). In fact, we have detected several difficulties in children's explanations (both pictorially and textually) regarding precipitation, but mostly condensation and evaporation. This is a common observation since these processes entail several conceptual difficulties as they are related to water properties and heat exchanges between the Earth and the sun. Particularly in our study, many children addressed the sun and the clouds as having an active role in water evaporation and precipitation (e.g., "Sun absorbs rain" or "Clouds take up or rain") as detected previously by other authors, such as Assaraf et al. (2012), Bar (1989), or Sammel and McMartin (2014).

In this regard, when explaining phase changes (i.e., condensation and/or evaporation), only secondary students mentioned the states of matter (gas, liquid, and gas). This observation probably corresponds to a greater knowledge of chemistry acquired by older students during a school year. Nevertheless, although some students mentioned condensation as one of the processes involved in cloud formation, approximately 30% of these students were erroneously using this terminology and most of them were really referring to evaporation. So, we agree with the conclusions drawn from previous works stating that using correct scientific words does not necessarily mean that students thoroughly understand the concept (Kikas 2005; Tytler 2000). In fact, many studies have highlighted that over-information may contribute to the generation of conceptual errors (e.g., Eisen and Stavy 1993) and we have certainly detected several misconceptions in older students' explanations.

Finally, despite precipitation (and secondarily evaporation) being the most common atmospheric process appearing in children' drawings, practically all on this study depicted precipitation happening over mountains only. Similarly, evaporation in drawings mostly appeared only at sea level. These misconceptions have been identified extensively by other authors (e.g., Cardak 2009; Henriques 2002) and seem to be related to the most common water cycle diagrams present in Earth science textbooks (Vinisha and Ramadas 2013). Studied drawings also reflected some animistic and/or anthropomorphic thinking of children (for instance when they added two eyes and a mouth to the sun or clouds), as detected by other authors such as Miner (1992) or Villarroel and Villanueva (2017).

Students' Level of Understanding About Rainfall and the Water Cycle Phenomena Using a Mixed Approach

The results obtained by the use of both methodologies suggest that children's conceptual knowledge of rainfall and the water cycle increases with age. These findings are consistent with previous studies (e.g., Bar 1989; Saçkes et al. 2010; Villarroel and Ros 2013) and can be somehow expected since, as mentioned before, some processes of the water cycle are quite abstract and might require a higher cognitive level, which develops with age (Piaget 1970). However, some authors have reported that children younger than nine are already able to embrace the water cycle phenomenon if they are taught related concepts earlier (Tytler 2000; Tytler and Peterson 2004). So, this progression in the conceptual understanding by older students could largely be consistent with curriculum developments in compulsory education as mentioned before. During primary school, when students are 8–10 years old, they learn basic ideas about the water cycle and by the end of primary education (11/12 years old) they should also have a basic knowledge of states of matter and phase change. But all these topics are covered in more depth during secondary school, mostly knowledge regarding states of aggregation (and especially water's states of matter), role of the sun on water cycle, and the existence of different fresh water reservoirs. In fact, we observed in this study that secondary school students mentioned more fresh water masses in both tasks (drawing and questionnaire), and the inclusion of processes such as evaporation or condensation was also higher in their explanations, together with mentioning phase changes and states of matter. Secondary school students were also the ones who most acknowledged the sun in the role of water evaporation. Thus, the obtained results could, at least partially, respond to higher instruction received by older students.

Regarding the effectiveness of the two methods employed for diagnosing students' conceptual understanding, the questionnaire allowed a better assessment and discrimination of children's lowest mental models (F.L.1 and F.L. 2) at both age ranges (11/

12 and 12/13). This might be explained in part by the fact that questions referred to specific water cycle processes, elements, and/or places, whereas, in the case of the pictorial task, children were just asked to draw all they knew about rainfall and sometimes they might not have related this process to the whole water cycle. In any case, for the identification of more advanced levels of conceptual understanding, the effectiveness of both methods (questionnaire and drawing) was similar.

Gender Differences

Overall, we did not observe substantial differences regarding boys' and girls' conceptual knowledge of rainfall and water cycle. The only gender differences detected were related to the pictorial task of primary education students. On the one hand, the formulation level inferred from girls' drawings was slightly lower than that of boys' using the same methodology (i.e., drawing), although these results should be viewed with caution, since effect size was just moderate (Pearson's $r = 0.257$), suggesting that more studies should be made in order to confirm these differences. Anyhow, analyzing students' drawings more deeply, we observed that 11/12-year-old girls tended to draw more biosphere elements like plants and animals, whereas boys favored the inclusion of physical processes such as evaporation and condensation, and for acknowledging evaporation to the sun. These observations are in accordance with previous works reporting that parents are more likely to talk to their daughters about life science concepts, whereas they tend to talk to their sons about physical science concepts (Crowley and Callanan 1998; Crowley et al. 2001; Tenenbaum and Leaper 2003).

Interestingly, we did not observe these differences at the next educational level (secondary school), probably because of the higher instruction received in response to the school curriculum.

Conclusions

This study has provided new insights into primary and secondary students' understanding level of the elements and processes of the hydrologic cycle and how they are integrated into their explanations regarding the rainfall phenomenon. Despite older children showing a slightly better conceptual knowledge of the water systems than younger ones, in general terms, the results suggest that 11/12- and 12/13-year-old students have an incomplete perception of the mechanism of rainfall and its integration into the water cycle. In fact, not all the students have a cyclic notion of water dynamics; they also miss the inclusion and role of groundwater in water systems and present misconceptions regarding key processes, such as condensation and evaporation. Thus, a need for a better addressing of this subject at school arises as other authors have pointed out (Sadler et al. 2017; Malleus et al. 2017). In fact, in the last decade, many suggestions have emerged in order to achieve a more comprehensive water systems education at schools (Gunckle et al. 2012; Lee et al. 2017; Saçkes et al. 2010; Sadler et al. 2017).

In any case, a thorough understanding of water the cycle includes grasping many physical-chemical features of water, its states of matter, and phase changes. Thus, a comprehensive understanding of water dynamics should encompass an atomic-molecular approach, including driving forces (e.g., gravity, pressure), and deal with energy transfer (Sadler et al. 2017). In this sense, recently, the Education Decree 236/2015 of the Basque Country (Basque Government 2016) has transferred "Water Cycle" from the curricular area of Natural Sciences into Social Sciences in Primary Education (while it remains in the same area, "Biology and Geology," in secondary education). This decision can have undesirable consequences since the water cycle can be taught disconnected from chemistry or physics (as well as from biology), which can lead to a fragmented and deficient understanding of the water cycle and water system dynamics.

Concerning the diagnostic tools (drawings and questionnaires) used in this research, questionnaires seemed more appropriate for assessing lower conceptual levels. However, as previously pointed out in similar studies (e.g., Cardak 2009; Saçkes et al. 2010; Villarroel and Ros 2013), each method has proven to be useful for detecting different key concepts and misconceptions related to the water cycle. Consequently, a mixed research design using different methods is advised for a comprehensive study of students' conceptions.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Appendix

Table 2 Elements from the hydrologic cycle mentioned in the students' responses to the questionnaire divided by Earth natural systems

Earth natural system	Element	11/12 (%)	12/13 (%)
Hydrosphere	Sea/oceans**	45	67
	Streams**	33	51
	Lakes/wetlands**	1	19
	Groundwater**	0	5
Geosphere	Mountain	6	5
Biosphere	Plants	9	12
	Animals	1	0
	Humans	1	1
Anthroposphere	Houses/factories	4	0
	Gutter	18	12

*Significant differences in the frequency of drawn processes between 11/12- and 12/13-year-old students (** $p < 0.01$)

Elements from atmosphere (i.e., clouds and rain) are not considered since they intrinsically appear in the questions and thus all of the students mentioned them in their responses

Table 3 Processes of the hydrologic cycle appearing on the students' responses to the questionnaire

Process	11/12 (%)	12/13 (%)
Evaporation**	65	85
Condensation**	8	43
Infiltration**	16	48
Transpiration/evapotranspiration	0	1

*Significant differences in the frequency of drawn processes between 11/12- and 12/13-year-old students (**$p < 0.01$)

Precipitation is not considered since it intrinsically appears in the questions and thus all of the students mentioned it in their responses

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