Acquisition of scientific and pedagogical competency by Quebec elementary pre-service teachers

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Abstract

The present qualitative study, shows the results of an experiment led with pre-service primary teachers from Quebec in Canada. The experiment, which lasted four months at the rate of three hours per week, took place in two phases. The first phase consisted of 4 steps to help student teachers acquire knowledge competency in science and in pedagogy, in accordance with the curriculum. In the second phase, the prospective teachers had to prepare two teaching sequences centered on laboratory experiments for their future learners. To achieve this goal, they had to follow an approach like the one experienced in the first phase. Finally, they had to complete a questionnaire to specify scientific and pedagogical difficulties they encountered. The analysis of the constructed sequences and of the data of the questionnaire show an important effort on their part, despite the scientific and pedagogical difficulties with which they were confronted.

Keywords

Prospective teachers, elementary school, pedagogical competency, scientific competency, science and technology

Résumé

Cette recherche de type qualitatif présente les résultats d'une expérience menée auprès d'étudiants québécois en formation des maîtres pour l'ordre primaire. La stratégie développée s'est déroulée en deux phases. La première avait pour objet de les aider à acquérir des compétences en sciences et en pédagogie, conformément au programme de formation. Dans la deuxième phase, ils devaient concevoir deux *séquences d'enseignement centrées sur des expériences de laboratoire pour leurs futurs élèves. Pour atteindre cet objectif, ils ont dû suivre une approche semblable à celle de la première phase. Après, ils devaient remplir un questionnaire pour préciser les difficultés scientifiques et pédagogiques rencontrées lors de l'élaboration de leurs séquences d'enseignement. L'analyse des séquences construites et des données du questionnaire montre un effort important de leur part, malgré les difficultés scientifiques et pédagogiques auxquelles ils ont été confrontés.*

MOTS-CLÉS
Formation des enseignants, école primaire, compétence, scientifique, pédagogique, science et technologie

THEORETICAL FRAMEWORK

The education of prospective primary school teachers in science and technology is deficient, as several studies have pointed out (Appleton, 2003; Criado & Garcia-Carmona, 2010; Van Aalderen et al., 2012; Narjaikaew, 2013). Teachers for example have alternative conceptions of scientific concepts, and the conceptions are similar to those of their students (Narjaikaew, 2013).

To remediate this problem related to the teaching of science by elementary pre-service and in-service primary school teachers, much research has intensively focused studies on teachers' beliefs and conceptions on teaching and learning science, as well as their understanding the nature of science beliefs (Trudel & Métioui, 2011; Gheith & Aljaberi, 2017). The nature of their beliefs represents a self-evaluation of the problems related to the teaching and learning of sciences at the elementary level (Varma, Volkmann & Hanuscin, 2009; Métioui & Trudel, 2013). In the following passage, Gheith and Aljaberi, precise the relevance of soliciting their point of view regarding this teaching is emphasized: "*[…] teachers' conceptions toward learning and teaching, based on the idea that having knowledge of these conceptions is key to comprehensively understanding the process of learning and teaching used by educators and their teaching practices used inside the classroom when being on the offset of their paths*" (p. 2).

This research highlights the discomfort experienced by teachers in teaching science and engaging their students in learning science. This uneasiness is due to their lack of scientific knowledge and their misconceptions of the way scientific notions are constructed and how the scientific community operates. These considerations of a social, philosophical and epistemological nature are important because their study will make it possible to consider science as a social activity (see Abd-El-Khalick & Lederman, 2000). In an education program, this would allow teachers to develop a positive sense of effectiveness in the teaching and learning of science (Bandura & Edwin, 2003;

Bahcivan & Kapucu, 2014). It should be noted that the development of a feeling of efficiency among teachers is a necessary but not a sufficient condition for them to appropriate the rudiments of the scientific approach as well as the basic concepts of science. To this end, more and more didactics researchers are developing strategies for the teaching of scientific concepts.

In Finland, Australia, France, Italy, Canada, England, Greece and other countries, studies were conducted on offering pre-service teachers who will be teaching at the elementary school an education allowing them to acquire the basic concepts in science and technology with hand-on laboratories (Webb, 1992; Heywood, 2005; Criado & Garcia-Carmona, 2009; Métioui & Trudel, 2012; Häkkinen & Lundell, 2012; Carpignano & Cerrato, 2012). The experiments presented in these laboratories consider the erroneous conceptions of the teachers in training and practice identified in the review of the international literature. For example, to consider Australian teachers' misconceptions about the functionality of a simple electrical circuits (battery, bulbs, and wires), especially those who believe that the current leaves the battery from one end, is partly dissipated in the bulb, its unused portion returning to the battery (the "attenuation model"), Webb presented them a strategy of teaching centered on the experimentation to destabilize this false conception. For this, these teachers were invited to measure current with two ammeters placed between the bulbs. Here is how Webb (ibid) proceeded: "*The teachers were instructed in the use of ammeters and allocated time to connect them at various locations within a series circuit containing two bulbs. The relative brightness of each bulb and the current readings of the ammeter in different positions in the circuit were recorded in a table*" (p. 424).

In making these measurements, the teachers concluded that the current is the same before and after the bulb, and so, with the help of the researcher they will acquire the law of conservation of charges (the number of the electric charges is the same at any point of the circuit in each time). In the same vein, Criado and Garcia-Carmona implemented a teaching unit with 52 Spanish student teachers to destabilize their intuitive ideas related to electrostatic phenomena (before and after teaching). For this purpose, they were asked from several experimental devices about the interactions between two rubbed objects (electrification produced by friction), and another rubbed object with a non-rubbed object (electrification produced by induction). As outlined above in the case of Webb's study, experimentation helps students to question their misconceptions, only by encouraging a debate between them with the intervention of the trainer throughout the experiments: "*Hence, we conclude that for experiments to fulfil their function of facilitating the learning of abstract concepts such as the electrical behaviour of matter, we as teachers will have to devote the necessary attention to these experiments for our students to be able to apply the concepts involved. There has to be group discussion of the different responses obtained in a pre-test of prior ideas. And to ensure the appropriate interpretation, we suggest that the* *empirical experiment should always be accompanied by a pencil-and-paper task. In this, the students should sketch the electric charges that correspond to each phase (neutral objects to start with, then the process of electrification and charge transfer, induction and polarization, etc.), and write brief descriptions of what is shown in the illustrations*" (p. 29).

However, the acquisition of these concepts is a necessary but not a sufficient condition for them to teach science in a non-traditional way. With a traditional teaching method, knowledge is transmitted from the teacher to the pupil, as if the latter was considered an empty jar which the teacher would have to fill (Bachelard, 1981; Driver, 1989; Seimears et al., 2012). In the following passage, Seimears et al. (2012, p. 267) underline the incompatibility between the constructivist and the transmission of knowledge models: "*Constructivism contends that students are not sponges ready to absorb and use transmitted knowledge; the knowledge already written on their mental slates affects how they interpret new observations and how they accommodate newly constructed knowledge. If, during instruction, teachers are not cognizant of students' prior knowledge, then the message offered by the teacher likely will not be the message constructed by the student*".

The teacher should also be able to manage his class so that his learners participate actively, a situation which requires skills in didactics and pedagogy as well as knowledge in science: "*[…] teacher should have different kinds of knowledge, not only subject matter or content knowledge but also knowledge of how to supports' learning*" (Sothayapetch, Lavonen & Junti, 2013, p. 84).

Unfortunately, many works emphasize that teachers have often limited pedagogical content. On this subject, Gheith & Aljabri (2017) indicate that the acquisition of pedagogical competency can't be adequate without the acquisition of skills in science. Unfortunately, very few teachers received an education that would help them to choose constructivist teaching strategies (Seimears et al., 2012). In this regard, Seimears et al., stresses that: "*The transmission model often is used because it is the instructional method by which the teachers have been taught and because it may be the only instructional method some teachers know how to use. Not only does it lack theoretical justification, but there also is mounting evidence that it is not the most efficient or effective model of instruction in science education*" (p. 266).

Very few studies in didactics develop strategies related to learning and teaching science at elementary level to allow pre-service teachers to acquire these different skills (Webb, 1992; Criado & Garcia-Carmona, 2010; Métioui, Trudel & Baulu MacWillie, 2015). The present exploratory study is conducted with this perspective in mind. To this end, we have carried out a qualitative study guided by the following questions:

1. Can an education in science be given that takes into account the results of studies related to the problems of the education of primary teachers in science while taking into consideration the work that has been done on their misconceptions?
2. Following this education, can pre-service students design a teaching strategy that considers pupils' misconceptions?

Description of the population

The preservice teachers who will be a teaching at the elementary level (grade 1 to 6) are future general practitioners, because they must teach several subjects: French, Mathematics, Liberal arts, Sciences and Technologies, etc. For teaching science and technology, they follow a course in didactics of a length of 45 hours (3 credits) taught over a period of four months. Most of the pre-service teachers already have a diploma of collegiate studies in liberal arts (3 years of study after their secondary studies of five years). Their education in science is deficient since they only completed a course or two credits in their secondary studies on basic notions of physics, chemistry and biology. These courses were taken about six years. Unfortunately, the concepts they studied in secondary school do not cover all the concepts necessary to teach at the elementary level. Finally, note that more than 90% of the student participated in the present research are female and their age vary between 19 to 24.

Strategy developped with preservice teachers and methodology

While being inspired by the constructivist approach founded on the hypothesis per which the learner constructs his knowledge, a strategy centered on four aspects was developed: (1) science, (2) technology, (3) didactics and (4) pedagogy. For this, five themes were covers as follows: 1) physical states of matter, 2) magnetism, 3) chemical transformations of matter, 4) study of the rectilinear propagation of light, 5) functioning of electrical circuits.

In the curriculum, these themes are grouped in the field of knowledge related to the study of the physical world (nonliving things). The scientific notions prescribed in the education program are presented in table 1. Note that in the education program, teachers are expected to engage pupils in scientific and technological activities that help them in acquiring the basic concepts of the following three domains of knowledge: (1) the physical world, (2) the Earth and space, and (3) the living things.

Note that these notions are not explicit. This situation is problematic for the teachers who have a limited education in science. Therefore, they do not know what concepts to cover within each of the themes and how far they should go in teaching them.

With respect to this topic, several studies underline the relevance of conducting a conceptual analysis of an education program to identify the most important concepts to teach because such a study might allow for an economy of concepts (Métioui & Trudel, 2014; Kahn & Zeidler, 2017).

Also, it is thought that the education program should consider science as a social activity to bring out the following dimensions: (1) the complexity of the construction of

Table 1

Scientific notions prescribed in the curriculum related to the physical world (MELS, 2002)

Theme	Notions prescribed
Physical states of matter	Conservation of matter Transformation of matter: solid, liquid and gas Heat and temperature: conduction, convection and radiation The water cycle
Magnetism	Magnetic poles Magnetic fields
Chemical transformations	Rust - combustion Acid - basicity
Study of the rectilinear propagation of light	Describe the behavior of a light beam (reflection, refraction) Image formation by the mirror Image formation by the lens Illustrate the formation of eclipses
Functioning of electrical circuits	Conception of simple circuit; forms of energy (electric, chemical, thermal, light) Conception of simple circuit; energy transfer: electric conductivity (conduction and insulating); consumption and conservation of energy.

concepts, (2) the interactions between experimentation and theory and (3) the causes of the development and stagnation of science and technology. Note that theses subject related to the study of the Nature of Science (NOS) are underlined in the education program. However, these considerations are not sufficiently clarified in the curriculum, a situation that discourages several teachers.

Thus, for our study, we specify for each of these themes, the concepts to cover and their historic consideration has been carried out with the goal of identifying the most important concepts. For each theme, the students should have knowledge about the following realities: (1) the objectives pursued by the development of science and technology across different times and in different societies, (2) the way scientists and technicians of different periods proceeded to construct their knowledge and (3) the political, social and economic factors that influence their development.

As for the didactic and pedagogical considerations in this approach, they served to encourage preservice teachers to learn the following aspects: (a) to guide their future pupils in sharing and confronting their ideas on natural and constructed phenomena with which they are in daily interaction (b) to identify their conceptions before and after teaching and (c) to bring them to recognize the relevant data in a series of observations linked to the study of a phenomenon (electric and magnetic) in a laboratory context. The strategy developed with the students to help them acquire the scientific notions took place in six stages. Below each stage will be presented and followed by its qualitative analysis.

Stage 1: Overview of the concepts prescribed in the Ministry of the education's program

This 3-hour stage took place in the following manner: before this meeting, the preservice teachers had to study the scientific concepts and the pedagogical content prescribed in the Ministry of Education's program. They also had to note their comments. It is important to point out that the time allowed is not sufficient to analyze the prescribed concepts. However, the discussions at the meeting, as well as the preservice teachers' questions, were constructive, since it allowed them to have a general idea of the objectives of the program and to realize its conceptual complexity.

Stage 2: The study of the physical states of matter, heat and temperature

This 6-hour phase was designed to study the physical transformations of matter (solid, liquid, gas), heat and temperature. As noted above, the knowledge related to these notions is not explicit in the education program. Thus, we first studied the physical properties of these states and their transformations on a macroscopic scale. Then we studied them on a microscopic scale. These studies were as follows: study of the notions of mass, volume, void, temperature and heat; study of the atomic and molecular aspects of matter; study of the physical transformations of water (solid, liquid, gas) and the conservation of matter; study of instrumentations (principles of the Roberval scales and the Celsius thermometer). Before this meeting, we asked the students to carry out the following activities:

1. Complete a multiple-choice questionnaire on the physical transformations of matter as well as the notions of heat and temperature. They had to complete it and justify their choice of answer by referring to their previous knowledge. The formulated questions were taken from the research done throughout the world on the pupils' and teachers' misconceptions.
2. They were then asked to view five videos (of five minutes each and pertaining to the aforementioned concepts) available on YouTube (TV Ontario Eureka / Science video series).
3. Finally, they had to verify some of their answers following the information presented.

During these two meetings, the students had first to discuss the videos they viewed and the questionnaire they completed. Following this, the students were presented with the molecular (and atomic) model of matter to explain the physical transformations of matter considering the principle of the conservation of matter. Then, they completed a multiple-choice questionnaire with justification of their answers to assess the evolution of their conceptions. Its analysis shows that many students have made significant progress, despite the short time devoted to the study of these notions. Unfortunately, some conceptual difficulties persist: explaining the increase in the volume of water during its transformation from liquid to solid by referring to the geometric structure of water in the solid state (hexagonal), differentiating the notions of Heat and Temperature, etc. On this last question, despite the illustration of the false theories developed during history (particularly the caloric theory developed during the seventieth century), their false conceptions persist. In this regard, several studies point out that such a change requires more time and need multiple strategies.

Stage 3: Magnetism

The 6-hour phase was designed to study magnetism. For this, the students carried out in a group of two a laboratory of a duration of 3 hours. Thus, each team member had to complete a multiple-choice questionnaire with justification to evaluate his previous conceptions. Then, each team had to carry out experiments related to ferromagnetic objects' attraction by a magnet, attraction, and repulsion between magnets, magnetic induction, and magnetic field. As a result of the experiments carried out, they had to check whether some of their answers were in line with the observations made. During the second session of 3 hours, we presented the scientific notions underlying the observations made and their historical considerations [Thales of Miletus (6th century before Christ), Pierre de Maricourt (13th century) and William Gilbert (1544-1603)].

Finally, they completed a questionnaire to assess the evolution of their initial conceptions. Contrary to the previous theme, the analysis of the pencil-paper questionnaire shows that they have abandoned some of their misconceptions such as a magnet attracts all metals, the magnetic field can be seen through iron filings, the poles of a magnet are the same as the (+) and (-) poles of a battery.

Stage 4: Chemical transformation

The 3-hour phase was designed to study chemical transformations. How to facilitate students' understanding of chemical reaction: (a) assessment of knowledge before teaching, (b) study of water formation, sodium chloride, rust, acids and alkalis: covalent and ionic bonds and (c) review of stage (a) and assessment of knowledge after teaching.

Stage 5: Rectilinear propagation of light

The 3-hour phase was designed to study the rectilinear propagation of light. How to facilitate students' understanding of the rectilinear model of light propagation: (a) assessment of knowledge before teaching, (b) study of shade, twilight, lunar and solar eclipses and (c) review of stage (a) and assessment of knowledge after teaching.

Stage 6: Electrical circuits

The 6-hour phase was designed to study the functioning of electrical circuits.

How to facilitate students' understanding of simple electric circuits functioning by experimentation (laboratory): (a) assessment of knowledge before laboratory experiment, (b) study of branching in simple circuits: open and closed circuits, (c) study of Volta battery and Edison lamp, (d) qualitative study of circuits' set, parallel and mixed study of short circuit, (e) quantitative survey: measures of current and tension with a multimeter and (f) review of stage (a) and assessment of knowledge after laboratory experimentation.

Strategy developped by pre-service teachers and methodology

For their future pupils, the pre-service teachers had to develop two learning sequences based on hand-on laboratory. Each one should be about one of the following themes: (1) branching in simple electric circuits, (2) floatability, (3) thermometer, (4) magnetism, (5) electromagnetism, (6) solid, liquid and gas, (7) rust formation, (8) heat conduction in solids, (9) flat mirror, (10) eclipses, (11) conduction in liquids, (12) construction principle of a battery, (13) acids and alkalis. The study of these themes is indicated in the curriculum.

Every learning sequence should have a duration of two periods of forty-five minutes each. It is a project that their future pupils should preferably be doing in groups of two. The document that will be handed over to every pupil for each of the learning sequences that must contain seven steps as illustrated below:

Step 1: Title of the project and introduction

The title must be formulated so that it is attractive to the pupil. It will be necessary to explain to him the objectives of the project. In short, at no time the elements that would unveil the results of the experimentation must be revealed. Also, it would be necessary to present the pupil with all the stages of the project.

Step 2: Questionnaire of introduction

A questionnaire made of six questions should at the same time consider the pupil's cultural, social and natural environments and the concepts that will be covered in the studied theme. Technical questions which the pupils risk not answering should be avoided. Questions should be formulated based on a simple experimental situation in the pupil's immediate environment. At this stage, it is important to specify why the pupil is asked to complete a questionnaire.

Step 3: Experimentation (hand-on/laboratory)

The experimentation part will take place in four stages: (1) an overview that aims to identify a problem belonging to the pupil's immediate environment to encourage him to formulate his own hypothesis. Then, the pupil is invited to conduct an experiment to solve the problem and to verify his hypothesis. (2) He will be given a list of the necessary material to achieve the experiment. It will be necessary to give him clear instructions all along the stages of the execution so that he can make the manipulations with success. On this topic, several studies analyzing the laboratories done in a school demonstrate that often the given instructions are not sufficiently clear and discourage some pupils (Métioui & Trudel, 2007). Likewise, if necessary, make clear the precautions to take in terms of security all along the manipulations. (3) The pupil must answer the questions he is asked while completing, for example, a table of measures. (4) He must also make note of his interpretations or provide a graph and record the tendency between two variables for example, or possibly illustrate his answer with the help of a drawing. After each experimentation, he will be presented with the results of the observations that he is supposed to achieve if he has followed the given instructions correctly. This part is important, because in the case where his results would not be identical to those with which he has been presented, he should repeat his experiment. Thus, he will advance while feeling confident. Finally, a description of the observations ensuing from every experiment as well as an analysis and a synthesis of the results must be completed by the pre-service student so that the pupil can compare his results.

Step 4: Scientific concepts

With the observations resulting from each experimentation, the pupil will be presented with the scientific concepts. These concepts will be more attractive for the pupil since he must study them once he will have successfully carried out his experiment.

Step 5: Review of the introduction questionnaire

This stage will allow the pupil to verify again his answers following what he has just learned. Then, he will receive the answer sheet so that he can compare the answers with his own.

Step 6: Assessment of the pupil's knowledge after teaching

This stage serves to evaluate the pupil on all the studied concepts. The number of questions depends on the content covered in the whole laboratory experimentation. No question being part of the initial questionnaire must be formulated in this questionnaire. In contrast with the questions formulated in the introduction questionnaire, the questions in the present questionnaire need to be linked with the concepts studied and the techniques learned in the laboratory.

Step 7: Answer sheet of the questionnaire

The pre-service student must present his own answers so that the pupil can compare them with his own answers.

Self-evaluation of the pre-service teachers and methodology

A questionnaire was given to the pre-service teachers to conduct a self-evaluation of their project. For this purpose, they had to individually complete each of the six-following question:

1. What were the challenges in the formulation of the 12 questions (6 by theme) in this first stage of your project? You had to design at the same time questions that must consider the environment of the pupil and the concepts that will be covered in each of your two themes.
2. What different problems did you encounter at each of the four stages you had to follow for the construction of your experiment? The four stages are as follows: (a) setting up the situation (b) experimentation material (c) formulation of questions all along the experimentation and (d) description of the observations arising from the experimentation.
3. What were the difficulties encountered when presenting the pupil with the scientific concepts related to the experimentation?
4. What were the difficulties encountered when evaluating the pupil's knowledge after the experimentation and the study of scientific concepts?
5. What were the difficulties encountered when presenting the pupil with the answer sheet of the questionnaire presented in stage 1?
6. What were the difficulties encountered when presenting the pupil with the answer sheet after the experimentation and the study of scientific concepts?

Note that this questionnaire was intended to know their self-evaluation on each of the following 6 steps of their project: (1) introduction questionnaire, (2) experimentation, (3) scientific concepts, (4) evaluation of the knowledge after the experimentation and the study of scientific concepts, (5) answer sheet of the introduction questionnaire and (6) solutions of questionnaire 2.

Analysis of the questionnaire

The analysis of the data took place in two stages. In the first stage, the answers were compiled, one question at a time, each taken separately. For each of them, we proceeded to the classification in distinct categories, the number of which being variable from one question to the other, according to the different answers given. The reliability of the research data was supported by a member of our group acting as an independent researcher. He analyzed the students' comments and came up with same the categories.

Analysis of the first question

The answers given by pre-service teachers related to the construction of the introduction questionnaire permitted us to identify two categories of answers as presented below; each of these categories is illustrated with an example of answer. In order to personalize information while preserving anonymity, the pre-service teachers were identified by the symbol P_i (ième pre-service teacher).

Category 1 (80%) - Pre-service teachers encountered difficulties to bring out the initial conceptions of the pupils before the experiment:

> "*I had some difficulties in the formulation of the questions to introduce the topic. I did not want to provide too much information and I wanted to captivate their attention. It was therefore a beautiful challenge for me*" (P_{20}).

Despite the difficulties encountered, the pre-service students stated that they had attempted to meet this challenge which included formulating questions that reflected the environment of primary school pupils.

Category 2 (20%) - Pre-service who did not report difficulties in formulating their questionnaire. They proceeded on considering the notes of the course and thus constructed questions that reflect the scientific phenomenon in question and the environment of the student:

> "*The challenges were to create concrete situations where the odds were high that the pupil would be aware of them in the past and to create a question bringing directly one or more links to the topic and the concepts being connected to the situation. Furthermore, the challenge has been to create simple and interesting situations to capture the pupil's attention*" (P_{30}).
>
> "*To create the questionnaire, I was inspired by my course notes on the thermometer. For example, the first question should do with finding out what the red is made of inside the thermometer. This question was linked to what was learned in the course and with the pupil' environment, since he is accustomed to see a thermometer in his daily life. The challenge that I faced at this stage was to create questions that would not be too difficult for the pupil, even though he had the possibility to make another attempt to answer them. I did not want him to feel discouraged at the very beginning of the project*" (P_{17}).

Analysis of the second question

The analysis of the data advanced by the pre-service teachers about the experimentation (hand-on/laboratory) made it possible to identify three categories of difficulties that are presented below and which are followed by the students' statements as an illustration.

Category 1 (40%) - Pre-service teachers encountered difficulties to achieve the experiment. Here are some answers:

> "*During the experimentation, I was confronted with a problem. On the Internet site, it said that the ink only served to better see the water going up in the bottle (thermometer). Thus, I made a first experiment with food coloring. Obviously, it did not work. Therefore, I redid it with printer ink and the experiment worked perfectly. Thus, it is necessary to pay attention to what one reads on the Internet and verify the information*" (P_{23}).
>
> "*Another problem with which our group were confronted was that we had to repeat the experiment about the evaporation because it didn't work the first time. We had left the glass inside and the results had not changed very much. When we repeated the experiment, we left the glass outside and we obtained better results*" (P_{32}).

Once the students carried out the experiments suggested on the Web, they realized to their surprise that, by following the instructions given, they did not obtain the expected results. To succeed, they took the initiative to introduce some changes in the protocol. Such awareness will prevent future teachers from proposing experiments that do not work, which may discourage many pupils from appreciating the use of experimentation in science.

Category 2 (50%) - Pre-service teachers encountered difficulties in synthesizing the essential elements underlying the observations arising from the experimentation done. Here are some answers:

> "*The stage of the experimentation that was the most difficult for me was to understand and achieve the description of the observations resulting from the experimentation. In fact, it was difficult for me to grasp what the analysis of the results meant. To help me, I had to ask my colleagues at the university. This was of help to me*" (P_{11}).
>
> "*For this stage of the experimentation, I admit that I had some difficulties in understanding the information to be included in each of the parts: the observations, the analysis and the synthesis of the results. Since my experiment was simple enough and the results easy to obtain, I found that it was hard to write down the information in each part without repeating myself*" (P_{17}).

Category 3 (60%) - Pre-service teachers encountered difficulties in formulating questions throughout the experimentation. Here are some answers:

> "*This part was complex, because our group had to formulate questions without revealing some results in order not to bias the observations of the pupils*" (P_5).

"*Seated in front of my computer, the questions to formulate all along the experimentation didn't come to me naturally. It is more difficult than one might believe. I then decided to do the experimentations myself and to amuse myself a little with light and shadows. I was then more inspired to create my questions*" (P_{17}).

"*It was difficult for me to formulate the questions all along the experimentation, because I had not experimented the scientific method for several years. I did not remember how to proceed. It was necessary for me to review the subject matter by reading many scientific books and this took me a lot of time*" (P_{43}).

Throughout the experiment, the pre-service teachers had to formulate questions to the pupil to allow him to participate actively. Formulating these must not influence the pupil response.

Category 4 (70%) - Pre-service teachers encountered difficulties to describe the observations from experiments in a language that elementary school students could understand. Here are some answers:

"*I found it difficult to describe the observations in an appropriate language for children*" (P_3).

"*For this stage of the development of my experimentation, I answered the observation questions at the end of the experiments. I found it difficult to put in simple words my answers in a school language for the primary level*" (P_8).

These answers are not sufficiently developed to know the nature of this difficulty. Probably, it results from the fact that they have introduced scientific terms into the description of the observations, as we will see in the next question.

Category 5 (60%) - Pre-service teachers encountered difficulties in separating the description of the observations from the scientific concepts:

"*The description of the observations was integrated with the description of the scientific concepts. To describe the scientific concepts, we described the observations made by the pupils*" (P_{72}).

Many preservice teachers encountered difficulties in synthesizing the most important observations from their experiments for their future pupils, without elaborating on the underlying scientific notions. It is possible that this problem results from their previous education where they carried out the laboratory experiences after studying the theory.

Analysis of the third question

In terms of the acquisition of scientific concepts to explain the observations resulting from the experiments, the analysis of the answers presented reveals three categories of difficulties which are provided below followed by some of the answers:

Category 1 (60%) - Pre-service teachers encountered difficulties in acquiring scientific knowledge. Here are some answers:

> "*First I had difficulty to entirely understand how rust is formed since it is a topic of which we spoke very little in class. I consulted many sites to learn more about the subject. It took some time because I wanted to get reliable sources. Besides, most sites contradicted each other. Indeed, some stated that it took dioxygen for rust to form, whereas others stated that it absolutely needed water and dioxygen. It is the discussion in the course about a boat that sunk to the bottom of the water that made me finally understand*" (P_9).
>
> "*We consulted many resources to understand the phenomenon of rust formation. Furthermore, we questioned people in our surroundings to learn a bit more*" (P_{15}).

Category 2 (50%) - Pre-service teachers encountered difficulty to formulating scientific explanations adapted to the language of the pupil. Here are some answers:

> "*The explanation of scientific vocabulary in simpler words was difficult in this part of the project, since the consulted Internet sites were not always adapted for children*" (P_{54}).
>
> "*The difficulty that I met was to put complex scientific concepts in words adapted for children*" (P_{59}).
>
> "*Once we understood the phenomenon, our group had to put what we had learned in simpler words. It was difficult since there are many relevant and interesting things to say. We therefore had to filter the information and select what was important for the pupil and especially what ensued of our experimentation*" (P_{63}).

For these pre-service teachers, this problem stems from the consulted references which use difficult language for young people. They stressed that they consulted references on the Web to understand the scientific concepts in question. Also, they indicated that the scientific information presented was often contradictory. Therefore, they asked people around them to find out what is false from what is right. Such a situation could discourage teachers with limited knowledge of science.

Category 3 (70%) - Pre-service teachers encountered difficulties to find the resources that synthesize in a simple way information linked to the historic development. Here are some answers:

> "*For the historical part, I found it difficult to find reliable sources. Some sources contradicted each other and there was very little precise information on the discovery of acid and alkaline substances*" (P_{73}).
>
> "*Besides, the sources that we found were often not in words that could be understood easily about the discoveries made throughout different centuries. This, in fact, made it even more difficult to write about for children at the primary level*" (P_{78}).

Analysis of the fourth question

The explanations about question 4 on the evaluation after the experimentation and the study of scientific concepts made it possible to identify two categories of answers presented below.

Category 1 (80%) - Some pre-service teachers did not encounter difficulties to formulate questions to cover all the studied concepts. Here are some answers:

> "*The second questionnaire was a lot easier to construct. More technical questions could be asked. It is simpler to formulate questions to evaluate the skills that the pupil will have acquired following the project*" (P_9).
>
> "*It was easier to elaborate this questionnaire instead of the introduction, since the writing of the scientific concepts was finished. We were inspired by the concepts in the sequence to create the questions emerging from the environment of the child and from what he had seen in class*" (P_{22}).

Therefore, contrary to the first questionnaire which aimed to evaluate the initial knowledge of the pupils, this one was easier to develop for most of the students and served to verify their knowledge on what they had learned in the experimentation. Below, we present the reasons given by the students as an illustration.

Category 2 (20%) - Pre-service teachers encountered difficulties to formulate questions to cover all the studied concepts:

> "*The choice of the questions was very difficult to make since I wanted to make sure that I covered all that was included in the scientific concepts. Therefore, I had difficulty to synthesize my questions to review all the concepts*" (P_1).
>
> "*After having achieved the project, it was necessary to ask the pupil questions which would allow him to make a synthesis of his new knowledge on the topic. In my case, it was relevant to ask questions on the name of the physical transformations of water. Subsequently, it was more complex to find questions related to the different molecular arrangements of water in these various states*" (P_{20}).

Analysis of the fifth question

The present question is about the solution of the introduction questionnaire. The answers that pre-service teachers must give to their future pupil must be fair scientifically and adapted to the children language. All the pre-service teachers indicated that they encounter difficulties in formulating the answers.

> "*The part that gave me the most problems in the answer sheet of the introduction questionnaire was probably the question that asks the learner what are the various causes that explain why a bulb does not light up anymore. I thought about giving many more answers but I decided otherwise, what was maybe a mistake since the learner*

> *would have had the advantage of knowing all the different possibilities that explain why a bulb does not light up anymore*" (P_{32}).
>
> "*I found it difficult to make answer sheets for the questionnaire, since it was necessary to pay a lot of attention to the choice of words. It was necessary indeed that I made sure to use all the good terms in the good contexts in order not to confuse the pupil. Besides, it was only necessary to answer the question without giving too much supplementary information. Since the introduction questions were not directly linked to the subject, but were meant to activate the pupil's previous knowledge, it was not necessary to insert scientific concepts at this stage. The pupils had several conceptions about buoyancy, therefore I made sure to modify these false conceptions in the answer sheet of the first questionnaire*" (P_{51}).

Analysis of the sixth question

The present question is related to their difficulties to give the solutions of the questionnaire in order to evaluate the learning carried out following the experiment and the underlying scientific notions. Their answers revealed that they encounter difficulties in formulating these solutions. Here is one answer as an illustration:

> "*What was the most difficult in this first part of the work was to cover the whole set of important laboratory concepts in the explanations of my answers. It was also difficult to know to what extent my explanations had to be explicit to be understood by all the pupils who did the laboratory. Finally, I found it difficult to use simple words in the answer of my last question on the concept of reversibility*" (P_9).

Conclusion and implications

A brief review of the literature related to the acquisition of skills in science and in pedagogy by primary pre-service teachers is deficient. This review shows also that the time offered to this training is not sufficient to change their naïve beliefs about their understanding of the nature of science as well as their misconceptions related to the scientific concepts. In this regard, Criado and Garcia-Carmona (2010) point out that because of the short time given to students, some of their misconceptions about electrostatics have not changed despite teaching centered on experimentation and debate: "*But there is still a long way to go. One needs to determine not only what the best practical approach in the classroom is, but also how much periodic and cyclic learning time would be required to produce satisfactory and steady evolution of the students' ideas. Therefore, there remains to address the question that, if these are the results following a short-term teaching process, what will be the case in the longer term?*" (p. 30).

Therefore, several questionnaires were constructed about the nature of science (Abd-El-Khalick & Lederman, 2000; Métioui & Trudel, 2013) and the hand-on-laboratory for pre-service and in-service teachers (Häkkinen & Lundell, 2012). However, this research didn't illustrate the strategy that had to be constructed for pre-service teachers' education in didactics of science at the university regarding the curriculum of the Ministry of Education. The short time offered for their education resulted in the numbers studies on pre-service teachers' understanding the nature of science and their misconceptions in order to help them to acquire skills in science and pedagogy.

The present research was done in this perspective. To this end, a 6-step strategy was developed and experimented with pre-service teachers. The result of this experimentation shows that they change their false conceptions related to matter, magnetism, light and electrical circuits. However, some of their misconceptions have not changed despite the education provided (e.g. Criado & Garcia-Carmona, 2010).

As emphasized in the review of literature, research was developed on self-evaluation by teachers in relationship with their pedagogical and scientific knowledge. In the present research, their self-evaluation did not focus on their attitude towards their teaching in class, but rather on the design of a teaching strategy similar to that which they experienced in the course and that they had to adapt for their future students on a theme of their choice.

The results of their self-evaluation demonstrate that they succeeded in developing some interactive sequences of teaching, while following a course in didactics of science. It should be noted that the review of literature on teachers' education at the university did not refer to the following aspects: which strategy must be constructed in view of the demands in the curriculum of the ministry of education; the short time offered for their education in science and pedagogy; the results of the numbers studies on teachers' understanding of the nature of science as well as their misconceptions. These are deemed necessary to help them acquire skills in science and in pedagogy.

The results of the experimentation revealed that the students faced several difficulties. These difficulties are as follows:

1. Difficulty to formulate the questions that consider the pupil's social, cultural and material environment.
2. Difficulty to formulate questions that consider the language of children.
3. Difficulty to formulate questions without using scientific terms (acids, alkali, rust, electric current, voltage, energy, condensation, etc.).
4. Difficulty to find documents that synthesize the development of a scientific concept in a historical perspective.
5. Difficulty to differentiate true from false in a text.
6. Difficulty to formulate some questions throughout the manipulations without influencing the pupil's work.
7. Difficulty to present a synthesis of the observations that result from the experimentations without providing explanations.

8. The Information presented on the Web is not always reliable, since contradictions appear between sites. The addresses of most sites used by most the students are indicated in the appendix.

Also, the number of periods dedicated to this education is not sufficient if the aim is to have them develop their courses so that they are not simply applying recipes which follow the content written for them and their pupils in school manuals. The risk here is that a real understanding of scientific concepts will not take place. Finely, it would be necessary that this education in science and pedagogy be linked closely to schools to create a bridge between the school and the academic environment.

In their profession, teachers must plan teaching sequences for their pupils and manuals remain the tool of reference mostly used. However, these manuals do not clarify the concepts, the methods and the most important know-how that should be taught (Métioui & Trudel, 2007). Unfortunately, several teachers feel they have no other choice but to follow the proposed methods of these books. This way of teaching does not leave space for creativity and, especially, it does not consider the conceptual difficulties of the pupils. The research carried out in this study aimed at offering future teachers tools with which they could develop their own strategy, while giving an active role to their pupils. Obviously, such an education requires time and cannot be achieved in a science education course of forty-five hours, as the results of this study demonstrates.

Despite this limitation, the statements made by the pre-service teachers show a certain awareness of the interactions that they will have with their pupils. Also, they noted the gaps that exist in the consulted electronic documents. Perhaps an extra course in science which would cover the science concepts that have to be taught at the elementary level should be mandatory to help these future teachers to feel more comfortable with science as a required subject to teach.

In such a course, epistemological ruptures that have marked the development of scientific knowledge during history must be highlighted. For example, in the case of the physics developed by Aristotle, the movement requires the application of a sustained force. This false theory persisted until Galileo for whom the rectilinear movement at constant velocity does not need the application of a sustained force (law of inertia). Such an approach makes it possible to recognize the positive errors (Bachelard, 1968) in the development of science and to bring out its social dimension since it is not strictly a logical-mathematical framework, as most pre-service and in-service teachers think (Métioui & Trudel, 2013).

Parallel to this education, didactics materials (school manuals in which the history of sciences would not be reduced to a chronological succession of historical facts, interactive simulation software, films, interactive hands-on laboratories, etc.) must be developed for students to use, thus avoiding access to incomplete and unreliable documents as underlined by the pre-service teachers who participated in this research.

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