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Constructing Scientific Knowledge through the Teacher´s Questions in a Guided-Inquiry Primary Lesson of the Water Cycle

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ABSTRACT

Background: Currently, there seems to be a consensus in considering guided-inquiry as a way to build scientific knowledge in school. **Objectives**: This paper deals with how scientific content emerged through the guide of teacher questions in an inquiry-based activity, what scientific concepts are constructed by students and teachers, and what kind of questions are used by the pre-service teacher to guide the thoughts of students? **Design**: The methodology used is based on video-analysis. The analysis is carried out at two scales, one mesoscopic (minutes) based on a thematic approach (games), the other microscopic (seconds) based on the cognitive demand of each question from the teacher as well as the decomposition of the knowledge involved in each oral intervention (facets). **Setting and Participants**: The study is carried out with a pre-service teacher in a science lesson of 6th grade formed by 17 students in a public school. **Data collection and analysis**: Our data source is a 1-hour video recording during a science lesson. The data is analysed with Transana software. **Results**: Findings show how the pre-service teacher uses questions in all games as a key lever to engage students in constructing meanings. Difficulties are perceived when students try to explain the scientific concepts (evaporation and condensation) in the context of the water cycle. **Conclusions**: The video allowed us to observe the difficulty in making knowledge move forward as the session progresses if student diversity is to be dealt with.

Keywords: guided-inquiry; primary-school; video-analysis; water cycle; questions.

Perguntas e respostas sobre o ciclo da água

RESUMO

Contexto: Atualmente, parece haver consenso em considerar a investigação

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orientada como forma de construção do conhecimento científico na escola. **Objetivos**: Este artigo trata de como o conteúdo científico emergiu por meio do guia de perguntas do professor em uma atividade baseada em investigação, quais conceitos científicos são construídos por alunos e professores e que tipo de perguntas são usadas pelo professor em formação para orientar os pensamentos dos alunos. ? **Design**: A metodologia utilizada baseia-se na análise de vídeo. A análise é feita em duas escalas, uma mesoscópica (minutos) baseada em abordagem temática (jogos), outra microscópica (segundos) baseada na demanda cognitiva de cada questão do professor bem como na decomposição dos conhecimentos envolvidos na cada intervenção oral (facetas). **Cenário e participantes**: O estudo é realizado com uma professora estagiária em uma aula de ciências do 6º ano formada por 17 alunos de uma escola pública. **Coleta e análise de dados**: nossa fonte de dados é uma gravação de vídeo de 1 hora feita durante uma aula de ciências. Os dados são analisados com o software Transana. **Resultados**: Os achados mostram como a professora inicial usa as perguntas em todos os jogos como uma alavanca fundamental para envolver os alunos na construção de significados. As dificuldades são percebidas quando os alunos tentam explicar os conceitos científicos (evaporação e condensação) num contexto do ciclo da água. **Conclusões**: O vídeo permitiu-nos observar a dificuldade de fazer avançar o conhecimento à medida que a sessão avança se se pretende lidar com a diversidade dos alunos.

Palavras-chave: investigação guiada; escola primária; análise de vídeo; ciclo da água; perguntas.

INTRODUCTION

Currently, there seems to be a consensus in considering guided-inquiry as a way to build scientific knowledge in school (Grandy & Duslch, 2008; Schwarz, 2009). In this research, our perspective of guided-inquiry is connected with the vision of Connelly and Finegold (1977), which considers it as a method of instruction where the teacher should raise questions to students, guiding the process and helping them to scaffold scientific knowledge. From this point of view, Kawalkar & Vijapurkar (2013; p. 2004) state that *'inquiry can be conceptualised as question-driven learning'* In that way, the teacher´s questions should enable students to make new connections with knowledge, guiding their thinking and leading them to rethink what they know in order to develop possible explanations. Therefore, the teacher plays a crucial role in acting as a guide, providing contexts and opportunities for students in the construction of scientific meanings (Huffman & Kalnin, 2003).

However, the actual application of inquiry practices in school life is certainly not an easy task. Scharwz and Gwekwerere (2007) indicate that, despite the crucial role of the teacher in inquiry-based activities, several studies have shown that these experiences are not frequent in classrooms, especially at elemental stages. Literature suggests that this fact can be related to different aspects, such as the teacher's lack of confidence (Windschitl, 2003), a lack of pedagogical content knowledge (Shulman, 1986) or an unclear understanding of what an inquiry-based teaching-learning process implies (Mule, 2006). In addition, these difficulties are even greater for initial teachers or pre-service teachers (Davis, Petish & Smithey, 2006).

All these reasons allowed us to consider that a way to promote the implementation of inquiry methodologies in schools could start with the professional practice of pre-service teachers during their Practicum (Brown & Melear, 2007). With the purpose of understanding how questions can help students to develop knowledge, different authors have focused on the role of the teacher´s questions in conducting guided- inquiry (Brown, 2012; Chin, 2006, 2007; Kawalkar & Vijapurkar, 2013; Odom & Bell, 2011). However, few studies have focused on investigating the role of the pre-service teacher´s questions in classroom practices using fine encoding by video analysis.

This research reports a Spanish case study aiming to obtain a deep comprehension of the teaching practice in an inquiry context with a pre-service teacher. We expect to contribute to improving the understanding of how 6th graders (11 and 12-year-old students) build and use scientific concepts (of phase transitions and the water cycle) during an inquiry activity, as well as of the role of pre-service teachers' questions in promoting this process.

THEORETICAL BACKGROUND

Children ask questions frequently with the aim of understanding the world around them. It seems reasonable that "teacher questions are a frequent component of science talk" (Van Zee, Iwasyk, Kurose, Simpson & Wild, 2001; p.160) in attempts to promote conceptual understanding in their students. Specifically, in elementary school, the teachers' questions play a central role in the student's connection of ideas as well as guiding their thinking (Chin, 2007). In an educational setting, the questions represent the learning objectives (Schank, Kass & Riesbeck, 1994) or what we want our students to learn. These learning objectives should give meaning to the questions that the teacher poses in the classroom during an activity so that in addition to taking into account the answers of the students, they serve as a guide to advance in the knowledge as well as to be able to apply said knowledge in other situations. We can assume that knowledge is not really acquired by the student until she is not able to apply it to another context or different situation in which she must put into play that conceptual knowledge (Omar, 2009). In this sense, Pickett, Kolasa and Clive (1994) pointed out that questions are what really promote the domain of scientific concepts and permit transferring this knowledge to other contexts. However, in our present education system, questions have traditionally had the function of evaluating what students know rather than promoting reflective thinking during their learning. Teachers constantly spend time thinking about the questions they will ask their students to evaluate them in the next exam, but they probably do not spend the same time thinking about what questions they will ask their students to learn. Many times, the questions raised by the teachers only seek the 'correct answer' (Omar, 2009), and when they do not find it, they often end up facilitating that explanation. It may seem that the teacher sometimes conveys an idea to students that the questions posed in the classroom are likely to be answered almost immediately. Nevertheless, providing the precise traits that define what would be a good question is not an easy task. Although different definitions are provided in the literature as to the quality of the teacher's questions, these do not provide a clear description of them. There are many aspects that could define what a good question is; the literature shows studies focused on certain aspects of the teacher´s questions, such as good research questions (Marbach-Ad & Sokolove, 2000), the level of openness in open-ended questions- (Graesser & Person, 1994) or parameters related to the consistency between target and question, context or amount of information and accuracy of the question (Roca, 2006). However, these studies do not provide a detailed description of questions over time or the context in which they are raised.

Maybe the greatest difficulty in adjusting the parameters necessary to raise a 'good question' is the need for the study of the context. Windschitl (2003) pointed out that guided-inquiry is a process where teachers should propose questions or tasks to discuss and explore solutions with the students. In this sense, if what we want is to give an educational value to each question, a functional theory of the questions should be based on a taxonomy that includes all aspects of the inquiry, questions that promote exploration, observation, search for explanations, checking, prediction or application to other contexts or problems. Among these different approaches to classifying questions, our research focuses on a more elaborate analysis carried out by Kawalkar and Vijapurkar (2013). In their work, they proposed a detailed category system elaborated from an inquiry-oriented class, which allows assigning a specific value, in terms of cognitive demands, to each of the teacher´s questions that arise within the classroom. These authors propose six categories in which all aspects of a process of inquiry would be collected; these categories are the following: Exploring pre-requisites/setting the stage, Generating ideas and explanations, Probing further (initial student responses), Refining conceptions and explanations and Guiding the entire class towards the scientific concepts. Nevertheless, authors such as Odom and Bell (2011) state that it is obvious that not all the questions posed to the students represent processes of reasoning or inquiry. Therefore, a fine analysis of the context is essential. Assigning an educational value to a question implies that it should be analysed considering the context or, in other words, the previous interactions between teacher, student and knowledge (Sensevy, 2011).

Our vision of knowledge is based on the perspective of Chevallard (1991). The knowledge 'lives' in the group of persons, and it is an abstract identity in the minds of students, so the only way to know what they know about students is through what they express in the classroom.

In a guided-inquiry class, knowledge is not facilitated by the teacher, but it is a construction between the teacher and students. Therefore, the construction of knowledge is also the responsibility of the students (Tiberghien, 2012). Scaffolding of knowledge is the result of a communicative joint action between student and teacher (Sensevy, 2011). Thus, the classroom is an entity where knowledge is built through a process that is mainly communicative (Sensevy, 2007).

It is apparent that of all volumes of the classroom 'discourse, it is important to develop an analysis that allows us to select the ideas that are related to scientific concepts. A practical way to accomplish this task is through the use of the *facet* concept. Knowledge constructed in an inquiry classroom is the result of connecting a set of small elements of knowledge (*facets*) which are produced through the interactions, mainly oral interventions, between student(s) -teacher or student(s) -student(s) (Tiberghien & Malkoun, 2010). One facet expresses a small idea about a scientific concept.

However, the knowledge expressed in the classroom is ephemeral, so that one way to obtain a record is through the video. It is essential to register audio and video recordings in order to capture the complexity of the classroom, going beyond the static moment that written registers or questionnaires would offer (Givry & Tiberghien, 2012). In that way, videotaping shows the advantage of providing oral, gestural and written registers (e.g. a drawing on the blackboard), which facilitate analysis in order to understand the classroom context in which knowledge is constructed.

In this paper, we present the analysis of a case study. Taking into account the previous theoretical elements, the research questions posed in this research are: 1. What scientific concepts are constructed by students and teacher? 2. What kind of questions the pre-service teacher uses in order to guide the thoughts of students?

Context

The study was carried out within the university program of teaching training (Practicum). A pre-service teacher tries to develop inquiry-based activities that have been prepared at the university during their instruction. Our source of data is a 1-hour video recording made during a science lesson in 6th grade. The class is formed by 17 students in a public school in Spain. The topic of the lesson was water phase transitions and their relation with the water cycle.

This lesson was conceived from a previous one in which students were working on the model of the water cycle. In this lesson, some students expressed the idea, derived from the model depicted in their textbook, that it only rains in the mountains, whereas others explained that it also rains in the sea because they had seen it in films. The aim of the experiment is to acquire deeper knowledge that would enable students to connect experimental facts of phase transitions with the natural phenomena actually involved in the water cycle. Previous to the lesson, the pre-service teacher left two glasses of water covered by a plastic film: one of them close to the radiator and next to the window (glass 1), and the other one in the darkness, without any heating source nearby (glass 2). The aim of the experiment is that students acquire a deeper knowledge by connecting the experimental facts developed during the lesson with the natural phenomena associated with the water cycle. The lesson is carried out with the whole class group, to which the pre-service teacher hands out a worksheet with a set of planned questions to be filled in by students. The entire lesson is carried out with the whole class group.

METHODOLOGY

The methodological approach is drawn from qualitative research oriented to analyse classroom practices. The complex nature of the classroom allowed us to carry out several scales of analysis.

Mesoscopic Scale: Analysis in Terms of the Didactic Games

Considering the interactions between teacher-students-knowledge, the analysis in terms of a sequence of the *didactic games* allowed us to identify the different goals and contexts in which the lesson is carried out. This structuring of the lesson offers an overview of what is going on in the class. We use the concept of the *didactic game* as the mesoscopic unit of analysis. From the perspective of the didactic joint action theory [JATD] (Sensevy, 2011), the classroom is considered a complex system that can be described in terms of the didactic games or scenes in which knowledge is involved. Similarly to a theatre play, the class can be described by a sequence of scenes. Each didactic game can be considered a 'scene' that has coherence, taking into account the context and a didactic contract or main aim (Sensevy, 2011). A didactic game starts when a new stage appears or when the main rule o goal is changed by the teacher or a student. Thus, a new game is produced when the researcher detects a change in the established didactic contract (rules, usually explicit) or the classroom context (such as involved actors, new material elements or modification of the organisation). The title refers to the purpose of the game and corresponds to an oral intervention by the teacher or the students.

To analyse the video data, we used *Transana* software (University of Wisconsin-Madison Center for Education Research, www.transana.com). Table 1 summarises the sequence of the 17 games in which the lesson has been arranged. After viewing the videotape several times with the transcripts, we identified the didactic games, assigning each one a title and duration.

Table 1

Presents the lesson classified into didactic games with the use of the Transana software

Game	Title	Time
Game 1	What will the experiment consist of?	(0:00:05)-(0:01:39)
Game 2	What happened in the glass?	(0:01:39)-(0:02:31)
Game 3	Why are there droplets on the plastic?	(0:02:31)-(0:04:52)
Game 4	Is there the same amount of water?	(0:04:52)-(0:06:27)
Game 5	What if we put an ice cube on the plastic?	(0:06:27)-(0:12:41)
Game 6	Do you think it only rains in the mountains?	(0:12:41)-(0:19:40)
Game 7	At night, will it happen the same?	(0:19:40)-(0:22:37)
Game 8	What happened in the glass?	(0:22:37)-(0:26:49)
Game 9	What happens if you put an ice cube on	(0:26:49)-(0:29:12)

	the plastic?	
Game 10	Why does it rain?	(0:29:12)-(0:33:38)
Game 11	Where is the water that was there before?	(0:33:38)-(0:35:11)
Game 12	Why is there more liquid water in one glass than in the other?	(0:35:11)-(0:36:37)
Game 13	Do you think it only rains in the mountains?	(0:36:37)-(0:38:07)
Game 14	How do you relate this with the experiment (rain)?	(0:38:07)-(0:50:39)
Game 15	Why does it sometimes rain or snow?	(0:50:39)-(0:55:57)
Game 16	Is there always the same amount of water in the clouds?	(0:55:57)-(0:56:28)
Game 17	Would it be the same at night?	(0:56:28)-(1:00:03)

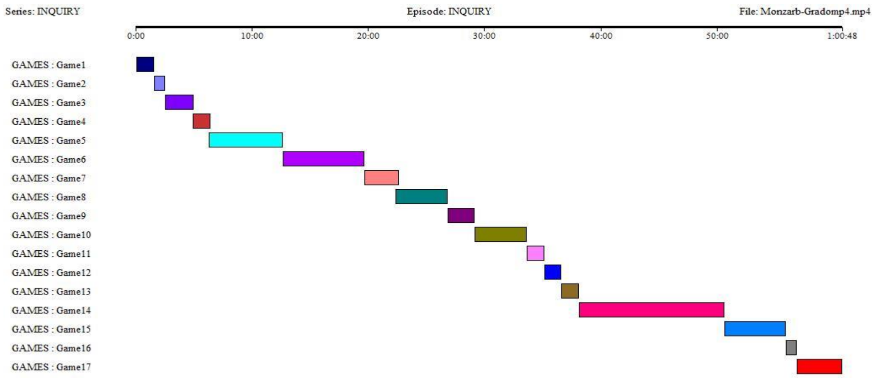
Here, we present an example of a change of didactic game -between games 1 and 2-:

> *(0:00:12.9) Pre-service teacher: This is for doing an experiment. I´m giving you some worksheets… You are going to fill them in in groups, ok? You are going to have a talk together. But first, you are going to tell me if someone knows what this experiment consists of.*
>
> *(0:00:13.8) Student 1: Ehhh, the evaporation of water?*
>
> *(0:00:18.7) Student 2: Exactly what Samuel said. Well, you see, the plastic is used so that the water doesn't disappear.*
>
> *(0:00:29.4) Student 3: To see in which one the water has evaporated faster.*
>
> *(0:00:34) Pre-service teacher: You have already observed. Good work.*
>
> *(0:00:36) Student 4: The change of water in specific areas.*
>
> *(0:00:40.2) Pre-service teacher: Ok. Right. First, I´m going to give you a worksheet, and we are going to talk about it. Are you reading the questions? Come on, Quique, read the questions aloud.*

Game 1 is developed with the whole class, and the duration is brief (Figure 1). The teacher introduces the lesson by telling students that they should answer the planned questions on a file of paper. The rule of the game is to guess the objective of the experiment, and, as a consequence, the students start to answer randomly. Our interpretation is that the teacher uses the question: ‘What is the purpose of this experiment?’ as an introduction and contextualisation of the activity. This game is over at the time (0:01:39) when the didactic contract changes because the teacher asks a student to read aloud the questions written on the worksheets (Table 1), and so game 2 starts.

Figure 1

Graphic obtained by Transana of the arrangement of the lesson in didactic games



Microscopic Scale: Teacher´s Questions

From a perspective of guided-inquiry at elemental stages, we consider that the teacher’s questions raised through the dialogue are what allow us to describe the dynamics of the inquiry. In that sense, we have differentiated questions that arise from the spontaneous dialogue or the context of the lesson and questions that have been previously planned (they do not arise from the dialogue) (Table 2).

Table 2

Planned questions were made by the pre-service teacher prior to the lesson *and handed out to each student on a worksheet.*

Planned questions (established by the pre-service teacher previous to the lesson)
1. What happened to the glasses?
2. Where is the water which was there before?
3. Is there always the same amount of water there?
4. Why do you think there is more liquid water in one glass than in the other?
5. If I put an ice cube on the plastic film, what would happen?
6. Do you think it only rains in the mountains? Why?
7. How would you relate it to this experiment?
8. If I put the glasses in the same way at night, will it happen the same?

This initial classification makes sense in the context of the lesson, which is designed according to several *planned questions* made by the pre-service teacher, to which the students should give written answers during the lesson. We consider this differentiation important in order to discriminate when the teacher uses questioning based on the dialogue with students and when he or she acts according to the previously designed plan. Based on the research of the authors Kawalkar and Vijapurkar (2013), we have elaborated a system of categories to code each *spontaneous* question made by the teacher (emerged in the context of the lesson). This category system allows us to assign a value to each question raised in the classroom. As a result, we can obtain a fine-grained analysis of the teacher´s questions, considering the gradualness of the cognitive demands. Table 3 shows the design of categories.

Table 3

Codes for the teacher´s questions

Code	Description	Example
Q1	Exploring pre-requisites/setting the stage	What is proposed in this experiment?
Q2	Generating ideas and explanations	Why has water evaporated?
Q3	Probing further -initial student responses-	But what would happen to the water inside?
Q4	Refining conceptions and explanations	And why are there drops falling?

Q5	Guiding the entire class towards the scientific concepts	One moment: How did we define this when the water was on the plastic film?
Q6	Extending applicability	What happens when the temperature changes? Has something happened?
Q7	Others	How? Which is your country?

The group defined by Kawalkar and Vijapurkar such as '*Classroom management*', has been renamed as '*Others*', where we have included questions related to classroom management but also questions that are not related to the considered contents (in particular, phase transition or their relation with aspects of the water cycle). Even though group Q7 of questions does not have substantive content, we encode them because we consider that they could help us to interpret the classroom dynamics. Furthermore, we have added an additional group called '*Extending applicability'*, to which we assign questions that encourage students to use the knowledge constructed in the classroom in a different situation.

Each question was analysed and coded according to the context and progression of the knowledge involved in the classroom. For these reasons, the relevance of the context implies that a certain question can be coded differently depending on the moment at which it is raised.

Microscopic Scale: Analysis of the Scientific Knowledge Involved in Terms of Facets

With the aim of reconstructing the knowledge involved in the classroom talk and its relationship with the teacher´s questions, we use the concept of *facet* (Tiberghien & Malkoun, 2010), which is a small element of knowledge that is expressed in an oral production (Galili & Hazan, 2000) conserving the meaning with which it is created. The set of facets was arranged in conceptual groups related to Evaporation (E), Condensation (C), Contrast of temperature (S), Freezing (G), Relationship between rain and experiment (L), Water cycle (F) and Others (O). Once the facet list was designed after the analysis of transcripts, we coded each oral intervention (students and teacher). The following example illustrates how facets are created:

(0:03:50.8) *Student:* Because of the *heat contrast*, for example, *when the gas is hot* because it *has been evaporated*, then when *it crashes into* *something* which is not at the same temperature, and it is *colder***,** it becomes *liquid again*.

This extract of transcript is associated with facet 'S. The hot gas crashes into something that is cold, and it becomes liquid', connected to the group Contrast of temperature.

RESULTS AND ANALYSES

The results are arranged in three sections. The first is related to the role of the *planned* and *spontaneous* questions of the pre-service teacher during the lesson. The second section shows the emergence of each group of *facets*. Finally, the third section describes the class development according to the teacher's questions and the facets used by students.

The planned questions in the didactic games

Table 1 shows that the description of the lesson in terms of didactic games is closely related to the planned questions prepared by the pre-service teacher. Our interpretation is that the teacher makes a rigid structure of the session. She proposes each didactic game according to the sequence of the planned questions, directing students to what they should deal with and think about. The session is structured in 17 games (Table 1). The majority of the didactic games are connected with one of the eight planned questions (Table 2). The pre-service teacher makes a repetition, more or less, between the first and the second part of the lesson. When game 7 is over, the pre-service teacher waits for a few minutes so that the students can answer the planned questions in groups. After this time, the pre-service teacher performs a similar structure to the first part of the lesson. Thus, she uses these questions as general guidelines throughout the lesson.

Table 4 shows the relation between the games of the first and the second part of this session (before and after game 7), both of which aim to answer the same planned questions.

Table 4

Relation between the didactic games during the lesson

Game	Title	Game	Title

2	What happened in the glass?	**8**	What happened in the glass?
4	Is there the same amount of water?	**11**	Where is the water that was there before?
5	If you put an ice cube on the plastic, what happens?	**9**	If you put an ice cube, what happens?
6	Does it only rain in the mountains?	**13**	Does it only rain in the mountains?
7	Will it happen the same at night?	**17**	Will it happen the same at night?

It is worth noting that although every game entails a question, it does not always take an interrogative form, as it is shown below:

> (0:26:49) Pre-service teacher*: If I leave "the cold" here... we have left some ice in here; if we put a lot of ice, the temperature would be much colder.*

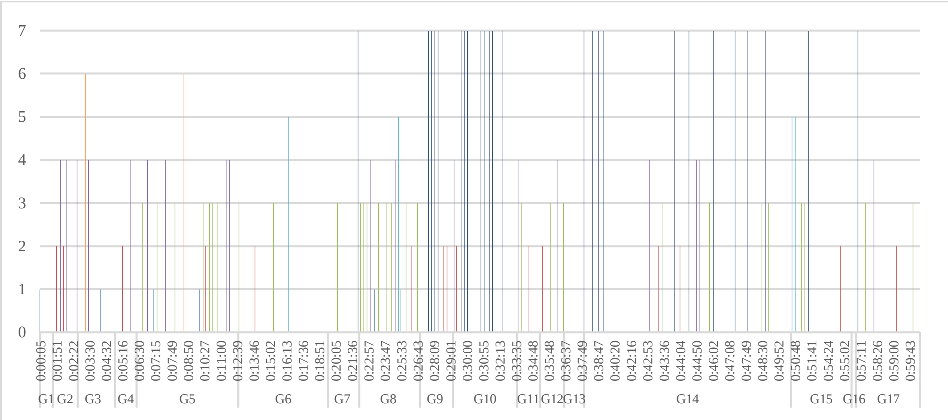
This sentence appears at the beginning of game 9 as a result of the introduction of the ice element (on glass 1, where the water has been evaporated). We consider that the context changes, and consequently, so does the didactic contract. In that way, the didactic game has changed, and a new game has started related to the planned question, "If I put an ice cube on the plastic film, what would happen?" (Game 9). In summary, the planned questions (included in the student´s worksheets) originate most of the didactic games, so the activity is closely structured around them. Only two of the didactic games are related to questions raised by students (games 15 and 16), so we interpreted that the teacher does not give the students the responsibility to structure the lesson.

The teacher's spontaneous questions in the didactic games

Figure 2 represents the class dynamics as a function of the distribution of the kind of questions raised by the pre-service teacher in each didactic game. The x-axis represents the time divided into games (G1, G2 … G17), while the y-axis represents the kinds of questions, represented by the code numbers shown in Table 3.

Figure 2

Spontaneous questions distributed during the lesson



Legend: Axe x: time distributed in didactic games (G1, G2… G17), Axe y: Type of questions 1= Exploring pre-requisites/setting the stage (Q1), 2= Generating ideas and explanations (Q2), 3= Probing further (initial student responses) (Q3), 4= Refining conceptions and explanations (Q4), 5= Guiding the entire class towards the scientific concepts (Q5), 6= Spreading applicability (Q6), 7= Others (Q7)

The results show a balanced distribution throughout the activity of spontaneous questions raised by the pre-service teacher (Figure 2). Only didactic games 15 and 16 are generated by student´s questions, whereas the rest of the games are initiated by the teacher’s questions. The teacher uses questions in all didactic games as a key lever to engage students in the construction of meanings. A main characteristic of the questions is that these cannot be answered with a sentence or word; the students need to provide explanations about what they observe, what they know about it and the reasoning they can provide to find an answer. The pre-service teacher does not give information when she tries to raise a new question to students, but she encourages them to justify and improve their answers by guiding their thinking continuously. In general terms, there is a gradual increase in the cognitive demands of the questions in each game. We illustrate this fact with the following examples of questions from the pre-service teacher:

> (0:06:33) Pre-service teacher: *But what would happen with the water inside?*
>
> (0:23:04) Pre-service teacher: *OK, and why were those drops*

there?

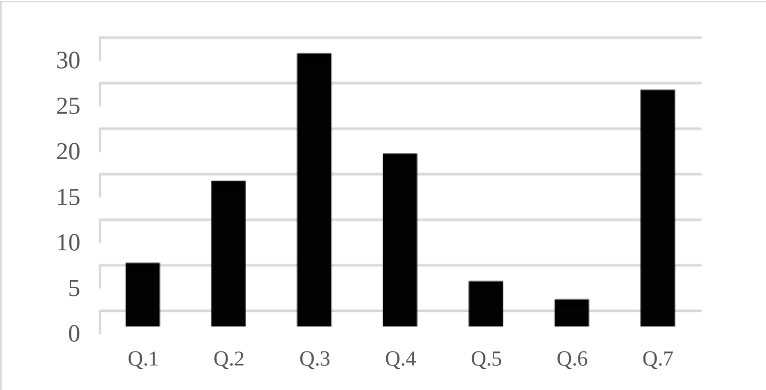
(0:26:49) Pre-service teacher: *If the ice was put in here, have we put ice, really? If we put a lot of ice, the temperature would be colder. What would happen if the gas went up hot and touched the plastic film?*

(0:29:15) Pre-service teacher: *So, what has happened?*

In particular, the teacher's guidance through spontaneous questions during the activity is interpreted as an effort to transfer the learning responsibility to the students. When students experience difficulties in giving explanations, the teacher goes on to pose questions, which encourages the students to propose solutions. Q1 (6%) [*Exploring pre-requisites/setting the stage*] represent 6% (Figure 3), which we consider acceptable, regarding that these questions serve as an introduction to the activity or memory of e facts. The data shows a preponderance of questions Q2 (15%) [*Generating ideas and explanations*], Q3 (29%) [*Probing further*] and Q4 (18%) [*Refining conceptions and explanations*] (Figure 3), which help students to develop their own thinking. However, the percentage associated with group Q5 (4%) [*Guiding the entire class towards the scientific concepts*] and Q6 (2%) [*Spreading applicability*] is considerably lower. This fact suggests difficulties in developing the entire process of inquiry. On the few occasions when the teacher asks Q5 and Q6 questions, it seems that a unique 'valid' response is not enough. The video shows how several students raise their hands, and the teacher signals to call on one student at a time. This is interpreted as an interest in detecting whether all students have equal progress in the construction of knowledge, which, to a certain extent, hinders progress in posing questions that require a greater cognitive process.

Figure 3

Distribution of questions during the session



Legend: Axe y: percentage, Axe x: type of questions Q1= Exploring pre-requisites/setting the stage, Q2= Generating ideas and explanations, Q3= Probing further (initial student responses), Q4= Refining conceptions and explanations, Q5= Guiding the entire class towards the scientific concepts, Q6= Spreading applicability, Q7= Others

Lastly, we found a high percentage of questions Q7 (25%) [*Others*]. On the one hand, this percentage is associated with aspects related to classroom management. On the other, it is linked to deviations in the discourse, such as when, in games 9 and 10, students start to talk about weather phenomena that are not related to the topic of the lesson (e.g. twisters). Furthermore, the pre-service teacher may ask questions that do not promote the understanding of the phase transitions or their relevance to the water cycle. We interpret that the teacher loses control of the knowledge development during games 9 and 10 by raising questions that are not related to the focus of the teaching session. Especially in game 10, as a consequence of the set goal of the game: 'Why does it rain?' For example, a discussion related to the aspects of the weather or the Earth rotation takes part in later games 14, 15 and 16, initiated by the teacher's questioning: 'How would you connect -the rain- with the experiment?', 'Why does it sometimes rain?' and 'Is there the same amount of water in the clouds?'. Games 15 and 16 have questions connected with the meteorological aspects. These kinds of questions were categorised in group 7 because of the lack of connection with the construction of the focus of the teaching session, as can be observed in these examples:

(0:43:57) Pre-service teacher: *When the sky is clear?*

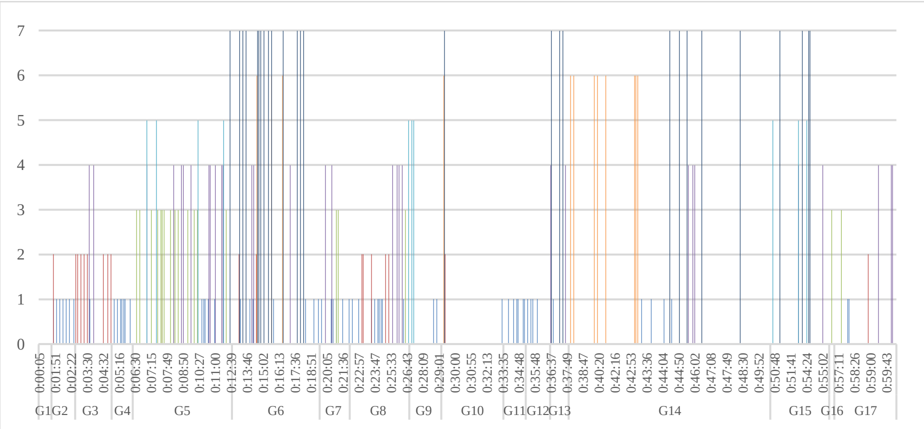
(0:51:42) Pre-service teacher: *But did you know that the height of the Pyramids is equal to the height of Everest?*

The scientific knowledge involved in the lesson (facets)

Figure 4 shows the distribution of the facets used or constructed during the lesson. The x-axis represents the time along the lesson, and the y-axis shows the codes assigned to each group of *facets*.

Figure 4

Distribution of facets during the session



Legend: Axe x: time, Axe y: type of facets 1= Evaporation, 2= Contrast of temperature, 3= Freezing, 4= Relationship between rain and experiment, 5= The process of the water cycle, 6=Others

Table 5

Percentages of the total groups of facets used/constructed by pre-service teacher, student, or co-constructed (student-student or pre-service teacher-student) in the lesson.

Group of facets	% / Number of facets used/constructed by:				
	Student	Teacher	Student-Teacher	Student-Student	Total

E: Evaporation	29/63	5/11	1/2	4/3	39/79
C: Condensation	8/16	2/4	-	-	10/20
G: Freezing	3.5/7	1/2	0.5/1	-	5/10
S: Contrast of temperature	12.5/26	3.8/8	0.5/1	-	17/35
F: Weather/Water cycle	14/31	-	-	-	14/31
L: Relationship rain with experiment	5/12	-	-	-	5/12
O: Others	9/19	1/1	1/1	-	10/21
Total	81/174	12.8/26	3/3	4/5	100/208

Table 5 shows that 90% of the facets belong to the main topics of the session (Evaporation, Condensation, Freezing, Contrast of temperature, Weather/Water Cycle and Relationship rain with experiment), whereas the rest (10%) mainly deal with aspects related to the plastic film in glass 1 or to hypotheses about what would happen if the experiment was carried out at night. This table also shows that students are the main actors in the development of knowledge, being responsible for 81% of the facets. This data is interpreted as the pre-service teacher offering the students the responsibility for the use and construction of knowledge.

Evaporation

The first process identified by students is evaporation, using this term to explain the conversion of water into gas as a consequence of a heat source. Students use facets on evaporation in 39% (Table 5) of the total of the activity (Figure 4). This group of facets further appears until game 5 (Figure 4). Although games 6, 7 and 14 also present facets related to evaporation, these are connected with the relation of the experiment with rain or with the reproduction of the experiment at night (Figure 4). Next, we illustrate how students continuously explain the phenomenon of evaporation when they try to explain a question that is not directly related to it:

> Pre-service Teacher: *Good, let´s go; we are going to establish a relationship between this experiment and the rain. How can you relate it?*
>
> Student 4: *With the water cycle!*
>
> Pre-service Teacher: *Ok. And how can you relate the experiment to the water cycle? What happens in the water cycle? Explain it to me.*
>
> Student 6: *The water is evaporated by the Sun in gaseous form, and it goes to the clouds. When it arrives at the clouds, the clouds crash against the mountain, and this liquid appears, and it forms small rivers in the mountains, and later it comes back again.*

This example suggests that students can associate the phenomenon of evaporation more easily than other phase transitions in their explanations, although, during games 9, 14, 15 and 16, there is a decrease in the students' use of the evaporation facets (Figure 4). This can be explained by the fact that the dialogue centred on the experiment conducted with the two glasses, which mainly deals with evaporation and condensation. For this reason, students tend to associate evaporation with explaining local weather phenomena, even if it is not present in these.

Condensation and temperature contrast

The fraction of facets associated with condensation is rather low (10%, Table 5), so we conclude that it is more difficult for students to explain condensation than evaporation. This group of facets appears only in game 2 and between games 7 and 9 (Figure 4). Unlike evaporation, students do not use the term condensation, which was introduced by the pre-service teacher, in spite of her questions on the matter. Students explain the apparition of drops on the plastic film in relation to the time in which the gas stayed inside the glass, to the crash of the gas against the plastic film and finally to the heat of the gas when it crashes against something at a lower temperature. To reach these conclusions, the pre-service teacher guides the students' reasoning through questions. Before the students answer, the pre-service teacher suggests the idea of temperature difference, as we show in the following example.

(0:03:30) Pre-service Teacher: *Do the drops always fall? What causes this?*

Student: *Because of the heat, the environment or…*

Pre-service teacher: *So, due to the heat in the water, this is evaporated, and it is put there. But is that water supposed to be hot when it touches the window?*

Thus, we conclude that condensation is interpreted as a contrast of temperature to explain why in glass 1 (which is covered with plastic film and placed near the radiator) there are some drops; thus, this is associated with the contrast of heat and gas (water vapour) when it crashes into the plastic film. This implies a comparison of temperatures, which is an interesting way of describing states in physics (Driver, Guesne, & Tiberghien, 1985).

The group of facets connected with the contrast of temperature represents 17% of the total facets (Table 5) and mainly appears between games 10 to 16 (Figure 4). Thus, the idea of temperature contrast is used by students mostly at the end of the lesson, to explain condensation phenomena.

Freezing

The facet group of freezing refers to the change of state from liquid to solid, and it is rather infrequent (5%, Table 5) in the lesson. They only appear in games 5, 9 and 15 (Figure 4). Games 5 and 9 are in relation to planned question 5 (If I put an ice cube on the plastic film, what would happen?) and game 15 is connected with a question raised by a student (Why does it sometimes rain or snow?). Although the experiment in the classroom does not involve this change of state, this group of facets appears when there are elements like ice or snow. The pre-service teacher uses an ice cube to condense vapour inside glass 1 (near the radiator). Although the ice element is used to create a temperature difference in glass 1, students do not associate it with the phase change of freezing. The activity is only related to phase transitions of evaporation and condensation, which is consistent with the low frequency of the facets of this group. In that sense, students associate freezing only with the necessity of cold and in connection with meteorological phenomena, as shown in the following facets:

‘G.3. If a cloud gets very cold, it freezes.’

‘G.4. It snows a lot in the mountains because it is cold.’

The process of the water cycle

Students connect phase transitions to concepts of climate and water cycle in 15 % of the classroom discourse (Table 5). Besides, Figure 4 shows how this group is distributed between games 6, 10, 14 and 15, which are coherent with the questions that drive these games in relation to the rain (see Table 1).

Furthermore, there are facets about the *Contrast of temperature* group which are connected with other facets about weather and water cycle, as shown in the following examples:

'F.7. The gas of a cloud with heat or cold produces water raindrops.'

'F2. It snows when the water vapour gets very cold and water drops are formed.'

Contrast of temperature

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Relationship of rain with the experiment

The facet group connected with the relation between the rain and the experiment shows a low percentage (6%, Table 5) and appears in games 6, 13 and 14 (Figure 4). This group is used by the students when the pre-service teacher raises questions in which rain is explicitly involved. Some examples of these facets are presented:

‘L. When it rains, it is like in the experiment: the cloud is the gas which crashes into something, such as the plastic film.’

‘L.2. The evaporated water in the glass with the plastic film is the same as the water in the clouds; ice on the film is the same as when the clouds get cold, so raining is the same as the drops falling from the plastic film.’

‘L.5. It rains over the sea because it happens the same as in the experiment.’

This low percentage show reveals the difficulty in associating phase transitions and rain phenomena. Students construct the idea that condensation is produced by a temperature contrast; however, they have difficulties in explaining the phenomenon of the rain afterwards. They doubt whether the rain is produced due to a crash between clouds and a mountain or by a contrast in temperature. Our interpretation is that students have deeply internalised the classical model of the water cycle, which is presented in textbooks. In these drawings, there is the sea, the sun, a cloud, and a mountain. Although students have explained the condensation in terms of contrast of temperatures, when they have to explain the rain, they propose that the cloud is formed in the sea and later goes to the mountain and crashes against it.

Relation between knowledge (facets) and the preservice teacher´s questions

The analysis shows how all the didactic games (except games 15 and 16) are connected with the necessity to respond to one of the *planned questions* prepared by the pre-service teacher before the lesson (see Table 4). The rules or aims of these didactic games are established by the pre-service teacher, so she has the responsibility to define the structure of the lesson. During the first part of the lesson, the discourse is characterised by a systematic construction process of scientific knowledge carried out by students and guided by the *spontaneous teacher´s questions*. The pre-service teacher uses questions to engage students in the reasoning, using their responses to ask follow-up questions in which they need to rethink their arguments and make new connections. However, even if the sequence of didactic games in the second part of the session is designed under the same objectives (see Table 4), during the latter, there is a decrease in the use of facets (Figure 2) together with a notable increase in questions made by the teacher which are not oriented to the considered work topic [Q7 25%, Figure 3]. These questions arise from the students’ dialogue about meteorological phenomena (e.g. typhoons) when the pupils try to express phase changes in the water cycle. The teacher uses the answers of students to propose new questions, and as a consequence, she losses control of the focus of study several times. We conclude that, at that moment, the class discourse is deflected to other contents by the students, while the pre-service teacher shows difficulty in redirecting the dialogue toward the lesson topic through her questions. This data reinforces the fact that, from game 9 on, there has been a decrease in the use and construction of facets by students, so the construction of knowledge seems to stagnate in the last games.

The data shows how the highest level of cognitive demands in teacher´s questions is related to ‘*Probing further -initial student responses*-’ and ‘*Refining conceptions and explanations*’ [Q3 (29%) and Q4 (18%), Figure 3]. Our interpretation is that the teacher tries to carry out an inquiry activity by raising further questions to push them to give reasons or, more generally, to develop their thinking. Whatever the scientific correctness of the students’ reasons, the pre-service teacher uses their answers to engage their thinking without giving information or correcting their responses. On the other hand, paying attention to all students results in an alternation between questions of high and low cognitive demand and, in general terms, in a rather small number of questions of higher cognitive level [Q5 (4%) and Q6 (2%), Figure 3], which might contribute to the connection of phase changes in the water cycle.

The result is a lesson in which students use and construct most of the facets (81%), which enables us to state that the pre-service teacher enhances the students’ construction of scientific knowledge by granting them the responsibility to accomplish it. Usually, when the teacher expresses a facet (12%, Table 5), this is only a repetition of the students’ answers without adding more information. In general terms, the lesson is developed by means of constant one-on-one interaction between the teacher´s questions and the student’s individual answers, so the analysis has only identified 4% of co-constructions of facets student-student (Table 5).

Evaporation is the most used concept by the students, and in the same way, it is the only change of state co-constructed by students (Table 5). Through observation of the experimental device directed by the teacher, evaporation is perceived in association with a heat source, whereas condensation is related to a temperature variation. These phenomena, evaporation and condensation, are not interpreted in the same terms by students (Driver, Guesne & Tiberghien, 1985; Tiberghien, 2012). Freezing is the least explained change of state, and it is only associated with the necessity of cold. The pre-service teacher introduced the question, ‘If I put an ice cube on the plastic film, what would happen?’ but since freezing is not observed in the experiment, students can only base on suppositions in order to predict this phenomenon. The teacher enables students to make connections between the phase's transitions and weather phenomena such as rain or snow. However, students find several difficulties in transferring the phase transition concepts to the meteorological context. Furthermore, it is interesting to observe how students begin using the idea of temperature contrast to explain condensation, but they feel the need to use this idea also for evaporation when they have to explain this phenomenon in the water cycle context. Clouds are considered gas or liquid (droplets) depending on which phase transition the students have to explain. Thus, they express the idea that the gas is cooled down in the atmosphere and turns into droplets when they talk about seawater evaporation, but, in contrast, when they have to explain the phenomenon of rain, they state that the gaseous clouds crash into the mountains. Snow is expressed as something exclusive to mountain areas due to the need for 'very cold' sites. In contrast with condensation and evaporation, students do not feel the need to explain the phenomenon of freezing in terms of a crash, a concept that is replaced when they explain the occurrence of snow by that of temperature contrast.

CONCLUSIONS

This study attempts to contribute to research studies focused on the analysis of pre-service teacher practices in the classroom. The analytical framework provides the characterisation of the teacher´s questions and the knowledge involved in an inquiry lesson. The findings obtained in this study can only be understood by taking into account that the lesson was designed by the pre-service teacher with two aims: 1) to interpret how students are able to transfer their theoretical model of phase transitions to an experimental context, 2) to interpret how students use their knowledge or the constructed model of phase transitions to make predictions in other contexts (in the atmosphere or in the mountains).

In this class, the pre-service teacher prioritises developing an inquiry activity above the previously designed plan. The high occurrence of the teacher's questions suggests an inquiry approach based on a high level of participation among students. This leads to a subordination of the teacher's role to the students' answers, forcing her to improvise and repeat the questions or vary the cognitive demand of each question. This research was focused principally on the analysis of oral productions; however, the video recording offers the chance to analyse the conditions in which teacher-student-knowledge interactions are produced. In this case, it can be observed how several students repeatedly raise their hands when the teacher poses a question, and she signals to call on one student at a time. This fact was interpreted as an interest to verify that all students are progressing at the same rate in the building of knowledge. Our interpretation was that the inquiry approach of the teacher is oriented to the constant search for consensus in the students' responses and, as a result, in the constructed knowledge. In this way, doing science at school implies, in contrast to other academic stages, doing science for all students.

The video allowed us to observe the difficulty involved in making knowledge move forward as the session progresses (in this case, for 17 students) if student diversity is to be dealt with. This might be an example of a situation that justifies the reluctance of teachers to carry out this kind of practice. When teachers try to develop inquiry-oriented activities, they are exposed to situations in which the students' answers can reveal their deficiencies as to their PCK didactic knowledge (Windschitl, 2003) or can generate a lack of confidence (Shulman, 1996) for their development.

A second difficulty experienced during the development of inquiry arose when applying the constructed knowledge to a different context to the one where it had been created or, in other words, when trying to extend the applicability of that knowledge. This was observed both in the knowledge transference from the theoretical to the experimental framework as well as when trying to extrapolate the observed phenomena to other natural contexts.

In this case, the inquiry activity confers a key role to the experimental device in the process of explaining phase transitions. At further stages, transferring this model of phase changes to the explanations of phenomena such as cloud formation, rain, or snow entails great difficulty for students. Extending the applicability of the knowledge that has been created by means of an experiment to other natural contexts implies the introduction of numerous variables (e.g., wind or atmosphere), which make it difficult for students to explain the complex processes involved in the water cycle using only partial scientific contexts (phase transitions). In this sense, the context limits the students' explanations and forces the teacher to use other materials, such as drawing on the blackboard, in order to guide them through her explanations.

Finally, this analysis allows us to understand some limitations experienced by the pre-service teacher of this case study. The findings of this analysis can be useful for the practice of other teachers and pre-service teachers.

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