

The Teaching and Learning of Diffusion and Osmosis: What Can We Learn from Analysis of Classroom Practices? A Case Study

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The objective of this study is to describe the way in which two important biological phenomena, namely diffusion and osmosis, are addressed in the classroom. The study builds on extensive research conducted over the past twenty years showing that students' appropriation of these two phenomena remains partial and incomplete. To understand some of the difficulties these students face in understanding such concepts, we have geared our research toward analysis of classroom practices based on a theoretical framework involving general and specific dimensions of teaching science. Using a case study (a course made up of eight periods), we collected data in three stages: interviews with the teacher regarding his planning; a video recording of the entire course; and feedback interviews with the teacher subsequent to the course. The study's results show that the difficulties encountered by the students cannot be attributed solely to their personal characteristics (state of development of the scientific mindset, prior learning, etc.). Instead, they appear to be largely associated with teaching practices and the potential these practices hold in terms of allowing students to appropriate these concepts. The results presented in this article are significant in their contribution to improving teaching methods for diffusion and osmosis, and thus to facilitating their understanding by students. The paper also presents an example of a conceptual and methodological framework for the study of classroom practices with a view to addressing the gap between educational research and classroom practice.

Keywords: diffusion; osmosis; classroom practices; conceptual knowledge; scientific investigation.

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INTRODUCTION

Students' understanding of the phenomena of diffusion and osmosis is a prerequisite for their understanding of certain fundamental biological functions. For example, they allow students to understand exchanges that the cells maintain with their surrounding environment: a) how certain simple molecules are able to enter or exit cells (diffusion), b) how concentrations on either side of a cell membrane determine the movement of water (osmosis) and the resulting state of turgidity of cells. Also, these phenomena help students to understand how maintaining different concentrations on either side of the membrane allows certain cells to perform their functions, as in the case of water absorption by root cells in plants and the case of nerve impulse transmission in neurons (Lodish, Berck, Matsudaira, Kaiser, Krieger, & Scott, 2005).

Many studies in the last few decades have taken an interest in the teaching and learning of the concepts of diffusion and osmosis. Some have made it possible to describe students' conceptions of these biological phenomena, while others have focused on the teaching strategies likely to promote changes in these conceptions.

When it comes to studying student conceptions, the research we have analyzed shows that at several grade levels, students have inadequate conceptions¹ or major difficulties in understanding these phenomena. Marek (1986), for example, administered concept evaluation statements to 10th grade biology students, and found that only 1,8% of them demonstrated an understanding of diffusion while 62,5% had no answer or exhibited misunderstandings about diffusion (Cook, Carter, & Wiebe, 2008, p. 244). A study conducted by Friedler, Amir, & Tamir (1987) shows that secondary school students struggle to understand a number of concepts associated with diffusion and osmosis, such as the relationship between dynamic equilibrium (with different concentrations on each side of a membrane), the role of osmosis in plant cells, and the relationship between the quantity of solvent and solute, on one hand, and concentration, on the other. Zuckerman (1993) likewise identifies eight osmosis-related misconceptions among high school science students.

In one study, Odom (1995) administered the DODT (Diffusion and Osmosis Diagnostic Test) to 116 secondary biology students, 123 college non-biology majors,

State of the literature

- During the last 20 years, several studies have shown that students have inadequate conceptions on diffusion and osmosis or that appropriation of these two phenomena remains partial and incomplete.
- Some studies have presented and analyzed the effects of constructivist teaching methods (scientific investigation, small discussion/laboratory approach, concept mapping and the use of computing tools) in teaching diffusion and osmosis. Results showed that students learned diffusion and osmosis concepts better with these methods than students in a more traditional biology course.
- In the literature, few researches have described authentic classroom practices that facilitate the understanding of diffusion and osmosis concepts by students or practices that are sources of difficulty.

Contribution of this paper to the literature

- This article presents a conceptual framework for the analysis of classroom practices. This conceptual framework puts in relation four main dimensions: What to teach (scientific content), Why (reasons for choosing this content), How to teach (pedagogy), and With what (resources or curriculum material).
- We also propose a methodological framework with two levels of analysis: 1) A macro analysis that describes some of the dimensions that characterize the course and, 2) A micro analysis that focuses specifically on the students' and teachers' discourse and tasks (technical and epistemic tasks).
- The study's results show that some practices should be encouraged because they can facilitate the understanding of diffusion and osmosis.

¹ In this article, the expression "inadequate conceptions" refers to student ideas that differ from those generally accepted by the scientific community. Depending on the author, these are also designated as "misconceptions" (Fisher, 1985; Odom, 1995), "alternative conceptions" (Astolfi, 2009), "preconceptions" (Gallegos, Jerezano, & Flores, 1994), "naive thinking" (Inagaki & Hatano, 2002), etc.

and 117 biology majors. "This study provides evidence that even following instruction, secondary biology students as well as non-biology and biology majors continue to have misconceptions about diffusion and osmosis" (p. 412). "Misconceptions were detected in five of the seven conceptual areas measured by the test: the particulate and random nature of matter, concentration and tonicity, the influences of life forces on diffusion and osmosis, the process of diffusion, and the process of osmosis" (p. 411). To interpret the results obtained in the study, the author points to the fact that teaching focuses not on understanding the concepts of diffusion and osmosis, but rather on acquiring facts.

Generally speaking, the cited studies and others (Friedler et al., 1985, 1987; Market, Cowan, & Cavallo, 1994; Kelly & Odom, 1997; Marek, 1986; Market, Cowan, & Cavallo, 1994; Odom & Kelly, 2001; Odom, 1995; Odom & Barrow, 1995; Odom & Settlage, 1994; Rundgren & Tibell, 2010; Simson & Marek, 1988; Westbrook & Marek, 1991; Zukerman, 1993, 1994) highlight numerous inadequate conceptions that are common among students:

- During diffusion, molecules (of dye, for example) stop moving once a balance of concentration is reached. The same is true for two media with different concentrations until isotonicity is reached;
- Diffusion is associated with solute molecules' inclination to occupy space (anthropomorphic vision);
- It is the quantity of water on each side of the membrane and not the concentration that is responsible for osmosis;
- Water moves to equalize the concentrations on each side of the membrane (anthropomorphic vision);
- Hydrostatic pressure must be equal on each side of the membrane once equilibrium is reached;
- The quantity of water must be equal on each side of the membrane at equilibrium;
- Water cannot cross over in the direction opposite to the pressure gradient;
- The structure of the lipid bilayer membrane, its fluidity, as well as its role in the phenomena of diffusion and osmosis, are likewise poorly understood.

Such studies also show that these inadequate conceptions can be linked to difficulties in other science-related learning. For example, a study by Zuckerman (1993) reported that misconceptions about osmosis blocked problem solving of other questions related to osmosis. The Cooke et al. study (2008) used the DODT (Odom & Barrow, 1995) among high school students to examine how their prior knowledge of a domain influenced how they viewed and interpreted visual representations of cellular transport processes. The results led to the conclusion that students who have a strong level of understanding of cellular transport phenomena (including membrane transport) interpret diagrams representing this phenomenon better than students with low prior knowledge.

Other studies have presented and analyzed the effects of certain teaching methods on changes in student conceptions (Christianson & Fisher, 1999; Concannon & Brown, 2008; Lawson, 2000; Market et al., 1994; Hohenshell & Hand, 2006; Matoussi & Simonneaux, 2007; Odom & Kelly, 2001; Rundgren & Tibell, 2010; Sanger, Brecheisen, & Hynek, 2001; Tekkaya, 2003). In one of their studies, Market et al. (1994) address the question of how students' diffusion-related misconceptions can be eliminated. Considering understanding of diffusion as a dependent variable, they applied two contrastive teaching methods to two separate but similar groups of high school students: one class participated in an experiment on diffusion (class A); the other class (B) learned through expository method (lecture and discussion). Pre-tests and post-tests conducted using the Concept Evaluation Statement (CES) showed that initially (pre-tests), 100% of the students in each class demonstrated

misunderstanding of the concept of diffusion. Answers on post-tests for Class A revealed that approximately 94% of the students demonstrated an understanding of diffusion following their experience with the learning cycle; in Class B (expository method) only 58% of the students demonstrated an understanding of diffusion.

Christianson & Fisher (1999) report that college students in a “constructivist” course learned significantly more diffusion and osmosis concepts than students in a more traditional biology course. Other research points in the same direction and tends to show the importance of using constructivist methods in teaching these two concepts. This is the case for a study by Christianson & Fisher (1999) in three universities: Instructors at two of the universities taught utilizing the very common large lecture/small laboratory approach. The instructor at the third university taught using a small discussion/laboratory approach that was informed by constructivist theory. Results of pre- and post-testing using the DODT (Odom & Barrow, 1995) indicate that students learned about and understood diffusion and osmosis most deeply in the small discussion/laboratory course.

Odom & Kelly (2001), for their part, investigated the effectiveness of concept mapping (CM), learning cycle (LC), expository, and a combination of concept mapping/learning cycle (CM/LC) instructional strategies on enhancing achievement in diffusion and osmosis content. The results seem to suggest that both the CM/LC and CM strategies enhance learning of diffusion and osmosis concepts more effectively than expository teaching. However, the two treatments (CM and CM/LC) were not significantly different from the LC treatment.

Some studies in this area have looked at the role of computing tools in the learning of diffusion and osmosis. For example, Sanger, Brecheisen, & Hynek (2001) have shown that, after being exposed to computerized animations, fewer students thought that molecules stop moving once equilibrium is reached. The authors nevertheless underline that animation in some cases might reinforce certain inadequate conceptions in students. A study by Matoussi & Simonneaux (2007) similarly notes that, in spite of the interest of using a CD-ROM on the “animal cell” to study cellular exchanges, this approach has produced numerous difficulties for students. Lewalter (2003), while maintaining the importance of animations in spatially visualizing diffusion and osmosis, notes that in a number of cases, images alone could be sufficient. A study by Rundgren & Tibell (2010) shows that using animation programs helps students to better appropriate knowledge related to, among other things, membrane structure and selectivity, as well as the behavior of molecules in membrane exchanges.

Finally, other authors, without necessarily studying their effect on classroom results, suggest other teaching methods based on scientific investigation (Concannon & Brown, 2008; Lawson, 2000) or on techniques that are conducive to conceptual changes, such as the use of concept maps (Tekkaya, 2003).

All of the studies cited, conducted over more than twenty years, underscore the presence of numerous student conceptions that are inadequate and resistant to the concepts of diffusion and osmosis. They also suggest the need to implement teaching methods that promote student engagement in appropriating these concepts. Furthermore, these studies are a reminder that the quality of students’ learning depends on the quality of teaching in the classroom. As early as 2003, Tekkaya regretfully observed the lack of studies devoted to classroom teaching methods aimed at changing student conceptions: “Although the need to identify students’ misconceptions concerning diffusion and osmosis concepts has been widely expressed in science education literature, there are few studies on how these misconceptions can be treated” (p. 6). For our part, we would like to make a contribution to the literature on the teaching and learning of diffusion and osmosis by considering another and scarcely explored question: How are the phenomena of diffusion and osmosis approached in classroom authentic teaching practices? This

description seeks to understand the opportunities offered to students so that they learn these two biological phenomena. It will also afford a way to understand the origins of certain conceptions and difficulties associated with specific teaching methods (classroom practices). As such, it will contribute to addressing the gap between educational research and classroom practices. The importance of this issue is emphasized by many recent studies (e.g.: Hand, Yore, Jagger, & Prain, 2010; McIntyre, 2005).

CONCEPTUAL FRAMEWORK

Our research question led us to use a conceptual framework that is based on two concepts: the teaching and learning of diffusion and osmosis, on one hand; and teaching practices, on the other.

Teaching and learning of diffusion and osmosis

In the context of current reforms-oriented science that values the idea of “science as process,” the description of approaches to science teaching must encompass both content (“*what is taught*”) and pedagogy (“*how it is taught*”) (Barko, 2006; Hasni, 2011; Hasni & Bousadra, 2015).

Regarding the content (*what to teach*), as we discussed in the introduction, conceptual knowledge involves, for example, identifying the main ideas associated with the concepts of diffusion and osmosis in a given class; the relationship between diffusion and molecules’ random motion; the relationship between concentrations on each side of the membrane and osmosis; etc.

However, the teaching of diffusion and osmosis should not be limited to acquiring decontextualized and unrelated facts (Market et al., 1994; Odom, 1995), or learning these concepts for their own sake. Instead, it should strive for students’ acquisition of the broad ideas that characterize the field of biology. Two of these ideas are worth mentioning here:

- 1) Associating diffusion and osmosis with transport through the cell membrane and with cellular exchanges, while also clarifying the role of the cytoplasmic membrane. Because of the selectivity of exchanges it enables, the membrane plays an important role in maintaining a cell’s internal equilibrium and, consequently, its survival. Selective permeability allows certain crucial molecules (glucose, amino acids, etc.) to penetrate into the cell, intermediate metabolites to be retained, and metabolic waste to be evacuated (Lodish et al., 2005).
- 2) Understanding the resulting dynamic equilibrium that is needed for certain biological functions. Aside from these characteristics that allow substances to be exchanged through diffusion, through facilitated passive transport or through active transport, it is important to underline the dynamic equilibrium that results from the membrane’s features and that in some cases prevents the achievement of equal concentrations on each side of it. A number of biological phenomena, including those associated with the production of ATP (in mitochondria, for example) or the transmission of nerve impulses (in neurons), require that the cells concerned be able to maintain a concentration gradient on each side of biological membranes, namely by spending energy. The osmotic gradient between root cells helps enable plants to absorb water. These are only examples.

Along with conceptual knowledge, it is important to consider the moments when students acquire the methodological skills associated more specifically with scientific investigation processes (microscopic observations that illustrate studied phenomena; experiments on diffusion and osmosis; etc.). These are all types of

scientific learning targeted by programs in numerous education systems. To give a few examples, one of the four “Foundations” of the Common Framework of Science Learning Outcomes published by the Council of Ministers of Education, Canada (CMEC, 1997), is that “students will develop the skills required for scientific and technological inquiry, for solving problems,... and for making informed decisions” (p. 6). One strand of the National Science Education Standards (National research Council, NRC, 1996) is the Science as Inquiry Standards, which “highlight the ability to conduct inquiry and develop understanding about scientific inquiry” (p. 105). In the Benchmarks for Science Literacy, the American Association for the Advancement of Science also highlighted the importance of developing scientific “habits of mind” alongside a knowledge of science content (American Association for the Advancement of Science, 1993). In the UK, one of the three aims set out in the Science National Curriculum (Department for Education, 2013), which prescribes the program of study for all students, is to develop an understanding of the nature, processes and methods of science through the specific disciplines.

One of the important aspects involved in the *how to teach* (pedagogy) is that of teaching processes as they relate to the appropriation of disciplinary knowledge (conceptual and methodological). In spite of the diversity of these processes, we will limit ourselves to mentioning the importance of distinguishing between those based on a logic of transmission and those based on constructivist foundations (Phillips, 2000).

Approaches that are based on a logic of transmission foreground the role of the teacher, the textbook or any other external agent in the presentation of scientific knowledge. As the knowledge “custodian,” the agent transmits it to the students through various means including explanation, presentation of definitions, reading in textbooks, consultation of dictionaries and glossaries, and so on. The student’s principal role is to receive a message and memorize it. At best, the student might be called upon to apply this knowledge to other situations, for instance in the context of exercises or labs. Once students have been exposed to the concepts of diffusion, osmosis, insect, etc. with the help of specific situations, they can then be presented with cases that have not been seen in class to verify whether they are able to understand them or not.

From a perspective that could be described as constructivist, the idea is to draw on approaches that enable students to be engaged in the conceptual learning and development process.

These approaches, when they are adopted by the students, involve more than solving the problems that are proposed or formulated by others (teachers, textbook designers, content adapters, etc.). In the context of implementing these approaches, students must first be led to construct relevant problems (in other words, to problematize), before proposing or implementing suitable strategies to solve them (1 in Figure 1). In the case examined here, this primarily entails the problem of exchanges between cells and their surrounding environment.

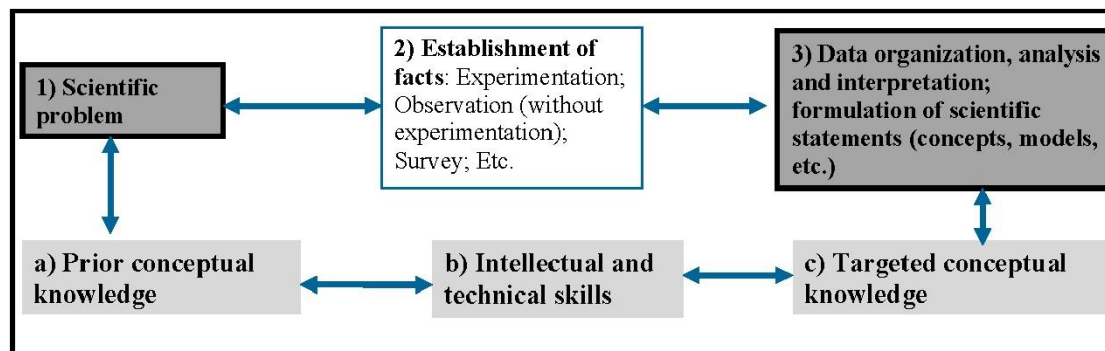


Figure 1. Relationship between scientific investigation process and the appropriation of concepts

As Bachelard (2004) has noted, scientific thinking forbids us to have an opinion on questions that we do not understand, or on questions that we are unable to formulate clearly. Above all, one must know how to formulate problems. Along these lines, Astolfi, Darot, Ginsburger-Vogel, & Toussaint (1997) and Fabre (1999) emphasize that in a school context, the problem must be constructed together with the students, in class, since scientific activities are not just about *problem solving*, but also and primarily are about *learning to formulate a problem*.

Aside from the fact that constructing a scientific problem must be based on presenting a situation that makes sense to students and prompts their desire to learn something new, two other characteristics, among others, are worth mentioning.

The first characteristic is the fact that a scientific problem cannot emerge in a conceptual vacuum. If students' representations and frames of reference guide their observation and their construction of the scientific problem, their prior knowledge does so as well (a in Figure 1). It is important, when choosing hypothetical situations that are aimed at problematization, to reflect on whether the students have the knowledge needed to develop the scientific problem that is intended. A student who does not master the concepts of a cell, a molecule, concentrations, etc. cannot understand a scientific problem associated with cellular exchanges.

While some knowledge needs to be mastered for problematization to take place, actually knowing the answer renders the formulation of a problem useless: if the concept and mechanisms of diffusion and osmosis are explained to the students beforehand, one runs the risk of trivializing the observation of their associated phenomena and making it uninteresting. In short, the absence of knowledge needed to formulate the problem makes the obstacle insurmountable for students; on the other hand, the prior presentation of the knowledge to which the problem is supposed to lead eliminates any obstacles and, consequently, extinguishes any desire to seek answers. Vygotski (1997) accordingly suggests that students be given problems situated in their zone of proximal development (ZPD).

The second characteristic of a scientific problem that we would like to recall here and that sets it apart from other sorts of problems encountered in everyday life is that a) resolving the problem requires a research process (2 in Figure 1) and b) this leads to conceptual development (3 in Figure 1). Hence, the two elements of the scientific process, namely problematization and conceptualization, are engaged in a rich and circular relationship.

One of the key elements of a research process is the establishment of facts or evidence (Avraamidou & Zembal-Saul, 2005; Kanari & Millar, 2004; Duschl & Osborne, 2002; Maloney & Simon, 2006; NRC, 2000): to scientifically answer a question or problem, what scientific data (evidence) will be used and how will it be obtained, validated and interpreted? The NRC (2000) reports that students should (a) "give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions" (p. 25), (b) "formulate explanations from evidence to address scientifically oriented questions" (p. 25), (c) "formulate and revise scientific explanations and models using logic and evidence" (p. 19), and (d) have a clear understanding that "scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories" (p. 20). Scientific inquiry, then, is fundamentally about acquiring relevant data, and then transforming it first into evidence, and then into explanations, that address particular scientifically oriented questions (Ruiz-Primo, Li, Tsai, & Schneider, 2010).

It is the nature of the problem which, without dictating them in linear fashion, guides the strategies to put in place in order to collect this data: experimentation while controlling variables, observation (without experimentation), use of a

questionnaire (survey), documentary analysis, etc. In the school context, it is also important to underline that while it is desirable for students to be engaged in developing these facts themselves, the constraints of the school (lack of time, for example) and the nature of certain objects of study (unavailability or high cost of laboratory equipment, for example) do not always permit this. However, this state of affairs does not justify the recourse to providing facts in solving the problems under study. This is why it is desirable to distinguish between the different origins of facts that students are called to use in S&T classes:

- a) Data gathered by the students (primary data), through observation, experimentation or other means;
- b) Provided (called-upon) data: data that the students cannot produce themselves, for the reasons we have cited. This data can be supplied by the teacher, by the textbook or by research in databases. This is the case, for example, for concentrations of ions on either side of a nerve cell membrane or osmotic pressure in root cells, which enable an understanding of nerve impulse transmission or the way water circulates in plant roots.
- c) Simulated or presumed data, as in certain cases of modelling.
- d) Etc.

If data gathering (searching for facts) (2 in Figure 1) is an important phase in the research process, data analysis and interpretation (3 in Figure 1) represent the key to understanding the phenomenon and to formulating scientific statements (and conceptual knowledge) related to the initial problem or question. All of these processes allow students to use intellectual skills and techniques specific to processes of scientific investigation (b in Figure 1). In the school context, both the conceptual knowledge that is produced (c in Figure 1) and the skills that are applied in the research process are targets of learning. In relation with this process, several authors (Maloney & Simon, 2006; Venville & Dawson, 2010) point out, among other things, the central place of debate in elaborating facts and in using them to produce a scientific understanding, or to foster conceptual development.

Scientific inquiry, in analysis of classroom practices, is examined through the discourse and actions of students and teachers, as means (*how?*) and ends (*what?*): “Inquiry as means” (or inquiry *in* science) refers to inquiry as an instructional approach intended to help students develop an understanding of science content (i.e., content serves as an end or instructional outcome). “Inquiry as ends” (or inquiry *about* science) refers to inquiry as an instructional outcome: Students learn to do inquiry in the context of science content and develop epistemological understandings about NOS [Nature of Science] and the development of scientific knowledge, as well as relevant inquiry skills” (Abd-El-Khalick et al., 2004, p. 398).

Teaching practices

Researchers approach classroom teaching practices in different ways and at different analytical levels. Some have examined the issue taking into account many variables that aim to study the teaching practices in general rather than specific practices in science education, i.e., the choice of content, the tasks of students and teachers, classroom interactions, resources, the organization of time, assessment methods, etc. (Bru, Altet, & Blanchard-Laville, 2004; Lenoir & Vanhulle, 2006). This research is oriented either to reported practice (the use of interviews with teachers, for example) or to observed practice (the recording of lessons in the classroom, accompanied by interviews and analysis of additional materials such as planning, student work, etc.).

Other researchers have looked into a smaller number of dimensions or aspects that specifically concern the teaching and learning of scientific content. For example, one of the three dimensions considered in the research of Robert & Rogalski (2002)

has to do with student activities in the classroom: the tasks they are given related to the acquisition of content; the forms of student work (individual, large group, teams); and the nature of interactions with the teacher. Campbell & Erdogan (2005) have analyzed student actions in the science classroom; Chin (2006, 2007) and Erdogan & Campbell (2008) have studied interactions in science class between the students and the teacher, with a focus on questions and feedback; Tiberghien & Malkoon (2007) and Tiberghien, Malkoun, Buty, Souassy, & Mortimer (2007) have specifically devoted their research to analyzing the knowledge addressed in physics class on different time scales, as well as the relationship between teaching practices and what students learn, by using the notion of facets of knowledge (Minstrell, 1992; Ohlsson, 1996).

We have adapted these conceptual and methodological frameworks for our research objectives in the following manner:

- 1) For data collection on teaching practices, we consider the three key moments of the teaching process (see Methodology section): before, during and after teaching the course of diffusion and osmosis.
- 2) For data analysis, while considering the three highlights of the scientific investigation (problematization, the establishment of scientific facts and the formulation of scientific statements), two levels of analysis are used (see the Data analysis section):
 - i. A general analysis (macro level) that describes some of the dimensions that characterize the course: lesson structure, classroom organization, the nature of classroom interactions, etc.
 - ii. A detailed analysis (micro level) that focuses specifically on the scientific content: students' and teachers' discourse and tasks associated with the acquisition of conceptual knowledge, methodological skills and processes of scientific inquiry, etc.

METHODOLOGY

Context

Diffusion and osmosis are part of the biological phenomena that students must learn in secondary school in Quebec, a Francophone province of Canada.² This content is more specifically prescribed in the program for the first cycle of secondary school (students aged 12 to 14).

The results examined here are part of a case study and are drawn from a course entitled *La cellule et son milieu* (the cell and its environment) that is aimed at teaching students the concepts of diffusion and osmosis in the first year of high school. The course, composed of eight periods (roughly 8 hours total), is taught by a teacher with more than 10 years' experience. The course content and progression are chosen by the teacher, who accepted for the research team to access the classroom to produce recordings. It is worth noting that this data collection falls under a broader project whereby, each year, a group of teachers produces recordings for two purposes: to allow researchers to study classroom practices, and to allow teachers to perform reflective analysis on their practices in the presence of peers and researchers (professional development). Teachers are free to teach the content of their choice. One teacher chose diffusion and osmosis, and it is this course that is the subject of analysis in this article.

Data collection

² Although there is a shared Canadian framework that sets out the broad orientations of scientific education in Canada, education comes under provincial jurisdiction; each province develops its own programs and manages its own education system.

Table 1. The two of the four dimensions dealt with in pre-recording interviews

What to teach? Examples of questions: What is the knowledge or disciplinary content that you would like for the students to learn in the class that we will be recording? What would you like for the students to retain about this content? Will the contents targeted in the recorded class present difficulties for the students? Or for you? If so, what specific content?¹

How to teach? Examples: Could you describe the progression of the period that will be recorded, clarifying your tasks and your students' tasks related to the targeted learning? Among these tasks, which, in your view, best promote student learning? Why?; Etc.

¹ Given that our research in classrooms was not aimed at any specific content, but rather depended on what teachers agreed to show us, the interview questions were formulated in general terms (the content that was taught).

The methodology, which stems from the conceptual framework and takes into account our research objectives, comprises three phases (Hasni & Bousadra, 2015):

- 1) Audio recordings of interviews held with the teachers before video recording the class concerned by the study (information on the pre-active phase). This interview is held as close as possible to the beginning of class and is aimed at reconstructing the meaning that teachers give to their practice. The pre-recording questions (see examples in Table 1) have to do with the two main concerns related to the teaching and learning of scientific content (diffusion and osmosis): *what* and *who*?

Considering that the recorded class is made up of eight periods, we conducted pre and post interviews twice: one for the first four classes and the other for the last four.

- 2) The in-class (audio and video) recording of the class concerned by the study. This recording was done in such a way as to collect data (teacher and student tasks and discourse) associated with the teaching and learning of the disciplinary knowledge in question (diffusion and osmosis). For the audio recording, two microphones were used: a lapel microphone worn by the teacher and a microphone placed front and center in the classroom to record all interactions.
- 3) The post-recording interview was composed of questions aimed at obtaining "fresh" feedback on the course that was recorded. These questions, for example, verify whether the learning content and progression of the situation changed compared to what had been planned, or revealed the challenges and difficulties encountered by the teacher and the students during the said situation. The interview was audio recorded for the purposes of analysis.

All of this data (interviews and classroom recordings) was transcribed in its entirety for analytical purposes.

Data analysis

For general analysis (macro), we used mainly the following three dimensions:

- a) The structure of lessons (Borko, Stecher, Alonz, Moncure, & McClam, 2005) or what other researchers call episodes (Robert & Rogalski, 2002) or didactic phases (Tiberghien et al., 2007): a description of the sequence of the key moments in order to shed light on the logic of the course. The identification of these moments is based, on one hand, on the pre-recording interviews: during these interviews, the teacher is asked to describe the key moments of the course and their sequence (Table 1). This identification is based, on the other hand, on video observation: identifying the episodes by analyzing the major tasks that the teacher asks the students to do (e.g., conduct an experiment, look for information in the textbook, etc.).
- b) The manners of classroom organization (Robert & Rogalski, 2002; Tiberghien et al., 2007), which are part of the dimension that Borko, Jacobs, Eiteljorg, & Pittman (2008) call *Grouping*: in our study, it is essential to identify the moments when students work individually, in teams or in a large

group. These manners of classroom organization are an indicator of students' engagement both with each other and with the teacher during learning-oriented interactions.

- c) The nature of classroom interactions. This mainly involves describing the time that students and teachers spend talking as an indicator of what Borko et al. (2008) call the *Scientific discourse community*. The nature of these interactions is described in the detailed analysis.

For the micro analysis, in order to describe the three dimensions chosen in connection with the teaching and learning of diffusion and osmosis (problematization, the establishment of scientific facts and the formulation of scientific statements), we used the following two main indicators:

- a) What certain authors call facets of knowledge (Galili & Hazan, 2000; Minstrell, 1992; Ohlsson, 1996; Thibergien & Malkoun 2007). Facets of knowledge constitute the basic statements formulated by teachers and students related to the learning at hand. These include conceptual facets, or "knowing what." For example, the teacher might say, "diffusion allows molecules to move from one place to another." Conceptual facets offer a way to reconstruct the main ideas conveyed by the teacher and students in line with the concepts of diffusion and osmosis. There are also facets associated with intellectual skills, namely epistemic facets or "knowing who." For example, a student might say, "I need to put the dye at the bottom of the flask filled with water to observe diffusion."
- b) Verbal interactions that provide a way to regulate student actions. An example would be when a teacher asks students, "How much salt do you need to put in your volume of water?" This type of question allows students to explain their understanding and their choices.

The analysis also dealt with the tasks carried out by the teacher and students in line with the appropriation of the knowledge at hand (epistemic tasks). This analysis offers a way to describe the technical skills used in class pertaining to targeted knowledge (for example, microscopic observation of cells in a concentrated medium, or the placing of dye at the bottom of a beaker to observe diffusion). Analyzing epistemic facets and the actual tasks carried out by the students and the teacher provides a way to reveal student' degree of engagement in the scientific process associated with conceptual appropriation (formulating problems, proposing and implementing scientific protocols, analyzing and interpreting results, elaborating scientific statements, etc.).

Analysis of the previously described data was performed taking into account the three principal moments of the scientific inquiry process associated with the teaching and learning of diffusion and osmosis, namely the elaboration of the scientific problem, the elaboration and treatment of facts, and conceptual development (formulating the concepts of osmosis and diffusion, as well as their associated concepts). It is the teacher who chose to organize the class based on these three moments, as attested by analysis of the pre-recording interview.

RESULTS

The results will be presented in two parts: a) a general description of the course; b) student and teacher discourse and tasks associated with the principal moments of the scientific investigation process that target the learning of osmosis, then, tasks and discourse associated with the learning of diffusion. Considering the nature of the research (case study), during the presentation of the results, the focus will be on qualitative rather than quantitative (statistical) aspects.

The results concerning osmosis are presented before those concerning diffusion, given the order in which they were covered by the teacher during the course.

Overview of the course under analysis

Analysis of the pre-recording interviews, of the teacher's planning, and of the class recordings brought to light the following content and intentions for each of the eight periods that make up the course (Table 2).

Table 2. Content and intentions for each of the eight periods that make up the course

Periods	Content and intentions cited by the teacher (pre-recording interview and video recording)
1 and 2	Reminder of concepts preliminary to the study of diffusion and osmosis: "I remind students of the concepts of homogeneous mixtures, heterogeneous mixtures, and pure substances [...] I then focus on homogeneous mixtures. When I focus on homogeneous mixtures, I make sure (that) the six notions (are) adequately called to mind: solute, solvent, solution, homogeneous mixture, saturated, unsaturated, oversaturated. Those concepts must be very clear before we can do the lab session" (excerpt of pre-recording interview with the teacher). ¹
3	Review of prior notions: presentation of a problem-situation (i.e. the proposed situation which should lead to the formulation of the problem) ¹ whose goal is to introduce the study of osmosis and to discuss the guidelines for drafting laboratory reports: "During this period, my goal is to have the students "write down the (lab session) objectives, the materials used and the protocol" (excerpt from the pre-recording interview).
4	Students' completion of the lab session, whose description has been provided by the teacher: preparation of three solutions of different concentrations, and microscopic observation of plant tissues (onion, carrot and celery) previously placed in each solution.
5	Continuation of microscopic observations.
6	Review of microscopic observations (review of the results).
7	Presentation of the link between the lab session and the concept of osmosis: <ul style="list-style-type: none"> • Review of observations and explanations relating to the observed phenomenon: reading of the textbook section that explains osmosis; • Completion of a comprehension exercise: analyze the results demonstrating a change in the length of potato sticks placed in salt solutions of different concentrations. Presentation of the phenomenon of diffusion through three teacher demonstrations, accompanied by a question and answer period.
8	Teacher presentation and explanation of examples of cellular exchanges in animal and plant cells (photosynthesis and cellular respiration).

¹ All English translations of direct quotes (in French) in this article are ours.

¹ The problem-situation in question will be presented later in the text (Section 4.2.1)

It should be noted that the large group format prevailed during this course, ranging from 45% of the time in Period 5 to 100% of the time in Periods 6 and 8 (with an average of 82%). Teamwork took place mainly during Period 4 (43% of class time) and Period 5 (55%), that is, during the lab sessions. Individual work was very scarce (approximately 3% and 2% of Periods 3 and 7).

With the exception of Periods 4, 5 and 8 (which correspond mainly to lab session tasks and microscopic observations), speaking time was mostly used by the teacher (from 70% to 87% of the time in each recorded period, with an average of 72%).

Tasks and discourse associated with the learning of the concept of osmosis

From the problem-situation to the elaboration of the problem

Two problem-situations were presented to the students during the course. In the first, presented at the beginning of Period 1, the teacher showed the students three roses whose stems had been placed in three solutions of different concentrations: tap water, a salt solution and a solution containing a mix from a florist. This problem-situation, later presented to students at the beginning of most periods, was never used to elaborate a scientific problem despite its scientific relevance. Its principal role was to spark curiosity, as the teacher explicitly told the students:

What have I just received? Lots of nice cells. What is the title of our document? "The Cell." Ah, how convenient (laughs) [...] Carefully observe what I'm doing... I want to help you understand something special here. Flowers and stems are just filled with cells. I am simply going to immerse my flower in tap water. Perhaps you don't understand

the link? (You're thinking), where is (the teacher) going with all this? Well, even if you don't find the answer today, you should find it by Period 6. I feel like trying something else in my other (beaker): I'm going to add salt. And I'm going to look at my flower inside the salty water. How will it react? That's what we're going to find out [...]. (teacher statement, Period 1, minute 7)

Responding to a question from a student who wanted to understand the problem-situation, the teacher continued: "No idea, my friend? Well, at least you'll remember this situation, this initial prompt [hook]. You won't be able to say that we went straight into theory without going over a few elements to make you think in different ways..."

The teacher continued to show the three flowers during the other periods, for the same reasons, as the following excerpts from Periods 2 and 5 illustrate:

I still have the small flowers, I will show them to you again [...] By the way, I just wanted to show you what my flowers look like [...] What is going on inside the cells? But next period is when we're really going to look at this question." (Period 2; minutes 48 to 49). "Just for fun, without really explaining why, I'm going to show you my flowers [...] You will see that one of them is just spectacular. (Period 5, minute 4)

An explanation for the state of these three roses was only given by the teacher later, during Period 7 (at the end of the course on osmosis).

The second scenario, taken from the textbook, was presented to the students during Period 3: "OK! On page 5 (of the lab session document), I outlined the general idea of the lab. On page 5, you find my triggering element, my situation, and my big question in the form of a problem-situation." The teacher had the students read the problem-situation description:

You are in a plane crash, but you survive. You find yourself on a tiny desert island. After a day of hoping and waiting to be rescued, your greatest challenge remains thirst. You have been suffering from thirst for a good while, so much so that you suddenly have a terrible urge to drink ocean water to quench it... But it's so salty! After having done the experiment proposed in this problem-situation, you should be able to answer the question, What effect do salt solutions have on cells?

The teacher then gave the students explanations so that they could link this learning situation with the lab session, which, for its part, involved an experiment with plant tissues:

To experiment with animal cells, we would need to take Pierre's skin and then give some to everyone to be able to make observations. Except that it isn't very nice (appropriate) to take time to observe animal cells from a living person. So that's why we're going to draw a parallel... We're going to draw a parallel with plant cells and then confirm our explanations by making logical links with animal cells [...] If you look at plant cells, you will then be able to talk about animal cells. (Period 3)

It is therefore during Period 3 that the students were exposed to the scientific problem that was intended to lead them to the study of diffusion and osmosis. A subsequent lab session was planned to establish facts.

From the scientific problem to the production of facts

First, the teacher led a discussion with students on how to write a lab report (communication competencies). Consistent with what the teacher had stated in the pre-recording interview, the students were not being led to elaborate a protocol; during this discussion, the focus was more on how to formulate the different steps of a lab session: using action verbs in sentences; describing one action per sentence;

using short statements; ensuring that statements were relevant to completing the lab; etc.

Following this discussion, which led each student to produce a written document that the teacher would later evaluate, a lab session description, taken from the textbook, was handed out:

I should mention that I provide them with a ready-made protocol they can use... I prepared a copy of a protocol that they will use to fully experience the lab session. So I'll be supervising the session, the students will be completing their tasks, and the lab technician will be there with me to make sure everything runs smoothly. (excerpt from the pre-recording interview)

The students then got into teams to carry out a series of tasks associated with the lab session, namely preparing three solutions of different concentrations and making microscopic observations of three plant tissues that had been kept in these solutions for four days. On the whole, the lab allowed the students to carry out several tasks related to technical and epistemic skills (measurements, handling of the preparations to be observed under a microscope, mapping of observed cells, etc.) associated with the scientific investigation process. The student discourse analysis, however, suggests that on several occasions the students did not understand the intentions associated with the tasks in which they were engaged. The following excerpt of a discussion between two students, and between the teacher and these two students, illustrates one of the difficulties encountered:

- 1 (S1³): The strange thing is that we can't really see the cell.
- 2 (T): Maybe it's just because we need to find a better spot on your slide. There, I think we've gotten rid of most of those air bubbles. There's too much light... Forget about what looks like water bubbles, or air bubbles; have a closer look at the cell structure.
- 3 (S1): What about that grid in the back, there?
- 4 (T): Yes, there's a kind of grid in the back. Like a brick wall.
- 5 (S1): ... Is that what we're supposed to draw?
- 6 (T): Yes, and now was this for your very salty water?
- 7 (S1): No, for the tap water.
- 8 (T): OK, now, flip your slide around because...
- 9 (S1): Done.
- 10 (T): I want (the preparation in) the tap water on the left...
- 11 (S1): OK.
- 12 (T): I thought it looked pretty clear for tap water...
- 13 (S1): Well, it looks fine...
- 14 (T): Yes, it's all right, let me show this to S2.
- 15 (S1): It's like a brick wall.
- 16 (T): Yes, it's a cell structure, of an onion peel.
17. S2: Hey! This is pretty neat.
- 18 (T): And when you move it to the right, you should see changes. It's up to you to look at them.
- 19 (S1): OK, go and try, S2. Well, on the right, like this.
- 20 (S2): Are we going to do Number 2?
- 21 (S1): Yes... OK! We have to try to draw this.
- 22 (S2): OK, the cells?
- 23 (S1): No. Well, we're only drawing the grid ... the one at the back, there, the brick wall.
- 24 (S2): OK, is this the brick wall?

³ S1, S2, etc. refer to students; T refers to the teacher.

25 (S1) It looks like it's more vertical. I don't know if we have to draw that, the whole length. What are you doing?

26 (S2): Well, um, I can't really do the whole square, because...

27 (S1): Argh! I don't know, I don't really know what he (the teacher) wants. I don't know what to do. I don't know what we're supposed to see... Hey, girls (addressing the team in front of them), do you think we need to draw the whole square? That's strange...

28 (S2): Well, I find the cells are really close together.

29 (S1): I'm not sure what he (the teacher) wants. Because he only said to do the drawings. He didn't even say we needed to draw a wall.

30 (S2): I think I'm going to ask him.

31 (S1): Yes, ask him.

32 (S2): What do I need to write?

33 (Student teacher)⁴: Draw!

34 (S2): OK, right; but do we need to draw the whole square or the brick wall?

Student teacher: Just a small part... as long as we can see the three differences.

35 (S1): OK, I'm going to do just a bit more...

36 (T): What was your question?

37 (S1): Well, if we had to draw...

38 (T): Draw it. You need to fill in the whole square.

39 (S1): I've almost finished filling in the whole square.

As this excerpt illustrates, interactions between the teacher and the students during the microscopic observations highlight some of the conceptual, intellectual and technical obstacles that students faced in completing the lab session:

- i. no use of scientific concepts to describe the phenomenon; choice of a common sense vocabulary (metaphors) that is not meaningful (has no meaning): a brick wall instead of tissues or cells, a square, etc. (statements 4, 23, 24 and 26);
- ii. deficiencies in identifying the part of the slide that has to be observed and in focusing a microscope. The teacher addressed these shortcomings toward the end of the lab session: while reviewing the lab as a class, he used a projector connected to a video camera placed on a microscope lens to show images of onion cells that had respectively been kept in the three solutions with different concentrations;
- iii. a lack of understanding regarding the intention behind the observation and its link to the problem-situation (the initial problem). While the teacher ended up explaining to the students that they had to draw a specific area of the slide (statements 1 to 24), the students did not seem to understand why such a drawing needed to be made (statements 25 to 29). Even if, at the students' request (statements 30 to 32), the student teacher and the teacher explained to the students that they had to draw cells (statements 33 to 39), they never, for example, guided the students in observing the state of the cells in the three solutions of different concentrations (turgor or cell plasmolysis);
- iv. the lack of any reference to facts associated with the phenomena of plasmolysis and turgor, whether during or after the microscopic observations.

Following the analysis of teacher and student discourse and tasks, other comments can be made concerning the laboratory's contribution to the understanding of osmosis:

⁴ A student teacher was present, with the teacher, during the lab.

- Without a coloration of the vacuoles and the cytoplasm, it is difficult for students to identify the difference between the cells found in the three solutions. During the microscopic observations, such coloration would have allowed them to clearly identify the distance or closeness of the cell membrane to the cell wall.
- The students (and the teacher) could not observe the cells of carrot tissues. This situation was predictable, as the teacher had mentioned to the students at the beginning of the lab session, "It is difficult to slice a carrot the right way so you can observe its cells... I admit that I have only seen carrot cells twice before... it is going to be difficult." The teacher nevertheless respected the textbook protocol that suggested making this observation. While reviewing the lab session, the teacher found it appropriate to divert this situation to accomplish a different goal, namely showing students cellular pigments:

We notice here somewhat of a small orange- and brown-tinted coloration. Well, these are pigments of beta-carotene, the pigments that give carrots their coloration. I don't want to, my aim isn't to explain (the effects of) tap water, salty water, or very salty water. I simply want to give you an additional piece of information... I am giving it to you so that you have an additional word in your vocabulary, or an additional image in your mind related to the inner structure of a carrot. (excerpt from the teacher's class)

From facts to conceptual elaboration

The student and teacher discourse pertaining to the analysis of microscopic observation results shows that discussions remained at the level of fact description and did not focus on establishing a relationship between the empirical components (experimentation, observation, etc.) and the theoretical components (elaborating on the concept of osmosis and its associated notions). The analysis performed by the students and the teacher primarily aimed to: 1) allow teams to "note down their observations on vegetable appearances in their data charts" (intention stated in the course textbook); and 2) "visualize osmosis thanks to a technique that makes it possible to see a big enough cell" (intention expressed by the teacher during the pre-recording interview). During the course, no time was allocated to a discussion of observed results in order to propose explanations or formulate scientific statements.

Two main sources of information were used after the lab to allow the students to understand the notion of osmosis (theoretical component) and to then establish a relationship between this notion and the results of the lab session. The first source was the textbook. To this effect, during Period 7, the teacher asked the students to read the textbook definition at the end of the lab. The teacher had already mentioned in the pre-recording interview that he would be using this information source at this stage: "For the concepts, they read the glossary and the concept description pages [...] I chose *Univers*⁵ for the concept descriptions, and for the data charts [...]. Yes. I've really relied on *Univers*."

The sequence privileged by the teacher, which consisted in approaching the lab sessions and the presentation of concepts independently, matches the logic suggested in the textbook (Bélanger, Chatel, & St-André, 2006a): once the lab is over, the students are asked to read the definition of osmosis in order to understand what they have just observed. The aim of the course that emerged from this analysis is not to use the facts gathered from observation to elaborate scientific statements, in

⁵ *Univers* is the title of the textbook used.

accordance with the scientific process, but rather to use textbook definitions given by the teacher to understand the observations performed.

The definition provided by the textbook is the following: "Osmosis is the movement of particles in a solvent, from the less concentrated medium to the more concentrated one" (Bélanger, Chatel & St-André, 2006b, p. 100). Although this official definition reflects the meaning that is generally assigned to the concept, Figure 2 and its accompanying explanation convey inadequate conceptions of the phenomenon:

- The arrows that show the movement of water point in one direction only (overall result), which reinforces the idea of a unidirectional motion;
- At equilibrium, the arrows disappear, suggesting that the motion of molecules in the solvent and the solute has stopped;
- The final concentration is reduced to an intermediate value of 4%, without any explanation. As a result, students are led to believe that if the intracellular concentration is initially 1% and that the concentration of the outer medium is 5%, equilibrium comes out to 4%! This explanation does not allow the students to understand that concentration depends as much on the quantity of solvent as it does on the volume of solute.
- The explanatory text conveys an anthropomorphic vision that suggests the particles' inclination to move ("travel") and find equilibrium: If the solute, namely salt, cannot travel from one side of the membrane to the other, it is then the solvent, water that must travel to try to reach an equilibrium in concentration on both sides of the membrane. Water therefore leaves the cell to try to dilute the solution to 5%" (excerpt from the textbook).

The second source of explanation for osmosis to which the students were exposed was the teacher's discourse, and more specifically teacher statements on different occasions, which complemented the readings in the textbook. For example,

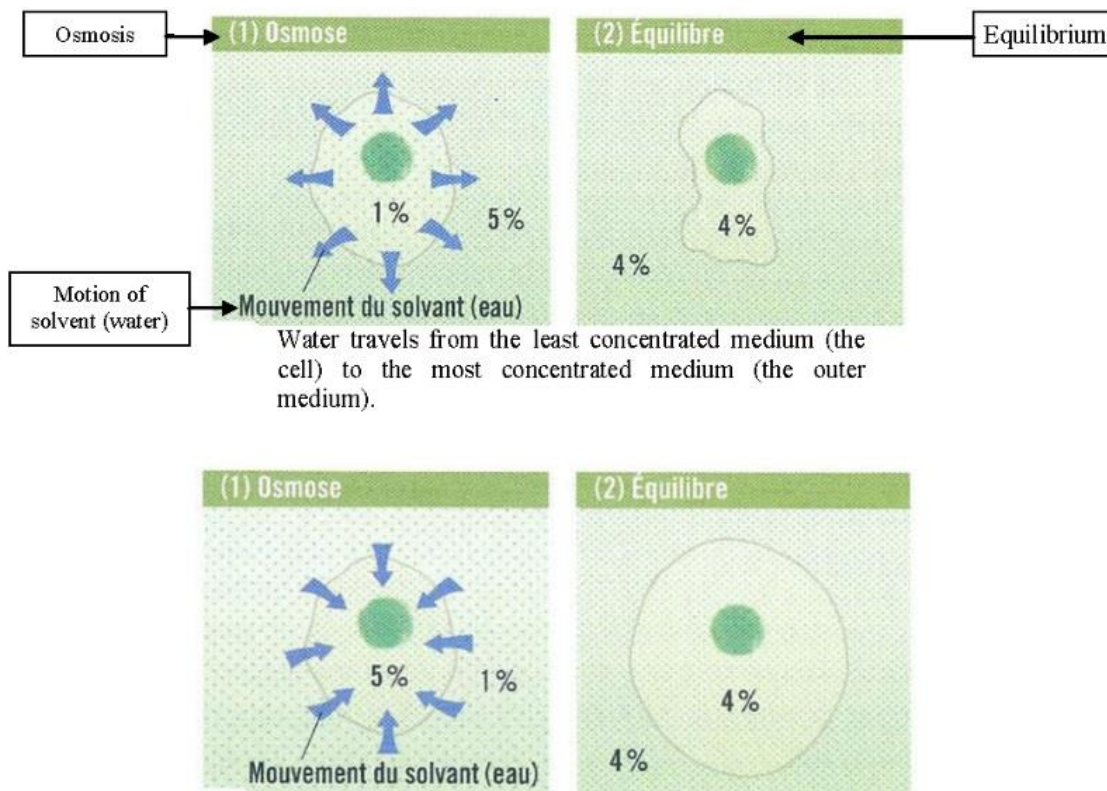


Figure 2. Explanation of osmois according to the textbook Univers (Bélanger, Chatel et St-André, 2006b, p. 100)

before addressing the concept of diffusion during Period 7, the teacher reminded the students of what was meant by osmosis:

Remember that osmosis is when the solute does not pass through. So if I have salt, for example, the solute would like to pass through but the membrane says no, so as a result, the solute won't allow itself to move from the outer medium to the inner medium, or vice-versa; it is the water that travels. When water travels, we have our key phrase: from the less concentrated medium to the more concentrated one.

This discourse is essentially consistent with the discourse found in the textbook and follows, among other things, the anthropomorphic vision conveyed therein.

Tasks and discourse associated with learning the concept of diffusion

The presentation on diffusion took place after the study of osmosis, during Period 7, and was based on teacher demonstrations: "Let me introduce my second phenomenon. I think I can explain it properly within 25 minutes. You see, I have set up three demonstrations to explain the second phenomenon: diffusion."

The teacher began by writing the definition of diffusion on the board before doing the demonstrations, as illustrated in the following excerpt of his discourse in the classroom:

Diffusion is when the membrane agrees to let the solute pass through. Is this possible? There are substances, solutes that will manage to pass through... However, here, the salt doesn't, the sugar doesn't, because those two substances can't pass through the membrane. Other substances can... I will give you examples later. So when something manages to pass through the membrane, that's when diffusion occurs. I am going to introduce the phenomenon of diffusion through three demonstrations.

The teacher then performed the three demonstrations:

- A drop of coloring was placed at the bottom of a beaker filled with water. The students had to observe the color as it spread throughout the beaker.
- Perfume was sprayed in the air. Students had to smell the perfume from the back of the class.
- Molasses, in a cylinder closed at both ends and made of a permeable membrane, was placed in a beaker filled with water. The students had to observe the color of molasses spread throughout the beaker after it crossed the permeable membrane.

Although a large part of the teaching strategy rested on the teacher's demonstrations, supplemented with explanations, the students were asked a few questions to verify their understanding. The students' answers showed the difficulty of applying the definitions provided during these demonstrations, as illustrated by the following excerpt of a discussion after the drop of coloring was placed in the water:

T: Who can come up with a short sentence that can explain the phenomenon of diffusion? I won't say whether they're right or wrong, because there's another example after this one.

S1: Well... It's as (if) the drop of coloring has entered into the water cells.

T: The drop of coloring has entered into the water cells? Does anyone have another idea?

S2: From the most concentrated medium to the least concentrated one.

T: OK, you're using the same type of sentence as this one (pointing to the board) ...

The first student answered using the explanation the teacher had previously given of diffusion through the cellular membrane, even though the demonstration had been made in a beaker (without any membrane); the second student used the definition written on the board.

The teacher ended this portion of the class by introducing examples of diffusion in human cells using a handout. More specifically, the examples described the diffusion of oxygen and carbon dioxide through muscular tissue membranes.

DISCUSSION

Although the general sequence of the course was based on taking into consideration prior knowledge and student conceptions (reminder of the concepts of solvent, solute, concentration, etc., during Period 1) and followed a scientific investigation process (scenario related to a scientific problem, choice of a focused research question, use of a lab session corresponding to the research question, gathering of data, etc.), the students demonstrated substantial difficulty performing the tasks in the lab sessions and acquiring the concepts of diffusion and osmosis.

Our analysis of student and teacher discourse and tasks in the classroom shows that these difficulties are associated on one hand with the close management of student engagement in the scientific process (elaborating the scientific problem; gathering and analyzing facts with the help of the scientific investigation process; formulating scientific statements), and on the other with a lack of identification, by the teacher, of the overarching ideas to which the concepts of osmosis and diffusion are related.

- 1) Some of the difficulties that have been highlighted in this study are situated at the level of the choice and management of the initial situation (problem-situation) to elaborate a problem or a relevant scientific question. In this respect, during Period 1, the teacher presented a problem-situation that could have led to an adequate scientific problem: why do the flowers in a salt-concentrated medium lose their rigidity (and consequently some of their water)? However, this problem-situation was used only as a hook and then as a tool by which to maintain student curiosity throughout the eight periods of the course. It primarily served a psycho-affective function. Another problem-situation, taken from a textbook, was used during Period 3. It involved three principal difficulties: 1) it was hypothetical and disproportionate (plane crash), and neither authentic nor realistic; 2) the question to which it led was more a personal type of problem (should I drink ocean water in these circumstances or not?) than a scientific one; and 3) it was used only as a pretext since the teacher ultimately proposed the observation of plant cells in a salt solution, arguing that this choice was based on the difficulty of observing osmosis in animal cells! In other words, the first problem-situation should have led to the problem of water exchanges in plant cells, but it was abandoned.

In addressing the specific scientific content of diffusion and osmosis, our case study helps document the challenge of developing scientific problems in the school context (Bachelard, 2004; Windschitl, Thompson, & Braaten, 2008). The students in our study were led to formulate their research problem and question only in light of their direct observation (of flowers), without this observation being based on students' prior acquisition of biology knowledge. Yet, as Furtak, Seidel, Iverson, & Briggs, 2012) notes, "all activities in science take place within an orienting framework of conceptual knowledge, connected not only to students' prior knowledge but also to the more sophisticated understandings they are expected to develop as a result of instruction" (Furtak et al., 2012). By conceptual knowledge (Anderson, 2002; Hasni & Samson, 2007, 2008; Duschl, 2008; Furtak et al., 2012;

National research council, 2007), the authors in the literature designate the facts, theories, and principles of science, i.e., science as a body of knowledge. In contrast, the way the problem was treated in the course we have examined “reinforces a naive ‘discovery’ worldview in which scientists pose random questions without the framing of any underlying model—tacit or otherwise” (Windschitl et al., 2008, p. 946).

- 2) The gathering and analysis of scientific facts (the establishment of facts), while integrated into the course, also expose other specific difficulties the students faced. More specifically, even though the students were given some time to discuss the lab, the analysis of classroom discourse shows that the link between the problem and the protocol was never discussed. Discussion of the protocol was mostly focused on the adequate formulation of laboratory statements from a linguistic point of view (language communication skills). Following this activity, the teacher guided the students to do the lab session. Beyond the technical difficulties underlying the execution of tasks (e.g. focusing the microscope), the principal difficulties that the students faced were associated with understanding the meaning of the task: why were they performing these operations? Even though a large portion of time was spent in labs, and as such to the gathering of scientific facts, little time was allotted to discussions and exchanges that could have allowed the students to express their conceptions and understand the link between the learning situation and the proposed laboratory. Among other things, why use the four types of plant tissues that were chosen? Why in three concentrations? Why observe onion cells without coloring them? Why leave the chosen tissues in the three concentrations for three days? None of these questions were discussed with the students prior to the lab sessions.

Our analysis, whose results are discussed in this paper, highlights the distinction that needs to be made in the course of scientific teaching (and the training for such teaching) between hands-on manipulation and experiments. The latter require students to have a clear understanding of the manipulations’ usefulness for gathering facts to help answer precise questions that have already been thoroughly discussed and understood. Our analysis underscores the necessity of helping students to understand the scientific relevance of tasks performed in a laboratory. This observation demonstrates that the availability of facts and definitions is not sufficient to allow students to understand the phenomena under study. In other words, students’ performance of technical tasks or scientific manipulation does not mean that they are engaged in a scientific investigation process (Bartos et Lederman, 2014). Moreover, in contrast with the vision that emerges from the course we have examined, the investigation process is not a universal sequential procedure (problem, hypothesis, experimentation, results, interpretation) (Hasni & Samson, 2007. 2008; Bartos & Ledrman, 2014; Furtak et al., 2012; Rudolph, 2005; Windschitl et al., 2008). Our results are consistent with those of other studies (Banilower, Smith, Weiss, & Pasley, 2006; Roth & Garnier, 2007; Windschitl et al., 2008), which have led some authors to say that “activity without understanding seems to be a regular feature of classroom life for science students” (Windschitl et al, 2008, p. 942).

- 3) The conceptual elaboration. The way in which the concepts of diffusion and osmosis were introduced bears witness to the continued separation between theory (the explanation of concepts) and practice (holding a lab session). Facts and their analysis were not the basis for the students’ conceptual elaborations. Definitions were provided by the textbook (for osmosis) and by the teacher (for diffusion) and they were then used to understand the results of the experiments performed. Furthermore, these definitions were somewhat problematic, as the student discourse demonstrates when these

two concepts are addressed. These results once again show the need to insist on circularity between the elaboration of a problem and the research question, on one hand, and conceptualization, on the other (Figure 1).

CONCLUSION AND IMPLICATIONS FOR TEACHING AND RESEARCH

The above discussed case study and results partially explain the difficulties students have in understanding the phenomena of diffusion and osmosis as described in the first section of this text. While some of these difficulties can be associated with student characteristics (state of development of the scientific mindset; prior knowledge; etc.), many of them can be attributed to teaching practices, particularly with regard to management of the scientific process.

The results of our research, despite the limitations associated with the case study (the difficulty of the generalization), are important for improving teaching practices related to diffusion and osmosis and for promoting students' learning of these phenomena.

The initial training and continuing education of teachers must emphasize certain key points in the conceptualization of diffusion and osmosis by drawing on the scientific investigation process:

- A problem cannot be formulated based on the sole (neutral) observation of reality. It is important to distinguish the problems observed in everyday life (a flower losing its rigidity in a saline environment) from scientific problems whose construction requires a minimum of knowledge on the observed phenomenon. It is when our observations contradict or cannot be explained by our prior knowledge that a scientific problem can emerge (Hasni & Samson, 2007, 2008; Furtak et al., 2012).
- The scientific process does not boil down to a procedure or a series of technical tasks to be performed by students. Instead, it is founded on developing the skills needed to reason scientifically when confronted with the phenomena of the natural world (Hasni & Samson, 2007, 2008; Bartos & Lederman, 2014; Windschitl et al., 2008).
- The investigation process is not always (and solely) based on experimentation as the only way to generate data (Windschitl et al., 2008, p. 947).

Finally, it is worth mentioning that this article, owing to the results and the conceptual and methodological framework that it presents, proposes a contribution to studies aimed at bridging the gap between educational research and classroom practice. The importance and necessity of this "reconciliation" is emphasized in many recent studies (eg. : Hand, Yore, Jagger, & Prain, 2010; McIntyre, 2005). McIntyre (2005), taking into account these studies' analyses, proposes three main criteria for addressing this gap:

- i. research should generate valid new understandings of realities of classroom teaching and learning;
- ii. these new understandings should provide a basis for clear indications to classroom teachers of how they might be able to improve their practice;
- iii. the new understandings, and the suggestions for improvement to which they lead, should make sufficient sense to teachers to persuade them to take the suggestions seriously and so to engage in dialogue about them (p. 380).

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