Conceptual demand of practical work: A framework for studying teachers' practices

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Abstract: The study addresses the issue of the type and the level of complexity of practical work present in teachers' practices, at the level of high school science education. The level of complexity was appreciated by the level of conceptual demand of practical work, as given by the complexity of scientific knowledge, the complexity of cognitive skills and the degree of relation between theory and practice. The study also analyses the scientific inaccuracies that teachers may make when implementing practical work. The concept of osmosis was selected as an exemplary study to show how this framework may work when studying conceptual demand of practical work of teachers' practices. Two teachers of two distinct schools were selected. The results showed that the two teachers' practices have in general a low level of conceptual demand which is mostly a consequence of the low level of complexity of scientific knowledge and skills required and also of teachers' scientific inaccuracies. The type of practical work selected by teachers (laboratory activities generally illustrative) also contributed to lower the level of conceptual demand. In methodological terms, the conceptualization and procedures followed in the study constitute an innovative approach that gives greater rigor to the analysis.

Keywords: practical work, conceptual demand, teachers' practices, osmosis.

Introduction

Practical work has an important role in science education (Hodson, 1993; Hofstein and Lunetta, 2004; Lunetta, Hofstein and Clough, 2007; Millar, Maréchal and Tiberghien, 1999). However, the potential of practical work has been contrasted with questions about its efficiency and benefits (Hodson, 1993; Hofstein and Kind, 2012). Many research studies have emphasized that for many teachers practical work means simple recipe-type activities that students follow without the necessary mental engagement. Further studies about practical work are still needed. The main aim of this article is to describe methods and concepts that may be used to appreciate the level of complexity of practical work of teachers' practices.

The meaning of practical work in the present study is close to Hodson's (1993), which includes any activity that requires students to be active, although it is made more precise in that considers that it must mobilize science processes skills. These skills were considered as ways of thinking more directly involved in scientific research, such as observing, formulating problems and hypotheses, controlling variables and predicting (Duschl, Schweingruber and Shouse, 2007). Also following the concept presented in the Biology and Geology Portuguese curriculum (DES – High School Department, 2001), practical work is defined as: all teaching and learning activities in the sciences in which the student is actively involved and that allow the mobilization of science processes skills and scientific knowledge and that may be materialized by paper and pencil activities or observing and/or manipulating materials.

The level of complexity of practical work of teachers' practices was appreciated by its level of conceptual demand. In the context of the research that has been carried out within Bernstein's theory (1990, 2000), the concept of conceptual demand was introduced by Domingos (1989) and at that time the concept was related to the complexity of scientific skills. Further studies (Morais, Neves and Pires, 2004) considered the complexity of both scientific skills and knowledge to characterize the level of conceptual demand. This concept evolved to include three dimensions, the complexity of scientific knowledge and skills and also the strength of intra-disciplinary relations, that is the strength of boundaries between distinct knowledges within a given discipline (Calado, Neves and Morais, 2013). The inclusion of intra-disciplinary relations was related to the importance of this dimension to raise the level of scientific learning (Morais, Neves and Pires, 2004). This is the concept of conceptual demand that is used in this study. Conceptual demand of science education is defined as the level of complexity of science education as given by the complexity of scientific knowledge and of the strength of intra-disciplinary relations between distinct knowledges and also by the complexity of cognitive skills (Morais and Neves, 2015). It is important to note that a concept of conceptual demand was used in several international studies in the 1970's and 1980's, where it was associated with Piagetian development stages (Shayer and Adey, 1981). The present study departs from that notion to follow the perspective described above and in doing so goes deeper in the analysis.

The concept of osmosis was selected as an exemplary study to show how this framework may work when studying conceptual demand of practical work of teachers' practices, at the level of high school science education. The teaching of the process of water movement across the cell membrane called osmosis, at the level of high school science education, is fundamental to further understanding of other life processes, such as water intake by plants and osmoregulation. Although there are several research investigations that have explored students' misconceptions about osmosis (e.g. Odom and Barrow, 1995, 2007; Rundgren, Rundgren and Schonborn, 2010), science teachers' practices have been the subject of limited research. These studies have been mainly focused on teaching strategies that can help students to overcome some misconceptions (e.g. Friedrichsen and Pallant, 2007; Odom and Kelly, 2001). Practical work contains great potential for the teaching and learning of the concept of osmosis. The results of Tomazic and Vidic's study (2012) showed that the students, future science teachers, who reported to have conducted experiments about osmosis in high school achieved better test results on the diffusion and osmosis diagnostic test (DODT), developed by Odom and Barrow (1995).

The study is part of a broader investigation that explores questions related to the directions the Ministry of Education and Science (MES) gives to teachers for the transmission and evaluation contexts of practical work in the discipline of Biology and Geology (although epistemologically distinct, Biology and Geology have traditionally been part of a same discipline in Portugal) and to the recontextualizing processes followed by teachers, by studying their conceptions and practices (e.g. Ferreira and Morais, 2013, 2014). The present article is focused on the analysis of two high school teachers' practices, of two distinct schools, dedicated to practical work about osmosis. The study addresses the following research questions:

1. What is the type of practical work that is present in high school teachers' practices when they teach the concept of osmosis?

2. What is the level of conceptual demand of practical work in the case of the concept of osmosis?

3. What are the scientific inaccuracies that teachers can make in their practices when teaching the concept of osmosis?

Methods

This study made use of a mixed methodology that combines quantitative and qualitative approaches (Creswell and Clark, 2011; Morais and Neves, 2010). The study contains a theoretical framework that directed the construction of instruments for collecting data – a characteristic of quantitative approaches. Furthermore, empirical data were used for the definition of some indicators and descriptors of the instruments – a characteristic of qualitative approaches. In this way the analysis of teachers´ practices was made through a constant dialectics between the theoretical and the empirical where research models and instruments represented the external language of description and the theory represented the internal language of description (Bernstein, 2000).

Participants

Two science teachers and their Biology and Geology classes of 10th grade students of high school (ages 15 – 16) participated in the study. Each one of these teachers taught in one of two distinct public schools, located in distinct towns both of the West Coast region of Portugal. Using a convenience sampling (Cohen, Manion and Marrison, 2007), the teachers were selected within those that were available and accessible at the time of the study: Ruth of Darwin high school and Sara of Mendel high school.

The school context was one of the important characteristics that differentiate the two teachers' practices. Darwin high school ranked at the highest levels of the national rankings, with results always above the national average in three consecutive years (2009-2011). Few students of this school benefited from social support (e.g. 19% of the students were on free or reduced lunch). Mendel high school ranked at the lower levels of the national rankings with 41% of students receiving social support.

Ruth was an experienced teacher with 38 years of experience. She received an undergraduate degree in Biology with pedagogical training integrated in the 5th year of that degree. Her 10th grade Biology and Geology class was made up of 23 students, 17 girls and 6 boys, with an average age of 15,5 years. Sara was also an experienced teacher with 26 years of experience. She received an undergraduate degree in Geology and she did in-service education. Sara's 10th grade Biology and Geology class was made up of 23 students, 14 girls and 9 boys, with an average age of 15,8 years.

The classroom lessons of both schools related to the thematic unit 'Obtaining matter' of the Biology and Geology syllabus were observed and audio taped. Those lessons included the teaching of concepts such as osmosis, diffusion, facilitated diffusion, active transport, endocytosis, extracellular digestion and photosynthesis. The selection of this thematic unit was related to the fact that it provides conditions to carry out practical activities, namely laboratory activities with an investigative character, which was the focus of the broader investigation. From February 13 to April 17, 2012, the researcher observed 13 classroom lessons (22 hours) of teacher Ruth. From April 11 to June 6, 2012, the researcher observed 16 classroom lessons (27 hours) of teacher Sara. The present article is only centered in the analysis of the units related to the practical work about osmosis. That choice was related to the relevance of the thematic in high school science education and also to the observed teachers' scientific inaccuracies about a concept that evolved in the past two decades.

Dimensions of analysis

The level of conceptual demand of practical work in high school science teachers' practices was appreciated through the analysis of three dimensions related to *the what* and to *the how* of the pedagogic practice, as shown in Figure 1. The former corresponds to the level of complexity of both scientific knowledge and cognitive skills and the latter corresponds to the strength of intra-disciplinary relations between theory and practice. Levels of complexity, particularly the level of complexity of cognitive skills, may be related (although not necessarily) to the type of practical work implemented by the teacher, in a range from illustrative to investigative activities. In this study the following types of practical work were considered: laboratory activity, simulation, application of knowledge to new situations, bibliographical research, guided discussion activity and field trip. The scientific inaccuracies that teachers may make when implementing practical work may also influence its level of conceptual demand.

Instruments construction and application

In order to characterize the message underlying each one of the units of analysis related to the transmission context of practical work in Biology and Geology lessons, three instruments were constructed, piloted and applied. The instruments used for this characterization contained various indicators and, for each indicator, they contained empirical descriptors that correspond to the degrees of the scales constructed and to aspects that were possible to be observed in the classroom.

After constructing the first version of this set of three instruments, which was discussed with two other researchers familiarized with the theoretical framework, two preliminary studies were conducted in order to validate the instruments and to introduce adaptations. In a first moment, from January 13 to February 22, 2011, eight classroom lessons (14 hours) of a 10^{th} grade Biology and Geology teacher were observed. The transcription and analysis of those lessons allowed the introduction of some changes in the instruments, especially the inclusion of other indicators and the modification of some empirical descriptors, in a dialectical relation between the theoretical and the empirical. In a second moment, from March 18 to May 12, 2011, eleven classroom lessons (18 hours), of a different teacher, were also observed. This process permitted the clarification of some empirical descriptors. All the instruments changes were discussed with the two other researchers.

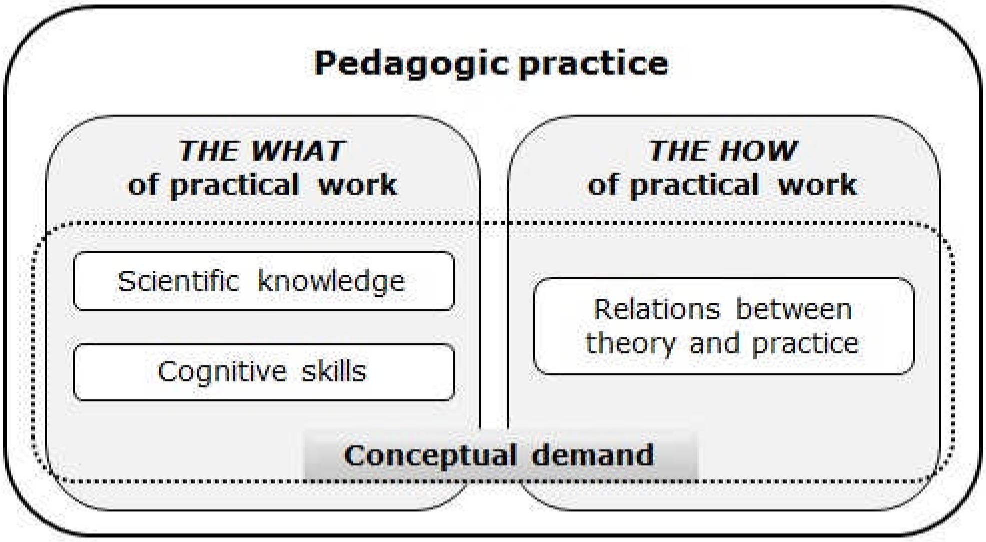

Figure 1.- Conceptual demand of practical work as given by three dimensions related to *the what* (skills and knowledges) and to *the how* (intra-disciplinary relations) of the pedagogic practice.

The instrument for the analysis of *the what,* with reference to the complexity of scientific knowledge, considered the distinction between facts, simple concepts, complex concepts and unifying themes/theories. A fact is "the data which results from observation" (Brandwein, Watson and Blackwood, 1958, p. 111) and corresponds to a very concrete situation resulting from several observations. The simple concepts correspond to concepts that have a low level of abstraction, defining attributes and examples that are observable. The complex concepts "are those that do not have perceptible instances or have relevant or defining attributes that are not perceptible" (Cantu and Herron, 1978, p.135). Unifying themes are structural ideas and correspond, in science, to generalizations about the world that are accepted by scholars in each subject area (Pella and Voelker, 1968). Table 1 presents an excerpt of this instrument, for the indicator "exploration/ discussion of practical work". The other indicators of the instrument were: request of practical work, students' questions in the exploration/ discussion of practical work, conclusion of practical work, and assessment activity of practical work.

The instrument to analyze the complexity of cognitive skills was based on the taxonomy created by Marzano and Kendall (2007) which considered four levels for the cognitive system. Retrieval, the first level, involves the activation and transfer of knowledge from permanent memory to working memory and it is either a matter of recognition or recall. "The process of comprehension within the cognitive system [second level] is responsible for translating knowledge into a form appropriate for storage in permanent memory" (2007, p.40). The third level, analysis, involves the production of new information that the individual can elaborate on the basis of the knowledge s/he has comprehended. The fourth and more complex level of the cognitive system implies the knowledge utilization in concrete situations. Table 2 presents an excerpt of this instrument, for the indicator "exploration/ discussion of practical work".

Degree 1	**Degree 2**	**Degree 3**	**Degree 4**
Scientific knowledge of low level of complexity, as facts, is referred.	Scientific knowledge of level of complexity greater than degree 1, as simple concepts, is referred.	Scientific knowledge of level of complexity greater than degree 2, as complex concepts, is referred.	Scientific knowledge of very high level of complexity, as unifying themes and theories, is referred.

Table 1.- Excerpt of the instrument to characterize the complexity of scientific knowledge (Source: Ferreira, 2014).

Degree 1	**Degree 2**	**Degree 3**	**Degree 4**
Cognitive skills of low level of complexity, involving cognitive processes of retrieval, are mobilized.	Cognitive skills of level of complexity greater than degree 1, involving cognitive processes of comprehension, are mobilized.	Cognitive skills of level of complexity greater than degree 2, involving cognitive processes of analysis, are mobilized.	Cognitive skills of very high level of complexity, involving cognitive processes of knowledge utilization, are mobilized.

Table 2.- Excerpt of the instrument to characterize the complexity of cognitive skills (Source: Ferreira, 2014).

The instrument for the analysis of *the how* at the level of relations between theory and practice, considered the distinction between declarative knowledge and procedural knowledge. Declarative knowledge, also referred as substantive knowledge, corresponds to the terms, facts, concepts and theories of a given subject matter (Marzano and Kendall, 2007; Roberts, Gott and Glaesser, 2010). Procedural knowledge refers not only to the knowledge of how to do something, of techniques and specific methods of a discipline, but also to the knowledge of scientific processes (Roberts, Gott and Glaesser, 2010). This instrument contained a four degree scale and the empirical definition of that scale was based on Bernstein's concept of classification (1990, 2000), to indicate the strength of boundaries between various types of knowledge. Degree 4, related to the weakest classification (C^{--}), corresponds to an integration of theory and practice, where both have equal status, and degree 1, related to the highest classification (C^{++}), corresponds to a separation between theory and practice. Table 3 presents an excerpt of this instrument, for the indicator "exploration/ discussion of practical work".

Degree 1 (C^{++})	Degree 2 (C^{+})	Degree 3 (C^{-})	Degree 4 (C^{--})
The teacher focuses on procedural knowledge to be mobilized in practical work, and does not refer declarative knowledge explored and/or to be explored.	The teacher focuses on procedural knowledge and on declarative knowledge, but does not make the relation between them.	The teacher focuses on the relation between procedural and declarative knowledge, being given higher status to declarative knowledge in the relation.	The teacher focuses on the relation between procedural and declarative knowledge, being given equal status to these two types of knowledge in the relation.

Table 3.- Excerpt of the instrument to characterize the relation between theory (declarative knowledge) and practice (procedural knowledge) (Source: Ferreira, 2014).

To characterize the two science teachers´ practices, all the observed lessons were transcribed in full and the text was segmented into units of analysis. A unit of analysis was considered as an excerpt of the lesson transcription, regardless of its length, containing a situation with a specific semantic meaning (Gall, Gall & Borg, 2007). Each unit of analysis was separately classified in the three dimensions considered by the main researcher of the study. To estimate the reliability and validity of the analysis and of the method used, a 15% random sample of units of analysis of the several lessons was analyzed independently by two other researchers. A preliminary discrepancy of 3,6% in relation to the initial analysis was found. The three researchers discussed both differences encountered in the classification of units of analysis and all the analyses were revised. Finally, in a later moment, the three researchers agreed with the classification of the units of analysis.

In order to clarify how the same unit of analysis was classified in the study in terms of the dimensions related to *the what* and *the how* of practical work, an illustrative example of the analysis that was made is presented (excerpt 1, Table 4). This example highlights the interpretative content analysis carried out when doing the teachers' practices analysis. In this excerpt, the teacher is discussing with the class the results of the microscopic representations of osmosis at geranium petal cells. With regard to *the what* of practical work, the discussion appeals to simple concepts, related to concentration gradient and hypotonic solution (degree 2), and to cognitive skills involving the cognitive process of comprehension (degree 2), since it implicates the interpretation of data (degree 2). With regard to *the how* of practical work, this unit of analysis involves a relation between declarative and procedural knowledge, but the focus is on declarative knowledge (degree 3/C^{-}).

Results

In the case of Ruth, two lessons (one of 135 minutes and another of 90 minutes), from the 13 lessons observed, were dedicated to practical work about osmosis. Also in the case of Sara, two lessons (135 minutes each), from the 16 lessons observed, were dedicated to the same practical work.

Both teachers developed the theoretical approach of this process in three further lessons moments.

Excerpt 1	Analysis
Teacher Ruth - […] Let's explain the differences found in the two preparations [microscopic representations of osmosis at geranium petals]. In the preparations B and C… B is a preparation in which the… Student - Distilled water. Teacher - Exactly, with distilled water. How can we explain the situation that occurred? What happened? We already know that the vacuole…? Student - Increased. Teacher - Increased its size. Why? Tiago? Tiago - Well, because it's in a hypotonic solution. Teacher - Yes. Tiago - More water entered into the vacuole. Teacher - And water entered into the vacuole. Tiago - Yes. Teacher - Now, with regard to the questions you have got in your book, one of the questions has to do with the tonality of the vacuole. How has the vacuole tonality become? Tiago - Clearer. Student - A little clearer. Teacher - Clearer. Why? Tiago, why did it became clearer? The pigments became…? More…? Tiago - Dispersed. Teacher - More dispersed. […] The vacuole increases volume, the nucleus and the cytoplasm are compressed against the cellular wall and it takes on a clearer tonality. […] (Lesson 4, UA14, indicator "exploration/ discussion of practical work").	Complexity of scientific knowledge: Degree 2 Complexity of cognitive skills: Degree 2 Relation between theory and practice: C^-

Table 4.- Illustrative example of the teachers' practices analysis.

The practical work on the concept of osmosis was present in both high school teachers' practices through the laboratory activity of observation and interpretation of the movement of water across cell membranes of geranium petals (*Pelargonium* sp*.*). It should be noted that the epidermal cells of that petals present a cell wall thickening that may distract students' attention of the purpose of the laboratorial activity. The pigmented epidermal layer of a red onion was a better option to microscopic representations of osmosis at a cellular level (Lankford and Friedrichsen, 2012). In the observed classes, students constituted small groups of two to four to carry out and interpret this activity, either following the procedure given by Ruth or the one presented in the textbook, in the case of Sara. Ruth carried out further practical works, all of them laboratory, namely the construction of osmometers by using carrots and decalcified chicken eggs. Ruth also led their students to observe lettuce leaves when placed in solutions of varying salt concentration.

Conceptual demand of practical work

The graph of Figure 2 shows, for each teacher, the level of conceptual demand of practical work about osmosis. The relative frequencies presented were determined by considering the analysis of all the units related to the transmission context of practical work about osmosis.

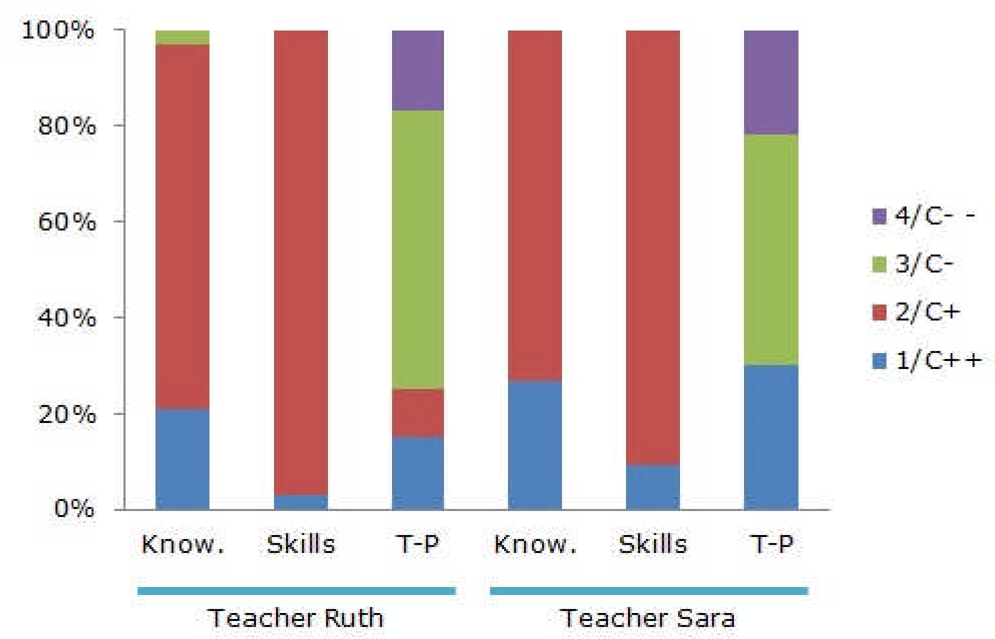

Figure 2.- Relative frequencies of units of analysis to each dimension of conceptual demand of practical work about osmosis in two high school teachers' practices (Know.: scientific knowledge, degrees 1 to 4; Skills: cognitive skills, degrees 1 to 4; T-P: relation between theory and practice, degrees C^{++} to C^{--}.).

The data of Figure 2 shows that the practical work about osmosis, for both teachers' practices, was centered on scientific knowledge of degree 2. These simple concepts referred specifically to the concepts of plasmolysis, turgidity, concentration gradient, hypotonic, isotonic and hypertonic solutions. In the case of Ruth, the practical work included also complex concepts (degree 3), when the concept of osmotic pressure was discussed in the interpretation of the results of the activity with decalcified chicken eggs. Unifying themes were absent in practical activities of both teachers' practices, as would be expected for lessons which were limited to the study of osmosis. The level of complexity of scientific knowledge could however have been higher had the teachers focused their practical work in other complex concepts, such as the selective permeability of the lipid bilayer. The excerpts 2, 3 and 4 illustrate some of these situations in the teachers' practices (Table 5). In the case of excerpt 2, the teacher mobilizes the terms of cell and vacuole, which, for 10th grade students, can be considered as scientific knowledge of low level of complexity. In the case of excerpt 3, the teacher discusses the simple concept of concentration gradient and in the case of excerpt 4 the teacher explores the complex concept of osmotic pressure.

With regard to the complexity of cognitive skills, the data of Figure 2 shows that practical work about osmosis mobilized cognitive skills essentially involving the cognitive process of comprehension (degree 2). In both teachers' practices, science process skills were centered on the identification of variables, observation, schematization and interpretation of simple data. It was clear that the two teachers wanted their students to learn how to formulate scientific problems and hypotheses, something that would increase the complexity of cognitive skills. However they were unable to do it. The excerpt 5 from Sara's practice illustrates this situation (Table 6).

Excerpt 2
Teacher Ruth - […] Guys, have you already started to make the drawing [sketch of the microscopic observation]? […] Now just make a cell. […later on, after some classroom interactions.] And there you have a cell. Do observe the vacuole. (Lesson 3, UA14, indicator "exploration/ discussion of practical work", Degree 1)
Excerpt 3
Teacher Sara - […] What is the way in which this movement of water occurs? Always from the places where it is more concentrated to where it is less concentrated. When you put that little fragment of epidermis [from geranium petals] into salt water, where was it that there was a higher concentration of water […]? Inside the cells or in the water? […]. (Lesson 3, UA13, indicator "exploration/ discussion of practical work", Degree 2)
Excerpt 4
Teacher Ruth - […] Imagine that I had inside here a little plunger and it was there, it made some pressure down [in the egg osmometer]. It would enter, isn't it, into there again. Ok, that force that I had to make in order that this liquid did not go up is the osmotic pressure. That´s why it is called an osmometer. [… later on, after some classroom interactions.] That pressure is evident over there [in the egg osmometer]. How is it evident? Through the amount of water that came up. Or of the content of the egg that came up. (Lesson 4, UA12, indicator "students' questions in the exploration/ discussion of practical work", Degree 3)

Table 5.- Excerpts from teachers' practices with regard to the complexity of scientific knowledge of practical work about osmosis.

Excerpt 5
Teacher Sara - […] The objective is to observe the osmotic movements. To observe osmotic movements, that is the problem. Ok? Pay attention. You can see a question in the experimental procedure of your textbook, that question is the problem [In what direction does the flow of water occur in the cell membrane?]. The objective is to observe the osmotic movements, that is, the movements of water in plant tissues.[…] (Lesson 3, UA18, indicator "students' questions in the exploration/ discussion of practical work")

Table 6.- Excerpt from teacher' practice with regard to the complexity of cognitive skills of practical work about osmosis.

With regard to the relation between theory and practice (Figure 2), the results show that the relation between theory and practice (degrees $3/C^{-}$ and $4/C^{- -}$) prevailed in the practical work about osmosis. The valuing of that relation was higher in the case of Ruth's practice (a total of 75% of units of analysis were classified with those two degrees). Most units of analysis of both teachers' practices were classified with C^{-}, i.e. the units reflect a relation between the two types of knowledge with a focus on declarative knowledge. These results depart from the results obtained by Abrahams and Millar's study (2008) which point out to the existence of a separation between theory and practice when teachers implement practical activities, particularly laboratory work. The excerpts 6, 7 e 8 illustrate some situations of Sara's and Ruth's practices (Table 7). In excerpt 6, the exploration of the lettuce leaves practical work was only centered on procedural knowledge, related to the identification of variables. In excerpt 7, the discussion of the results of the microscopic representations of osmosis at the cellular level involved a relation between procedural and declarative knowledge, but the scientific concepts had higher status. In excerpt 8, the discussion of the results of the lettuce leaves practical work was centered in procedural knowledge about the identification of variables and that knowledge was related with declarative knowledge about isotonic and hypotonic solutions, being given equal status to these types of knowledges.

According to the results of the study, both teachers' practices evidence a low level of conceptual demand of practical work on the concept of osmosis with regard to both dimensions related to *the what* – complexity of scientific knowledge and complexity of cognitive skills. With regard to the dimension related to *the how* – relation between theory and practice – the level of conceptual demand was higher in the cases of both teachers. Although the level of conceptual demand was slightly higher in Ruth's practice, for the three dimensions analyzed, differences between the two teachers' practices were not in general very marked.

Teachers' scientific inaccuracies

However, there was an important factor that made the level of conceptual demand of practical work on the concept of osmosis to decrease even further down. This factor was given by the scientific inaccuracies (in fact errors) about the concept of osmosis, made by both teachers in their practices. These inaccuracies were identified through the content analysis of the field notes and the lessons transcripts focused on that concept. The scientific inaccuracies of both teachers were centered on four inaccurate conceptions about osmosis: (A) osmosis is only a particular case of simple diffusion; (B) the phospholipid bilayer of the cell membrane is impermeable to water molecules; (C) the phospholipid bilayer of the cell membrane is permeable to ions and polar molecules; and (D) the process of osmosis ends after the cell is dead. Each of these four inaccurate conceptions will be discussed below.

(A) Although the movement of water across the cell membrane occurs directly through the lipid bilayer (simple diffusion), in many cells the major proportion of osmosis is greatly facilitated by channel proteins known as aquaporins (Agre, 2004; Agre et al., 1993). Peter Agre was awarded the Nobel Prize in Chemistry in 2003 for his discovery of those water channels. In several moments of all lessons that focused the process of osmosis, Ruth mentioned that osmosis is only an example of simple diffusion or non-mediated transport. In the case of Sara, other inaccuracies occurred. Sara began by noting correctly the existence of aquaporins as water channel proteins (this comes as a note in the teacher's textbook) but she never mentioned those proteins again. In the following lesson, Sara referred that osmosis was a particular case of simple diffusion, contradicting what she had said earlier.

Excerpt 6
Teacher Ruth - […] So let's… I am asking Paula to help me, we are going to fill in here… we are going to fill in a little bit of this beaker, here halfway, with tap water which is what we usually use, isn't it? Let´s go. We will make two variants, here is beaker A and we will make two things to vary. Here we have distilled water. Well, Maria, come here and put distilled water inside beaker B, c´mon… About the same amount, that's enough, enough. Ok. Place the A over there… It [the water] must be the same amount, you see, things should not vary. How do you see it? Go on, write A. And now we are going to place water, tap water with…? Lisa - Salt. Teacher - With salt. Come to put it, Lisa. But it should be very salty. You can abuse the salt, c´mon. […] This will be beaker C. Now Joana, who brought our lettuce, takes three leaves off, of more or less the same size. Well, try that they are the same size. This is C, isn´t it? […] (Lesson 3, UA4, indicator "exploration/ discussion of practical work", Degree 1/C^{++})
Excerpt 7
Teacher Sara - […] And that basically meant that when you introduced a vegetal tissue inside distilled water, which was a hypotonic solution, you observed an osmotic movement of… of what? Water enters or leaves the cell? Student - Enters. Teacher - Enters. Did it respected the principle of water diffusion? Students - Yes. Teacher - Why was it respected? Are you all paying attention? Student - There was more water outside the cell than inside. Teacher - And so the water… Student - Passed from the outside [environment] to the inside. Teacher - Ok? Now, with regard to the other situation, when the tissue was placed in salt water… […] (Lesson 4, UA14, indicator "exploration/ discussion of practical work", Degree 3/C^{-})
Excerpt 8
Rita - Beaker A is for comparison, isn´t it? So it is in an isotonic solution. If the teacher asks… Teacher Ruth - It may be… It is a term of comparison, so…? Rita - So it is in an isotonic solution. Teacher - It is the control. Rita - Which means…? Teacher - It is the control! At the start, it may not be isotonic. Rita - (it should be). Teacher - […] What we made was a comparison with that concentration. I can't say [it's isotonic], because I don't know the chemical composition of that [tap] water. For example, in terms of the percentage of sodium chloride, which amount is there? I have no idea. So, we started from there because that's what we usually do at home. So let's compare with that [tap water solution]. Sure, when we put distilled water, automatically we know that this… What type of solution is it? Diana? The solution where is the… the distilled water in relation to the cells of the lettuce tissue… It is hypotonic. […] (Lesson 4, UA6, indicator "students' questions in the exploration/ discussion of practical work", Degree 4/C^{--})

Table 7.- Excerpts from teachers' practices with regard to the relation between theory and practice of practical work about osmosis.

This scientific inaccuracy made by teachers Ruth and Sara in their practices can lead to students' misconceptions, as those that have emerged in the study made by Rundgren and co-workers (2010). The excerpt 9 exemplifies this scientific inaccuracy in teacher Ruth's practice (Table 8).

(B) Water molecules are polar. This makes it energetically unfavorable for water molecules to pass the hydrophobic core of the phospholipid bilayer. However the cell membrane is not totally impermeable to water molecules and, in certain cells, the movement of water occurs only directly through the cell membrane, but does not cross it very rapidly (Campbell and Reece, 2008). Despite the fact that Ruth and Sara had considered that the movement of water only occurs by simple diffusion, without proteins mediation, they also considered that cell membrane is impermeable to water molecules. This scientific inaccuracy occurred in one moment of one lesson of each one of the teachers. The excerpt 10 exemplifies this scientific inaccuracy in the case of teacher Sara's practice (Table 8), an inaccuracy that occurred at the same moment in which Sara mentioned the presence of aquaporins in the cell membrane.

Excerpt 9
Teacher Ruth - […] In conclusion, what is osmosis? It is the passage of water […] from the hypotonic solution to the hypertonic solution, it is a transport non… Does it need the help from anyone? No. It [the water] goes by itself. It needs nothing. […] (Lesson 2, UA13).
Excerpt 10
Teacher Sara- […] In those aquaporins […] they are open and just let pass what? Water! Ok? These [proteins] act as channels. Can you understand? They do not change their configuration. This is how they are in order that the water passes easily through, what? The membrane. But doesn't the water cross the membrane easily? Student - No, the water is not soluble. Teacher - That's right, the water is not soluble in fat, isn't it? Thus there must exist preferential sites for the passage of water, ok? […] (Lesson 2, UA7).
Excerpt 11
Student - Because we had a hypertonic solution and a hypotonic solution, then there would be a balance between the number of salts [sodium and calcium ions], that was higher in one [solution] and lower in the other, and the same would happen with water. Teacher Sara - But what have we been studying? We have not been here studying the simple diffusion or the facilitated diffusion. The objective of our work was basically the study of…? Student - Osmosis. Teacher - The movement of water, isn't it? […] because if we are asked about osmosis, we have to refer to water, if ionic variations are mentioned, then we have to talk of salts. Understood? We know that they are associated and that for that reason we run this risk of mixing things up, isn't it? […] (Lesson 4, UA12).
Excerpt 12
Student - But they poor little things look so dead. Teacher Ruth - They [the cells] are not at all dead. If you put in some distilled water, you would see. [The teacher observes the preparation at microscope.] You choose one that has got just one… contracted vacuole. […] (Lesson 3, UA22).

Table 8.- Excerpts from teachers' practices with regard to the scientific inaccuracies about the concept of osmosis.

(C) The lipid bilayer of the cell membrane is semipermeable and functions as a selective barrier against large molecules and ions or polar molecules, delaying or impeding its passage (Campbell and Reece, 2008; Lodish et al., 2008). In two moments of the theoretical approach, Ruth did know how to explain this scientific knowledge and referred that in the cell membranes there is the movement of water and solute. At several moments of the lessons of practical work about osmosis, Sara mentioned that the cell membrane is semipermeable but she could not explain why and she also indicated that the sodium and calcium ions could diffuse across the membrane down its concentration gradient. This is also a common incorrect students' idea (ions, because of their small size, can diffuse through cell membrane), as evidenced in the study made by Shi and co-workers (2010). The excerpt 11 exemplifies this scientific inaccuracy in teacher Sara's practice (Table 8). Sara considers that the movement of sodium and calcium ions across the geranium petal cells it was possible but she does not discuss that in the class, since the focus of practical work was the movement of water.

(D) The process of osmosis would continue after the cell was dead. This scientific knowledge was not present in the lessons of the participant teachers. On the contrary, in three moments of practical work about osmosis of Ruth's practice and in two moments of Sara's practice it was transmitted to students that the movement of water would stop after a cell was dead. This scientific inaccuracy has also been a students' misconception, evaluated through their answers to item 11 in DODT test – in this item a plant cell was killed with poison and placed in a 25% saltwater, followed by the question of whether or not diffusion and osmosis would continue (Odom and Barrow, 1995, 2007; Tomazic and Vidic, 2012). The excerpt 12 illustrates this scientific inaccuracy in Ruth's practice (Table 8), since she assumed that only cells that are not dead will react to changes in water concentrations of extracellular environment.

Discussion

The article intended to show a multidisciplinary approach for analyzing the level of complexity of practical work of teachers' practices by studying its level of conceptual demand. Although the analysis was focused on two Portuguese high school science teachers' practices about osmosis, the instruments constructed and the concepts involved can be used to appreciate the level of conceptual demand of practical work about other subjects and also of other international science teachers' practices. By using the same instruments it is possible to make comparisons between them. It should be noted that the conceptualization and procedures followed in the study gives greater rigor to the analysis.

The results of the study showed that practical work on the concept of osmosis has in general a low level of conceptual demand in the practices of the two participant teachers. This result is mostly a consequence of low complexity of scientific knowledge and skills and also of teachers' scientific inaccuracies. The absence of scientific knowledge of very high level of complexity puts at stake the understanding of the hierarchical structure of scientific knowledge (Bernstein, 1999) by students. If science education is to reflect the structure of scientific knowledge it should lead to the understanding of concepts and big ideas, although that understanding requires a balance between knowledge of distinct levels of complexity (Morais and Neves, 2015). On the other hand, practical work should not be limited to simple skills, involving cognitive processes of retrieval and comprehension, but should also mobilize complex skills, involving cognitive processes of analysis and knowledge utilization as for example formulation of hypothesis and planning an investigative lab activity. The development of complex skills, which is important by itself, is crucial for the learning of complex scientific knowledge. The type of practical work selected by teachers also contributed to lower the level of conceptual demand. The laboratory activities were mostly illustrative and the students did not have the opportunity to carry out activities with a real investigative character. The relation encountered between declarative and procedural knowledge, with a focus on declarative knowledge, which is unusual in other studies found in the literature, was the only characteristic that raised somehow the level of conceptual demand of the practical lessons observed. The authors consider that this is the situation that best represents an efficient scientific learning, i.e. learning that is supported by the understanding and applying of science processes knowledge. Differences in the two teachers' practices may be related to the social context of the school. Previous research (e.g. Domingos, 1989) has shown that social disadvantaged schools influence teachers' practices in the direction of lowering their level of conceptual demand.

The study shows that experienced teachers may commit scientific inaccuracies in their practices that can compromise the understanding of the concept of osmosis and lead to students' misconceptions about this subject matter, also identified in several studies (e.g. Odom and Barrow, 1995, 2007; Rundgren et al*.,* 2010). Some of these inaccuracies, specifically those related to the presence of aquaporins in the cell membrane, seem to indicate that the participant teachers have not been making the effort of updating their scientific knowledge from the time they received their undergraduate degree. This is compounded by the fact that textbooks, that might help teachers in the updating of their knowledge, are in fact not doing it. An informal analysis of the two most widely-used Biology textbooks at the 10^{th} grade level in Portugal revealed the absence of any explanation of water channel proteins (one of them gives only a short explanatory note to the teacher). On the other hand, the lack of a sound understanding of scientific concepts by the teacher may by itself lower the level of conceptual demand, as the teacher will tend to focus on lower level concepts and skills.

The conclusions of this study should not go in the direction of generalizing from practical work about osmosis conducted by two teachers only, but instead should raise questions related to teacher education and to conceptual demand of practical work. The exemplary study described showed the potentialities of the framework that was developed for studying conceptual demand of practical work of teachers' practices.

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