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MANDATED INTERDISCIPLINARITY IN SECONDARY SCHOOL:
The Case of Science, Technology, and Mathematics Teachers in Quebec

by

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Abstract: New curricular orientations in the secondary schools of many Western countries invite teachers of STEM school subjects (science, technology, engineering, and mathematics) to integrate these school subjects (Czerniak, 2008). In Quebec, such interdisciplinarity is not a mere recommendation, but an official component of the curriculum (a prescription). Teachers are expected to integrate the school subjects composing the STEM subjects, and to integrate this area with other school subjects. While this interdisciplinary orientation is laudable, it is important to discover how teachers whose training is disciplinary understand this mandated interdisciplinarity and apply it in their teaching practices. Based on a survey of 245 secondary school teachers, this study shows that the interdisciplinarity practiced and described by these teachers is a superficial one and is based on links that do not enable an integration of the contributions of the subjects concerned in order to solve complex problems or achieve unified knowledge (Klein, 1985, 1990; Lenoir & Klein, 2010). These links mainly involve theme-based approaches, the contextualization of subject knowledge (relationship with life outside the school), or the mobilization, in a given school subject, of prior learning acquired in another school subject. These means of understanding and implementing interdisciplinarity can be attributed to teacher education and to the organizational context and the curricular structure of the schools. This article suggests recommendations to help overcome obstacles to understanding and implementing full interdisciplinarity as highlighted by the study in question. Moreover, it also suggests that comparative studies, along with the sharing of training experiences among teachers in different countries, might shed important light on this issue. These comparative studies would make it possible to identify the best ways to train teachers to be able to implement more-than-merely-superficial interdisciplinary practices in their classrooms. Moreover, the analytical framework and methodology used herein, as well as the results obtained, are not limited to STEM subjects but also apply to all other school subjects. Therefore, such studies as the study we report on here should be of interest to all actors (practitioners and researchers alike) concerned with interdisciplinarity in school programs at any level anywhere in the world.

Keywords**:** interdisciplinarity, science and technology, STEM, school subject, curriculum

Introduction

The development of the modern sciences is based on the creation of the scientific disciplines toward the end of the 18th century (Fourez, 1996, 1998; Serres 1989; Stichweh, 1990). Despite this necessary specialization, the contribution of the scientific disciplines to understanding the world and to offering solutions for human needs increasingly requires the use of interdisciplinary approaches (Fourez, 1998; Klein, 1990, 1998; Lenoir, 1995). Indeed, understanding phenomena as varied and complex as those concerning the environment, plate tectonics, genetic engineering, or carbon sequestration techniques requires multiple viewpoints and the integration of insights that go beyond the contribution of any one discipline.

This need for interdisciplinarity is true of school sciences, first for the same reasons: Schools cannot content themselves with introducing students to what Schwab (1964) and others have named the structure of subjects (or disciplines) or the structure of knowledge (Bartos & Lederman, 2014; Schwab, 1964; Shulman, 1986)[1]. They must also enable students to understand the complex

[1] According to these authors, a) each discipline operates within a domain; practitioners of the discipline operate within the domain by means of a substantive structure (a set of concepts, models and theories and the relationships that organize them) and a syntactical structure (means of providing evidence); and b) school subjects should serve as faithful and valid introductions to the academic disciplines whose names

world in which they live and to act within it by mobilizing knowledge from various school subjects in an integrated manner.[2] Second, more and more schools in the Western world are undergoing changes that require these multiple viewpoints and insights. The competency-based approach and the fact that school science takes into account social issues such as environmental education or health education require this school science to open up to issues that extend to other disciplines and to life outside the school. As we will explain in regard to the specific case of Quebec, the evolution of curricula in Western countries as well as in most developing countries has led to an explicit call for the use of interdisciplinarity, in terms of both official prescriptions and classroom practices (Lenoir & Klein, 2010).

In Quebec, a Francophone province of Canada, the latest curriculum reform for primary school (Gouvernement du Québec, 2001) and secondary school (Gouvernement du Québec, 2004, 2007) identifies interdisciplinarity as one of its main orientations. This curriculum's implementation has been guided by three broad aims: 1) to create a fairer school in terms of equal opportunity, hence promoting the success of all students; 2) to put in place a more thoroughly developed and focused academic program; and 3) to ensure greater coherence and convergence among curricular components. The school sciences (and other school subjects) have undergone many changes with a view to achieving these aims. To better explain these changes and the ways these school subjects involve interdisciplinarity, the following section briefly presents the previous and current structures of the science and technology (S&T) program.

1. The structure of the S&T program and the conception of interdisciplinarity that it conveys

Before the latest reform, the secondary school science program in Quebec was organized into school subjects that were generally named after the main university disciplines: ecology in the first year of secondary school, physics in the second year, biology in the third, etc. With the reform, the primary program and the first four years of the secondary program introduced an integrated program entitled "Science and Technology," designated a "Subject Area"[3] by the provincial ministry of education. This subject area

they bear (Gardner, 1975).

[2] This article deals with interdisciplinarity in the school context, not with academic interdisciplinarity in the university context. To refer to disciplinary knowledge in school programs, following on other authors (Deng, 2007; Klein, 2002), we will use the term "school subjects" or "school S&T."

[3] Considering the specific nature of the Quebec S&T program, and for the sake of

is made up of contents from five disciplinary fields (astronomy, biology, chemistry, geology, and physics) and from technological disciplines, and is organized into two key components (Figure 1).[4]

A) Three subject area competencies. The curriculum puts special emphasis on competency 1, which has to do with scientific inquiry and technological design processes. The emphasis on this competency is consistent with the orientations of programs in numerous other education systems. For example, one strand of the National Science Education Standards in the USA (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 has also highlighted the importance of developing scientific "habits of mind" alongside a knowledge of science content (AAAS, 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 subjects. For example, Competency 1 in Figure 1 (Seeks answers or solutions to scientific or technological problems) aims explicitly at what standards in the USA call "scientific inquiry" and what programs in the UK call "process and methods of science."

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clarity in this article, we will use the following terminology throughout this text: "subject area" when referring to the integrated S&T program; and "school subject" when referring to the contents of a particular subject (astronomy, biology, geology, physics, chemistry, etc.).

[4] The structure is similar for mathematics. The three mathematical competencies are as follows: solves situational problems, uses mathematical reasoning, and communicates by using mathematical language. The mathematics "program content" is composed of different school subjects, such as arithmetic, algebra, geometry and statistics.

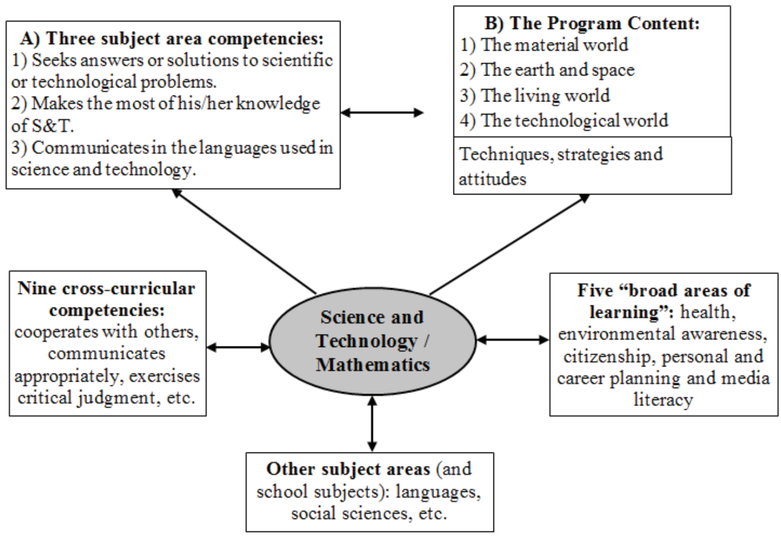

Figure 1. Structure of the S&T program and its relationship to other components of the curriculum in Quebec

B) The Program Content. This content is composed partly of concepts, models, and theories from physics and chemistry (called *The Material World* in the program), geology and astronomy (*The Earth and Space*), biology (*The Living World*) and engineering (*The Technological World*). It is also composed of learning grouped into *Scientific Techniques, Strategies, and Attitudes*. The Ministère de l'Éducation additionally underlines the importance of connecting this content with students' social, cultural, and everyday realities to promote learning. Generally speaking, the components of the S&T subject area are comparable to the contents of this subject area in various other education systems. As a result, the reflections and results presented in this article should be useful for debates on the contribution of S&T to the interdisciplinary approaches of these other education systems.

In the Quebec curriculum, S&T teachers are also asked to use interdisciplinarity to teach their school subjects in connection with other curricular components (Figure 1): a) cross-curricular competencies (procedural knowledge that goes beyond subject-specific contents, such as cooperation, critical thinking, etc.), b) the "broad areas of learning," which address five social issues in the curriculum (the environment, health, citizenship, personal and career planning, the media), and c) the other subject areas (and school subjects).

Thus, the new curriculum has various implications for the teaching of S&T from an interdisciplinary perspective. It would appear, in our view, that the choices made with regard to interdisciplinarity in the Quebec curriculum go beyond many countries' recommendations for an integrated approach to the STEM subjects. Indeed, interdisciplinarity in Quebec is not a mere recommendation, but an official component of the curriculum (a prescription). This prescription, moreover, goes a step further than international recommendations for integrating the STEM subjects in that it extends to all curricular components, including other school subjects such as humanities and social sciences, as well as languages. However, key questions remain, questions that our study seeks to answer. Which conceptions of interdisciplinarity are conveyed by the Quebec curriculum, and how do teachers understand and implement this approach?

The curriculum proposes four forms of curricular organization by which to promote interdisciplinarity and to mitigate the compartmentalization of subjects:

a) The integration of scientific and technological school subjects (astronomy, biology, chemistry, physics, etc.) within the same subject area. This integration requires teachers to use a first form of what is referred to as interdisciplinarity, one that is established among the school subjects in the S&T program.
b) The integration of S&T and Mathematics (M) in the same subject area. The ministry justifies the mandate of this integration by the desire to promote these disciplines' "natural" interdisciplinarity:

> Mathematics, science and technology have long been intrinsically linked, and their evolution as well as their internal dynamics reflect their synergistic relationship. Hence, the design or representation of certain technical objects, the development of mathematical models or the representation of scientific phenomena are all a product of the inevitable connections between these subject areas[5]. (Gouvernement du Québec, 2004, p. 183)

In this sense, the *Programme de formation de l'école québécoise* or Quebec education program (QEP) is consistent with the strong international tendency today to group these disciplines together as *Science, Technology, Engineering, and Math*, or STEM (Beatty,

[5] See footnotes 3 and 4 in this article for the meaning given to the term "subject area."

2011). However, in Quebec, S&T and M programs were written by two independent departmental teams and are generally taught by different teachers (S&T teachers and M teachers). Consequently, in this article, we will designate them separately (S&T and M), rather than use the acronym STEM. This second way of organizing the curriculum (integrating S&T and M in the same subject area) invites teachers to use a second form of what is called interdisciplinarity, namely solving problems that call upon the S&T school subjects as well as the mathematics subjects (algebra, geometry, statistics, etc.). This form of interdisciplinarity requires collaboration among S&T teachers and M teachers, since the two subject areas are generally addressed by different teachers.

c) Different forms of dialogue (including interdisciplinarity) among the S&T and M area and the other subject areas or school subjects, such as languages and social sciences:[6] "To ensure that students receive an integrated education, it is important to connect scientific and technological learning to learning in other subjects" (Gouvernement du Québec, 2004, p. 229). Like the second form of interdisciplinarity this third form that is prescribed by the curriculum requires collaboration among teachers in different school subjects and different subject areas.

d) The introduction, in the QEP, of issues that relate to life outside the school (environmental education, health education, citizenship education, etc.). The curriculum designates these issues as complex problems whose understanding requires the integrated contributions of different school subjects and subject areas, including S&T and M. By addressing these issues, the curriculum prescribes a fourth form of what is designated as interdisciplinarity, one that implies not only collaboration among specialist teachers in different subject areas (S&T, mathematics, social sciences, etc.), but also collaboration with non-teaching professionals (environmental specialists, health specialists, etc.).

The four forms of curriculum organization that we have just described are the ones mandated by the ministry in order to promote interdisciplinarity. However, the ministry does not provide school staff (teachers, pedagogical advisors, etc.) with explicit definitions of interdisciplinarity or of other types of links among subjects (pluridisciplinarity, multidisciplinarity, theme-based approaches, etc.), or with suggested ways to use any version of these

[6] The QEP is made up of five subject areas: a) languages; b) mathematics, science and technology; c) social sciences (geography, history and citizenship education); d) arts (drama; visual arts; dance; and music); e) personal development (physical and health education; moral instruction; Catholic moral and religious instruction; and Protestant moral and religious instruction). In 2008 moral instruction and moral and religious instruction were replaced by an "ethics and religious culture" program.

approaches in practice.

In addition, even if the official documents that accompany the QEP explicitly mention interdisciplinarity, the S&T and M program abundantly uses other terms that can create confusion regarding the meaning of interdisciplinarity: connections, links, etc. The following excerpts serve as an illustration of the confusing way these terms are used to designate different supposed forms of interdisciplinarity:

> They [students] also gradually discover the role of mathematics in society by, for example, carrying out interdisciplinary projects involving related strategies and mathematical knowledge, while continuing to develop on a personal level. (Gouvernement du Québec, 2004, p. 192)

> Making connections between mathematics and other subjects enriches and contextualizes the learning situations in which the students will be developing their competencies. (Gouvernement du Québec, 2004, 2004, p. 193)

> The knowledge related to one subject area can shed light on another subject area and vice versa, which is useful for the development of the subject-specific competencies. There are fundamental links between the study of mathematics, science and technology and the study of languages. Through these subject areas, students can master everyday vocabulary as well as mathematical, scientific and technological terminology, express their understanding, begin learning how to present an argument, communicate their ideas, and conceptualize and clarify their thinking. Mathematics, science and technology and arts education can also be linked in a number of ways. (Gouvernement du Québec, 2004, pp. 184-185)

These excerpts do not put forward a clear definition of interdisciplinarity, as defined by the scholars in the field (see Section 2.1).

In this context, it is important to verify how S&T and M teachers interpret these prescriptions, how they understand interdisciplinarity and how they apply it in their teaching practices.

The 2010 special issue of the journal *Issues in Integrative Studies* (Lenoir & Klein, 2010) is comprised of texts that show how interdisciplinarity influences and shapes national curricula and secondary school teachers' practices in various countries: the United States (Boix Mansilla & Lenoir, 2010), Australia (Long, Morin, & Harris, 2010), Canada (Clausen & Drake, 2010; Lenoir & Hasni, 2010), and France (Niclot & Baillat, 2010), etc. The articles presented in this special issue shed important light on interdisciplinary practices by adopting a broad perspective (an overview of the situation in each of the countries concerned) rather than looking at the impact of this approach on specific school subjects, such as S&T and M. The object of this article is precisely to make a contribution that is complementary to those of the above mentioned special issue by dealing with interdisciplinary practices in S&T and M: How do S&T and M secondary school teachers appropriate the concept of interdisciplinarity and incorporate it into their teaching practices, in Quebec in particular?

The present article attempts to address this question by examining a study performed with 245 S&T and M teachers at the secondary school level. It also contributes to the literature by presenting a conceptual framework for analyzing interdisciplinary practices specific to S&T and M, or at least practices understood as interdisciplinary. The results of the study and the conceptual framework presented in this article are intended to nurture reflection on the best ways to train teachers so that they will be able to successfully implement truly interdisciplinary practices. The results, in addition to shedding light on the Quebec situation, are also important for the Organization for Economic Cooperation and Development (OECD) countries at large, since the desire to provide interdisciplinary instruction is shared by S&T and M teachers in these countries.

The study builds on and is complementary to the research on interdisciplinarity and primary schools in Quebec that has been conducted by Professor Yves Lenoir over several decades (Lenoir & Hasni, 2010).

2. Analytical framework

The analytical framework for this study was developed in the context of past research on interdisciplinarity in Quebec schools (Hasni, Lenoir, Larose, Bousadra, Samson, & dos Santos, 2008; Hasni, Lenoir, Larose, & Squalli, 2012). The framework, which we will briefly present here, is based on four principal dimensions: conceptual (What is interdisciplinarity?), functional (Why is it useful or necessary to implement interdisciplinarity?), operational (How can interdisciplinarity be or how is it planned and implemented in classrooms?), and organizational (What are the conditions and constraints that accompany the implementation of interdisciplinarity?).

2.1 The conceptual dimension

As researchers, we fully subscribe to the definition of interdisciplinarity developed by the foremost specialists on this concept (e.g., Fourez, 1998; Jacobs, 1989; Klein, 1990, 1998, 2002; Lenoir, 1991; Lenoir & Sauvé, 1998*a*, 1998*b*; Vars, 1993), namely "a process of answering a question, solving a problem or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession" (Klein & Newell, 1997, p. 393). "Interdisciplinarity draws on disciplinary perspectives and integrates their insights through construction of a more comprehensive and integrated perspective" (Klein & Newell, 1997, p. 394). Interdisciplinarity in this sense pursues the aim of conceptual synthesis, that is, one might say, an approach that strives for unified knowledge (Klein, 1985, 1990; Lenoir & Klein, 2010). Interdisciplinarity can also have an instrumental aim of providing integrated solutions for complex social problems (for example, cases related to pollution, healthcare, etc.). This twofold aim of interdisciplinarity (theoretical and instrumental) has been presented and argued in depth by certain authors (e.g., Klein, 1985, 1990; Lenoir & Klein, 2010).

However, this is not always the definition to which teachers, teacher educators, and curriculum designers are exposed. As Klein notes, "Not all interdisciplinarities are the same.… Disagreements about definition reflect differing views of the purpose of research and education, the role of disciplines, and the role of critique" (Klein, 2005, p. 55). The same author further points out that "there is no unique interdisciplinary pedagogy" (Klein, 2002, p. 14). This is why, in order to analyze teachers' (and program designers') conceptions of interdisciplinarity, it is important to take into account both the definition we have just presented (interdisciplinarity in a strict sense) and other forms of relationships between subjects (intra-, multi-, and pluri-disciplinarity; theme-based approaches; etc.) that can be inaccurately considered as full interdisciplinarity (Fourez, et al., 2002; Jacobs, 1989; Klein, 1990, 1998; Lenoir & Sauvé, 1998*a*, 1998*b*). Moreover, in Quebec as in the United States (Boix Mansilla & Lenoir, 2010; Klein, 1990), the concept of interdisciplinarity is strongly associated with the concept of integration, and the two concepts are sometimes used interchangeably. This is why, in the context of our survey with the teachers, we addressed both concepts (interdisciplinarity and integration).

2.2 The functional dimension

The intent here is to reveal the function that teachers attribute to this teaching approach among the possible functions reported in the scholarly literature. These functions could schematically be situated with respect to three poles (Hasni, et al., 2008).

First, from a psycho-pedagogical point of view, interdisciplinarity is seen by some authors as a means for pedagogical differentiation (Legrand, 1986), as a response to the psychological diversity of groups to be educated (Meirieu, 1986), or as a way to address student motivation. This aim is explicitly presented in the QEP:

> This approach [interdisciplinarity] gives students a grasp of the interrelations between different themes or subjects and broadens the scope of their learning. In addition, considering a situation from several angles increases the likelihood that all learners will find it meaningful in terms of their own experiences, interests and values—and thus contributes to their motivation. The interdisciplinary approach also allows for the practice of differentiated instruction, which is necessary because of the heterogeneity of the student population and the objective of educational success for all students. (Gouvernement du Québec, 2004, p. 57)

Second, from a sociological point of view (Beane, 1997, 2002; Bernstein, 1997), the degree of specialization and segmentation (or compartmentalization) involved in the division of school knowledge conveys an elitist conception of its appropriation by students. Interdisciplinarity is then an avenue that facilitates access to knowledge for all and enables students to participate in democratic life. According to Beane (2002), who also refers to a "democratic core curriculum,"

> Curriculum integration has long been proposed as a way of organizing the "common learnings" or life skills considered essential for all citizens in a democracy. Curriculum is organized around real-life problems and issues significant to both young people and adults, applying pertinent content and skills from many subject areas or disciplines. The intent is to help

> students make sense out of their life experiences and learn how to participate in a democracy. (p. 26)

Finally, from an epistemological point of view, certain authors have emphasized the interdisciplinary contribution to constructing meaning (understanding complexity) (e.g., Fourez, et al., 2002; Klein, 1990; Lenoir & Klein, 2010), as well as to proposing practical solutions to societal problems (students' use of knowledge in life situations outside the school). In our view, this dual aim should be the foremost purpose of interdisciplinarity in schools. It is also the dominant purpose in the scholarly literature on this subject. Although interdisciplinarity can contribute to fulfilling the first two functions (psycho-pedagogical and sociological), these can be just as adequately pursued through specific disciplinary instruction, as shown by numerous texts on student motivation, attitude, and interest related to S&T (Potvin & Hasni, 2014).

2.3 The operational dimension

Many questions can be considered in order to study this dimension: What place do teachers give to interdisciplinarity in their teaching? With what other subject areas or school subjects are S&T and M engaged in interdisciplinary approaches? How? What is the degree of collaboration among specialist teachers in these disciplines? What components of these disciplines are integrated together when using this approach? Etc. In response to this last question, two important remarks are worth making, since they justify our choices:

1) To avoid problems when planning and teaching based on an interdisciplinary approach, it is important for educational actors to clearly identify the components of each subject that are involved and the degree to which they will be integrated. The fact that two subjects are taught together does not constitute an interdisciplinary approach. Reading or writing a text on amphibians (S&T) in a language course (French or English) does not constitute an interdisciplinary approach, because amphibians can merely provide a context for language learning, without leading to S&T learning. Many issues of this nature can arise, and have been extensively described in previous research (e.g., Jacobs, 1989; Lenoir & Hasni, 2010).
2) In the school context, interdisciplinarity cannot be limited to mobilizing and integrating previously learned subject-specific knowledge in order to understand a situation or solve a complex problem. The use of

interdisciplinarity must also enable new learning (concepts, investigation and inquiry processes, etc.) in S&T and in the other school subjects concerned.

Based on the two previous remarks and the writings of authors who have attempted to describe the ways interdisciplinarity is implemented (Jacobs, 1989; Fourez, 1998; Klein, 2002; Lenoir, 1997), two sets of questions warrant consideration, since they determine the quality of interdisciplinary teaching:

a) For each school subject, what are the components (conceptual knowledge, skills, scientific inquiry, competencies, etc.) that are integrated in the teaching of an interdisciplinary course? Earlier in the article, we presented the main components of the S&T program in Quebec. These components are consistent with international choices in this regard, which stress, among other things, two general bodies of knowledge: conceptual knowledge (which some call declarative knowledge) and methodological knowledge (which some call procedural knowledge). The former includes concepts, models, theories, etc. The latter includes technical and intellectual skills (being able to use a thermometer, being able to formulate a hypothesis, etc.) as well as scientific inquiry and technological design processes.
b) In addition to identifying the components of each school subject that contribute to understanding a problem using an interdisciplinary approach, our analyses also address the following question: Are these components the subject of new learning or are they simply mobilized (recalled) subsequent to prior learning?

To illustrate the ways interdisciplinarity is put into practice in relation to the two above questions, let us take the case of two simplified situations: The first (Figure 2) illustrates an approach focused on appropriating and integrating concepts in S&T and M (a relatively simple problem); the second (Figure 3) illustrates an approach focused on solving a problem related to pollution (a more complex problem).

In situation “a” of Figure 2, the initial problem is: What is the likelihood that a couple’s newborn will be a boy or girl? Why is the proportion of men and women approximately the same in society? This problem leads to the study of reproduction and of its role in the transmission of hereditary traits, namely during meiosis and fertilization. One of the questions to examine in this regard concerns embryo formation with female (XX) or male (XY) chromosome baggage. This process involves the random segregation of sex chromosomes during meiosis (formation of male and female gametes) and their random recombination during fertilization. The question of embryo formation thus leads to a contextualized mathematical problem: Is it possible to predict the chances of having an egg, and subsequently a female individual or a male individual, at the time of fertilization? Answering this question leads to constructing the concept of M (mathematical) probabilities or, at the least, of some of its facets, i.e. assessing the probability of an event. The same initial situation therefore leads to appropriating concepts in both S&T (fertilization, zygote, etc.) and M (probabilities).

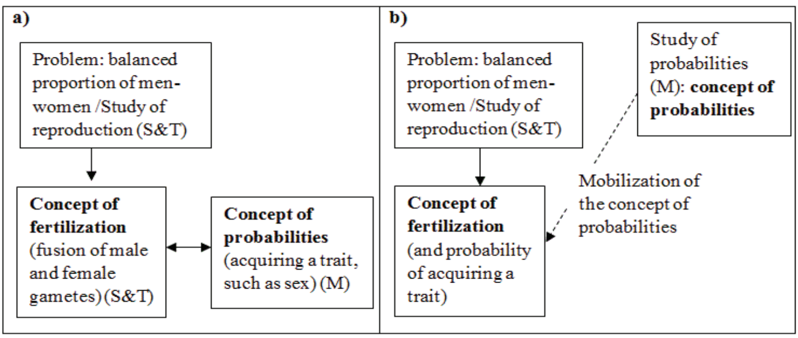

Figure 2. Examples of the integration of S&T and M via their co-construction (a) or their mobilization (b)

In Figure 2a, the initial situation is based on the study of reproduction; the starting point is thus biology. One might also consider the same situation with a mathematical starting point: The study of reproduction in S&T is an example among the variety of possible situations aimed at appropriating the concept of probability.

Another possibility, illustrated by Figure 2b, would be to mobilize the concept of probability already acquired in M, with a view to building the concepts of reproduction and of the transmission of hereditary traits in S&T. In other words, the S&T class would benefit from prior learning achieved in M. The opposite case might also be considered: Based on the concept of fertilization already acquired in S&T, students might be led to appropriate the concept of probability in M. What is at play here is the temporality of some learning, since the idea, in the same situation, is to achieve new learning for one subject and to mobilize already acquired (or supposedly acquired) knowledge for another subject.

In the examples we have just presented in Figures 2a and 2b, whether the starting point is an S&T problem or an M problem, what is targeted in both school subjects is the appropriation of new concepts and an integrated understanding of the original problem. Comparable configurations might be considered for other components of school subjects (skills, scientific processes, competencies, etc.).

The above example illustrates a moderate level of integration (which concerns concepts only). The following example (Figure 3) presents a more complex problem whose understanding requires the integrated contribution of several disciplines. The example involves the blue algae pollution affecting numerous lakes in Quebec. In a school context, S&T and M could contribute to understanding the scientific issues associated with blue algae (the plants' development conditions) and the social sciences could contribute to understanding the social issues associated with the problem. Owing to space limitations, this article cannot discuss all of the teaching and learning potential that such a complex problem represents. We will limit ourselves to presenting the integrated contributions of S&T and M, by way of illustration.

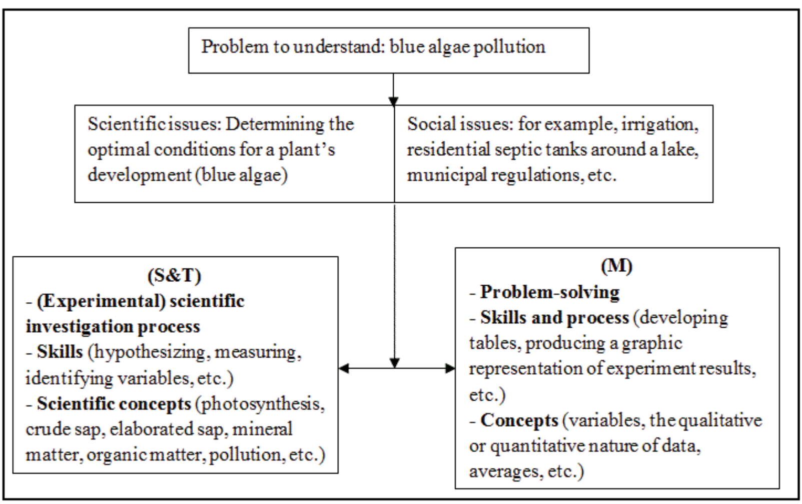

Figure 3. Integration of knowledge (concepts, skills, and processes) in M and in S&T in the context of an interdisciplinary situation

As the above figure shows, the study of optimal conditions for the algae's development is intended to lead students to hypothesize about its nutritional needs (mineral salts, light, carbon dioxide, water, etc.), and then to suggest and carry out an experimental protocol in order to verify each of these elements' (or variables') effects. For example, the students might measure the algae's growth (in millimeters or grams) depending on the quantity of each element. The experiment's results should lead the students to conclude that the algae (plants), with the help of light energy, use mineral matter (including phosphorous, which is common in fertilizer and septic tanks) to produce their own organic matter (photosynthesis). While utilizing a scientific investigation process, the students are also led to appropriate important S&T concepts. Over the course of this situation, the students are confronted with various mathematical problems (but also chemistry problems), including, for example, how to prepare various concentrations of mineral salts (chemical fertilizers). In the problem-solving process associated with this situation, the students are led to acquire diverse skills (identifying the nature of a functional relationship, developing tables, producing graphic representations, etc.) and to appropriate various concepts (variables, the qualitative or quantitative nature of data, functional relationships, etc.) in M. This situation also offers students the opportunity to approach the mathematical modeling of scientific and technological phenomena.

A detailed description of other configurations for integrating knowledge from S&T (and M) with other school subjects in the context of interdisciplinary approaches has been presented elsewhere (Hasni, et al., 2012; Lenoir, 1997). In this article, we merely wish to provide an overview of the framework that we used in the study.

2.4 The organizational dimension

What are the conditions and constraints associated with implementing interdisciplinarity at the secondary level? The teachers' understanding of interdisciplinarity and its implementation in classroom practice take shape in a context marked by constraints that need to be understood. Such conditions and constraints include, among other things, socialization in specific disciplines (in connection with teacher education), disciplinary programs' possibilities (or lack thereof) for achieving the desired integrations, the school's structure, and teachers' tasks, etc.

3. Methodology

In order to be able to describe these four dimensions of interdisciplinarity (conceptual, functional, operational, and organizational) as understood by secondary school teachers, in our research we used various types of data-gathering tools, namely focus groups, interviews, questionnaires, classroom recordings, etc. In this article, we examine results from a questionnaire survey that was complemented by individual interviews. The questionnaire was answered by 245 volunteer teachers[7] in secondary school in Quebec who teach S&T, M, or both, and was made up mostly of closed questions dealing with the previously described dimensions. A phone interview was subsequently held with 32 of these teachers who had participated in the questionnaire survey. The data have also been complemented by other data obtained in the context of previous surveys conducted via focus groups.

To consider other concepts used in the Quebec context (such as the "integration of subjects"), our questions used the terms "interdisciplinarity," "integration" and "interdisciplinary links." Our goal was twofold: to ascertain how the teachers describe the concepts of interdisciplinarity and integration; and to ascertain any other types of ostensibly interdisciplinary links that they might seek to establish. This approach allowed us to assess the actual nature of the supposed interdisciplinarity that exists within the secondary school S&T teachers' instruction.

The answers to the closed questions were processed using descriptive analyses (by means of SPSS software). The textual data were analyzed based on the techniques of thematic categorization (Bardin, 2007) and lexical analysis (Lebart & Salem, 1998). Finally, it should be noted that the questionnaire questions and the teachers' answers were in French. The results presented here have been translated from French to English.

4. Key results

4.1 Regarding the conceptual and functional dimensions

4.1.1 What is interdisciplinarity?

Three groups of questions were used to ascertain the meaning that the teachers assigned to interdisciplinarity. The first two questions were direct: 1) In your opinion, generally speaking, what is interdisciplinarity? 2) When you hear the word "interdisciplinarity," what are the main words or expressions that spontaneously come to your mind? When you hear the word "integration," what are the main words or expressions that spontaneously come to your mind? The third question was indirect: We asked the teachers to describe two units of study[8] in their

[7] The ministry of education provided us with a representative sample of 1,000 teachers. The questionnaire was sent to this sample. Of this number, 245 agreed to return us the completed questionnaire.

[8] In Quebec, the ministry of education uses the term *situation d'apprentissage*

classrooms that were representative of their interdisciplinary practices, and then to tell us how these units were interdisciplinary. In this section, we will address the answers to the first two questions. The answers to the third question will be presented in the section reserved for the operational dimension.

1) The answers to the first question were not very elaborate or structured. Analysis of these answers reveals two common elements:
   - Defining interdisciplinarity using vague expressions that emphasize the use of several subjects in the same class;
   - Using examples to explain the nature of interdisciplinarity. In these examples, certain concepts were abundantly referenced: project, collaboration between teachers, links and connections, etc.

The following excerpts illustrate the teachers' suggested definitions:

> For me, interdisciplinarity means teaching notions while using a topic that is common to different school subjects.
>
> Well, I think, as the name implies, it means being able to use several school subjects. For example, we start a big project, where the students are going to make a model [of a heart]. This project involves technology. At the same time, the idea is to have students do medical research: They do research on cancer, on cardio-vascular diseases, etc. So they will have to do biology research on this topic. Afterwards they can present the project in French, but also translate it into English. So, they're using several subjects for the same project, which allows them to cover several facets of different programs.

2) Analysis of the answers to the second question shows that certain words frequently arise associated with the concepts of both interdisciplinarity and integration: "school subjects," "projects," "links," "work," "time,"

("learning situation") to refer to classroom teaching units focused on specific contents. Given the potential confusion here of using the term "learning situation"—a free translation of the French term, which, to our knowledge, has no widely-recognized equivalent in English—in this article, we will instead use the concept of "units of study." The concept of "situation" will be reserved for excerpts of ministry or teacher discourse.

"difficulties," "application," etc. Other words, in terms of frequency, are more closely associated with either the concept of integration ("competencies," "interests," "usefulness," and "knowledge") or interdisciplinarity ("teachers," "planning," "meetings," and "complementary"). The words specifically associated with the concept of integration appear to involve an aim or target (the learning outcome), while those associated more specifically with interdisciplinarity appear to be more closely related to the teaching process. Analysis of the lexical context with which the more frequently used words are associated shows that, for the teachers, integration associated with interdisciplinarity (i.e., that seeks "links" and "integration" among different "school subjects") refers to "work" in "projects" that make use of "teams." Also associated with this concept are "interest," "usefulness," the "acquisition of learning," and the "application of learning." The respondents emphasized the "difficulty" associated with "integration" and the "lack" of resources (including time) available for it.

The answers to the two questions regarding the definition of interdisciplinarity, which we have just presented, vary substantially from the definitions found in the scholarly literature on this concept. The teachers' definitions emphasize superficial characteristics (the presence of more than one school subject; collaboration between teachers; common projects; etc.) rather than the characteristics that form the kernel of interdisciplinarity as understood by scholars (presence of a question or a problem that is too complex to be dealt with based on a single discipline; integration of insights from two disciplines or more; etc. See the earlier presented definitions). These answers may suggest that the teachers have an insufficient understanding of interdisciplinarity. Another hypothesis that should not be neglected is that the teachers struggle to abstractly conceptualize and formulate what they do in practice. In this regard, our analysis of classroom practices should shed light on the meaning that the teachers give to interdisciplinarity (see the results for the operational dimension).

4.1.2 What justifications were given for using interdisciplinarity (functional dimension)?

The most common reasons that the teachers gave to justify the importance of using interdisciplinarity (as they understand it) at school have to do with utilitarian and psycho-pedagogical aspects: anchoring learning in everyday life (so it's concrete) and making it meaningful (25.5%); applying knowledge in life or in other contexts or disciplines (transfer, usefulness, etc.) (12.9%); and students' interest and motivation (12.4%). Few justifications had to do with solving complex problems by incorporating different viewpoints from different subjects.

These definitions and justifications of interdisciplinarity are consistent with the examples of units of study described by teachers as being representative of their practices (see the operational dimension). The 10 units of study examples reported to illustrate what they think of as being an interdisciplinary approach primarily involve links between learning in school disciplines and life outside the school, and relate to utilitarian and psycho-pedagogical definitions and justifications. In 21 other units of study involving two school subjects or more, what teachers called interdisciplinarity consists in the mobilization, in a given school subject, of prior learning acquired in another school subject, as a form of enrichment (see results for the operational dimension).

4.2 Regarding the operational dimension

Over the course of data collection relating to the operational dimension, we considered three items:

1) The importance that the teachers assigned to interdisciplinarity at school. Interdisciplinarity is a mandate issued by the ministry of education in a top-down fashion. Teachers are informed, by means of the curriculum, that they must use this approach. It is worthwhile, consequently, to determine whether these teachers consider that the approach is important and useful or not. Their attitude toward this prescription is a decisive factor in their practices.
2) The teachers' perceived ease in using this approach. The fact that teachers subscribe to the approach is a good thing; however, the quality of interdisciplinary practices also depends on the teachers' sense of competence and on their understanding of what ID is or should be.
3) The ways interdisciplinarity is implemented (classroom practices). The intent is to describe how the teachers use interdisciplinarity (as they understand it) in their teaching. Considering the large number of teachers who participated in the survey, it was impossible for us to observe classroom practices. Instead, we asked each teacher to describe the progression of two units of study that are representative of the way he or she applies this approach.

What results emerge from our analyses regarding each of the three above items?

4.2.1 The importance of interdisciplinarity. The wide majority of the interviewed teachers are in favor of interdisciplinarity. On a scale from 1 to 4 ranging from "not important at all" to "very important," most respondents (90.1%) consider that it is "very important" or "fairly important" to use interdisciplinary approaches in school. This percentage is slightly higher for interdisciplinarity that involves the school subjects comprising the S&T program, such as biology, physics, or chemistry (95.4%), or among the areas of S&T and M (94.7%).

As for the importance of interdisciplinarity among S&T or M and other school subjects (or subject areas), slightly fewer than three quarters of the respondents (71.3% and 69.6% respectively for S&T and M) consider that this is "fairly important" or "very important." This percentage is slightly higher regarding links among school subjects (or subject areas) other than S&T or M (78.1%), for example among social sciences and arts.

Our data suggest that their answers (adherence to interdisciplinarity) cannot be explained by the societal desirability of interdisciplinary instruction (i.e., the desirability of following and conforming to curricular prescriptions), but rather can be explained by the fact that these teachers do not primarily define themselves by their belonging to a discipline. They are first and foremost teachers, and only then teachers of a particular school subject. As we have reported elsewhere (Hasni, Bousadra, & Étienne, 2012), a great many S&T teachers, for example, are ready to take on the responsibility of teaching completely different school subjects in the program (languages, humanities, and social sciences, etc.). In fact, in the survey discussed in this article, almost 20% of the teachers stated that they underwent initial training in another area than S&T and M, which they are currently teaching. Disciplinary socialization therefore does not constitute a real source of resistance to interdisciplinarity. This situation appears to represent a profound transformation in professional identity, since, some 30 years ago, such teachers primarily identified with the discipline that they had been trained to teach. In other words, the fact that teachers are trained in a disciplinary fashion does not lead them to be opposed to interdisciplinarity.

4.2.2 The ease of implementing interdisciplinarity. The teachers were also asked to say whether they consider it "easy" to implement interdisciplinarity among the school subjects (or subject areas) prescribed in the program. Analysis of their answers suggests two broad groups:

a) Interdisciplinarity is considered to be "easy" or "very easy" among the disciplines composing the area of S&T (89.1%) as well as between this area and M (86.5%).

b) Interdisciplinarity ranges from "difficult" (level 2 of the scale) to "easy" (level 3 of the scale) among S&T and other subject areas, such as languages, social sciences, and arts (85.5%) or between M and these last areas (79.2%).

4.2.3 The classroom practices involving interdisciplinarity. Six open-ended questions were used to discover how these teachers put interdisciplinarity (as they understand it) into practice.

1) In the first question, we asked the teachers to complete the following statement: *The S&T subject area is more conducive to implementing interdisciplinarity with...* The answers to this question are comparable to the previous answers: M ranks first, followed by languages and social sciences. As for the question *The subject of M is most conducive to implementing interdisciplinarity with…,* the answers vary slightly: S&T come first, followed by social studies and then languages. The other disciplines (arts, physical education) come afterwards for both questions.
2) While most of the teachers are in favor of interdisciplinarity and consider that it is relatively easy to implement in the context of S&T and M instruction, the portrait is different when it comes to practice. This can be seen in their answers to the second question bearing on the ways interdisciplinarity is implemented, and more specifically their self-assessed interdisciplinary competence and the extent to which they use interdisciplinarity (according to their understanding of this approach). More than half (55.8%) stated that their competence in implementing interdisciplinarity in education is "very low" to "low," versus 44.2% for "good" to "excellent." In addition, most of the respondents (71.6%) described the degree to which they implement interdisciplinarity as "low" or "very low" and fewer than one quarter (23.7%) described it as "high." Only 11 teachers (4.7%) answered "very high."
3) What are the school subjects (or subject areas) and the teaching processes that teachers draw upon in their interdisciplinary practices? In the third question we asked the teachers, based on their experience during the current academic year, to cite the school subjects (or subject areas) involved when they implement interdisciplinarity in their classrooms. The answers are consistent with those obtained for the questions regarding the degree of ease: The S&T teachers for the most part respectively reported mathematics, languages, and social sciences, while the mathematics

teachers reported S&T, social sciences, and languages among their first three choices. In other words, in addition to the subject areas that they teach (S&T and M), the teachers say that they mainly use languages and social sciences in their interdisciplinary practices.

4) Regarding collaboration with other teachers in implementing interdisciplinarity (question 4), only a small proportion of the teachers stated that they worked together with peers, mainly for planning (25.5% said they "sometimes" plan their interdisciplinary teaching situations as a team). Forms of collaboration were very rare for teaching and evaluation.

Two open-ended questions (questions 5 and 6) were used in the context of the individual interviews to get a better idea of the ways interdisciplinarity is understood and put into practice.

5) The first of these two questions (question 5) was formulated as follows: *In your view, which school subjects (or subject areas) are most conducive to implementing interdisciplinarity and why?* The teachers had to answer by suggesting up to three groupings of school subjects (or subject areas). The answers to this question were analyzed with a view to revealing groupings of school subjects (or subject areas) chosen together as being favorable to interdisciplinarity. The analyses show that while S&T and M were combined in 20 teacher statements,[9] a greater number of combinations did not put these school subjects together: In 18 cases, the teachers considered that interdisciplinarity is easier among S&T and school subjects other than M; in 16 cases, M was chosen with school subjects other than S&T; and in 13 other cases, it was school subjects other than S&T and M that were mentioned together as being favorable to interdisciplinary instruction. In other words, in terms of actual (classroom) practice, S&T and M are not considered to be the subject areas best suited to interdisciplinarity. Among the observations emerging from our analysis of justifications for these proposed disciplinary groupings, two are worth mentioning here:
   - The ease, in the respondents' views, of using languages in interdisciplinary teaching:

> Well, I think French can make links with almost all the subjects. . . It's easy to work on French in different areas. . . French and English, because there's always a way to integrate those subjects. . . it's easier, through translation, through writing…

[9] The respondents gave 67 proposed groupings, or on average approximately 2 groupings per respondent.

- The difficulties associated with using M in interdisciplinary instruction:

> What is hardest? Probably math… But for the other subjects I think it can be relatively straightforward… Making interdisciplinary links, for example in mathematics, I think that would be one of the most difficult. It's harder because it involves more "mechanics" (procedure) … Current events are more difficult to approach in mathematics than they are in science or social studies.

6) The second question (question 6) was formulated as follows: *Can you describe the progression of a sample unit of study that clearly reflects how you implement interdisciplinarity in your teaching practices?*
The respondents described 31 units of study. Analysis shows that these units of study can be divided into two groups. The first group (10 units) involves the consideration, in a school subject, of a context of life outside the school, rather than the integration of elements or components of two or more school subjects. The three following excerpts of the teachers' answers illustrate the common points of this group of courses, the first two for M and the final one for S&T.

> We were discussing statistics at the end of the year. I wanted to make it a little more approachable (for the students), a little more practical. What I did is take the example of the draft in the NBA and in hockey, so students would better understand how statistics can be used in our society. I showed how the NBA was able to draft its first three teams ... And what the statistical chances were that they would get first, second or third draft pick. The idea was to help understand an everyday reality for young people, especially those attracted by these kinds of sports events, to be able to interest them in statistics, which can seem somewhat neutral and boring to a 14-year-old (student).

> We did a project this year with a group of students. The subject came from my students… It connects mathematics with their life in school, their everyday life. It has to do with the cafeteria menu. We did a statistical study on it….
>
> [In ST, one topic was] ... the principle of fingerprints and how they are dealt with when arriving at the scene of a crime…. So we made links with the work of an investigator, with the person who does the really technical work… with the fingerprint powder… We invited a police officer to class to show us the technique. We also showed this to a lot of other people…. A lot of educational kiosks were put up [to do this].

The seven other examples of supposedly interdisciplinary units reported by the teachers in relation with this category also had to do with matters of life outside the school, namely a field trip to a hydroelectric plant, student research on S&T careers, understanding road signs, and determining the best speed to approach a curb when driving, etc.

The second group of units described by the teachers as representing their interdisciplinary practice (N = 21) involves elements or components of two or more school subjects. Our analysis shows, first, that aside from S&T and M, it is languages that are reported as being integrated with other subjects in more than half of these examples (12), with social sciences being reported in five of them. The analysis also shows the predominance of two forms of what teachers call interdisciplinarity (although they are not fully interdisciplinary as defined by scholars):

1) While teaching a school subject or a subject area (S&T, for example), mobilizing (recalling) elements or components from another school subject (M, for example). In courses involving this type of mobilization, S&T and M are reported as often as social sciences and languages. This type of instruction is overseen by a single teacher who draws from the contents of other school subjects. The following excerpt illustrates an S&T teacher's mobilization of concepts learned in M (proportions, exponents, etc.) to achieve learning related to the school system:

> Last September, there was an activity where we looked at the school system, and it involved the study of scales. So I did the proposed project, which was to produce a scale representation of a sports field on an oversized poster board… based on data that they [students] had. The students then had to produce a scale image of the school system on the sports field. This required them to use the notions of scale, of proportions [and] of exponents, since the school system involves… very, very high numbers. So I started by reviewing proportions…; I explained to them what exponents are; I asked them if they had seen them (in M), and they said: "We're looking at them now." So then I checked… to make sure they had already seen these notions and would be able to work with them. By chance, the math notions were exactly the ones that I needed….

Preparing an (imaginary) expedition to Mount Everest illustrates an example of mobilizing content learned in other school subjects (geography and M) in an S&T situation. The students were required to draw from their geographical knowledge: "So we had maps, we had worked a lot on this in social sciences, but without involving the social sciences teacher" (excerpt from a teacher's answer). The students also had to mobilize their mathematics knowledge (calculating percentages and proportions, for example): There were "mathematical calculations to determine how much water and food they would need, the weight they would need to carry, and so on."

2) The use of a theme (a subject or content) to pursue learning in parallel in two or more school subjects. An initial example that illustrates this type of course was studying the theme of the Canadian Far North independently in several disciplines, as illustrated by the following excerpt of a teacher's answer:

> For that project, I think all the disciplines were concerned, except physical education. In French and math, they [the students] had to build something associated with snow and we had also given them texts… The only common thread for that project was

> the Far North.

Another example had to do with the theme of vaccines, approached independently in S&T and in French, and in relation with the debate in Quebec about the spread of the H1N1 virus:

> In January…, before the students got their vaccinations, well, in science, we discussed immunology… The students wrote about it. In their French class, they had to write an opinion assignment. So they had to write this opinion piece [to say] whether or not they wanted to get vaccinated this year. … They actually wrote the text in French class....

It is also worth noting that in the 21 examples involving two or more subjects, only a minority exhibited the potential to go beyond the superficial interdisciplinarity of a mere mobilization (recall) of knowledge or a theme-based approach involving some application of two or more subjects. However, these few examples were not exploited in depth by teachers: For example, these units did not lead students to integrate the two disciplinary perspectives (S&T and M) to study the initial problem. In the excerpt below, illustrating such a unit of study, the initial problem was common to S&T and M and used by both teachers to start what they designated as an interdisciplinary course, but the final classroom work—involving the use of data and the formulation of a common and integrated understanding of the initial problem — was dealt with on a disciplinary basis:

> I had worked with the science teacher on a slide… In the winter I had made a sort of snow bank where students had to bring a sled and slide down. And that was when we were discussing vectors. Both of us, each on our side, were studying vectors and movements… I had targeted the notions the students would need for their experimentation. They went outside to conduct the experiment, which was to slide down the snow bank. Then they came back to their math and science classes [to do a] report on the results they had obtained.

4.3 Regarding the organizational dimension

In their answers to one of the written questions, the teachers reported different types of obstacles and constraints that influence their use of interdisciplinarity (as they understand it). These include some associated with the teachers themselves, essentially the habit they have developed of working alone, as well as their resistance to opening up to other disciplinary logics than those they teach (out of a lack of knowledge of these school subjects). Such difficulties are illustrated by the following excerpts of the teachers' answers:

> You need to master your program (your subject)… But when you've been teaching too long, it's like you're no longer open to change, open to working in other ways… this becomes an obstacle…
>
> One of the problems that was noticed in the project I taught was that the two teachers don't clearly understand each other; they don't understand each other's expectations. They have a general idea… But when the time comes to start the project, of course, their expectations aren't the same…
>
> With the other teacher, we don't understand each other or we don't always see things the same way. Maybe we weren't clear enough on the types of connections and links we wanted. I wanted it to be really realistic, to have safeguards, with everything carefully planned out, but not my colleague… When the students were ready to draw up their plans, they started asking me a lot of questions… But because I didn't know exactly what he (my colleague) had covered in his class, I couldn't answer, I had to say "I don't know!"

Other teachers also pointed out a lack of training in their own discipline and in others. This situation leads them, first, to invest more time in the learning of their own discipline than in the exploration of other disciplinary logics. Second, it leads them to remain close to didactic (instructional) materials when planning their teaching, which is primarily disciplinary. The following excerpt from a teacher's answer provides an illustration in this regard:

> Time [is a constraint]. Why? Because we don't really know our program well. We are just getting a handle on it. This is a problem. When you don't really know what you're doing, you stick with what the [textbook] publishing houses suggest.

The teachers also reported other difficulties associated with their work context. Three such difficulties frequently came up in their answers: a) a lack of resources (including time, but also courses or resources illustrating interdisciplinary approaches that they could use or adapt in their teaching); and b) the academic structure in secondary school, which does not foster exchanges and teamwork. For example, dividing students into classroom groups sometimes prevents teachers in two or more different subjects from having the same students (the group varies from one subject to another); and c) school programs that are limiting, since program content seems to have been developed without consultation among disciplinary teams (some S&T and M content that could be conducive to interdisciplinarity belongs to different grade levels):

> [The challenge was with regard to] being able to coordinate what we were doing. We always have to do this within the time we have to meet. We see each other in the hallway and say, "Oh! It would be great if we could do such-and-such…" But in the end, we never really have the time to sit down and say, "Alright [sic], how are we actually going to organize this?"

4.4 Discussion of study results

Even if the training of the teachers who took part in the survey was primarily disciplinary, most of them were in favor of interdisciplinarity in school and spoke in favor of interdisciplinarity both among STEM subjects and among all curricular components, including humanities and social sciences, languages etc. However, the teachers' understanding of the concept of interdisciplinarity and its aims, as well as how to implement it in the classroom, does not align with interdisciplinarity as defined by scholars. Indeed, to illustrate what they considered to be interdisciplinarity, the teachers described three types of units of study that scholars would not consider truly interdisciplinary:

1) Units of study in which S&T and M are taught in connection with life outside the school: the use of the data from a hockey league or the school cafeteria's menu in order to learn statistics in M; the study of a crime scene to learn S&T; etc. Even if interdisciplinarity can, in some cases, foster a contextualization of learning, this contextualization is not a defining characteristic of interdisciplinary instruction. Indeed, contextualization can just as well be used in the context of disciplinary instruction in S&T, as shown by many studies on the question over the past decades (Bennett, Lubben, & Hogarth, 2007; Glynn & Winter, 2004; Schwartz, 2006).
2) Units of study in which knowledge learned in one subject is mobilized or applied in another. It is important to bear in mind that this type of link is not characteristic of true interdisciplinarity. Following grammar and spelling rules (languages) in an S&T course does not constitute an interdisciplinary approach. Nor does calculating percentages or plotting graphs (mathematics) in an S&T course. In both cases, the main objective is to learn S&T (disciplinary learning), while taking into account knowledge (concepts, rules, and methods) from other disciplines (languages and mathematics). Even in the context of university teaching and research, this type of recourse to knowledge from other disciplines is a constant necessity. Biology, physics, and chemistry, among other disciplines, frequently leverage mathematics. Yet this does not mean that these disciplines are interdisciplinary or that they use interdisciplinary approaches. As indicated in the first part of this article, full-fledged interdisciplinarity draws on disciplinary perspectives and integrates their insights through construction of a more comprehensive and integrated perspective. The objective is to gain a fuller/richer understanding of the complexity of the problem under study by illuminating its various aspects, each of which is the focus of a different discipline (Klein & Newell, 1997).
3) Units of study that use a theme (the Canadian North, the H1N1 vaccine, etc.) as a context for teaching several school subjects simultaneously. Our study shows that the teachers' use of these themes does not involve a sufficient degree of integration to be able to qualify the work as interdisciplinary. The units of study, as they were described, instead involve multidisciplinarity, since learning in different school subjects is done in parallel (and is even addressed by different teachers). In these courses,

> the theme merely serves as a pretext for compartmentalized disciplinary teaching. Only when these subjects' contributions are integrated so as to achieve a richer and fuller understanding of the Canadian North or vaccines might one speak of a truly interdisciplinary approach.

The units of study described by the teachers to illustrate what they believed to be interdisciplinary practice offer an unquestionable advantage for students compared to traditional units of study: For example, the units are able to improve the quality of teaching and learning in S&T and M, since they require teachers to go beyond these subjects' traditional teaching strategies; they also demonstrate the teachers' efforts to decompartmentalize their teaching and to make links among school subjects. However, as we have just shown in the discussion of results, the examples given by the teachers cannot qualify as fully interdisciplinary practice.

5. Conclusion and recommendations

This article has described the way Quebec teachers of specific school subjects in S&T and M define interdisciplinarity and declare that they use it in their classroom teaching practices.

Among the results that emerge from this study, it is important to underscore the gap between the place that S&T and M teachers wish to give to interdisciplinarity in secondary school, on the one hand, and their actual classroom practices, on the other. Generally speaking, they consider that interdisciplinarity (as they understand it) is important in school, and that it is easy, yet they rarely implement it, and many consider that their training hasn't given them the competence required for this educational approach. Our results point to the impacts of this lack of training (declared by the teachers). These impacts in fact touch upon several dimensions, namely conceptual (definitions that the teachers assign to interdisciplinarity), functional (justifications for using supposed interdisciplinarity), operational (examples of units of study proposed to illustrate what the teachers consider to be interdisciplinarity), and organizational (extent of collaboration with other disciplinary teachers). The teachers' answers demonstrate that their understanding and implementation of interdisciplinarity do not align with the scholars' descriptions of this approach. In the first section of this article, we also showed that the curriculum's suggested definitions of and justifications for interdisciplinarity are not sufficient to offset teachers' lack of instruction in this regard.

The results presented in this article show that actions are required of various actors in education and teacher education in order to improve teachers' understanding of this approach and of its use in their classroom practices:

1) On a curricular level, it is important to clearly assert the place that interdisciplinarity should be given in school. Without such an explicit prescription by ministries of education, interdisciplinarity cannot become the reality that is desired. The low implementation of interdisciplinarity that is not so prescribed is shown, for example, by American schools. In spite of efforts by the National Middle School Association in recent decades (for example, Beane, 1997; Jacobs, 1989; Vars, 1993), interdisciplinary practices do not seem to be generalized in American schools. In Quebec, the prescription of interdisciplinarity constitutes a courageous position on the part of the ministry of education. Moreover, this prescription goes further than international recommendations for integrating STEM subjects in that it extends to a consideration of all curricular components, including other subjects such as humanities and social sciences. However, the confusion in the ministry discourse regarding interdisciplinarity does not help teachers to properly implement this prescription.

   In curricula, ministries need to present a clear conception of interdisciplinarity that takes account of the research published in this field over the past decades. It is not sufficient to declare that a curriculum must use interdisciplinarity. The absence of a definition and of explicit justifications for this approach opens the door to any and all interpretations by teachers, leading to problems in their practices. The curriculum must also clearly distinguish between interdisciplinarity and integration, and between their respective functions in teaching-learning processes.

2) While theoretical foundations are necessary, they cannot be sufficient in themselves. Teacher education, both initial and ongoing, must provide examples of operational modes that will be meaningful for teachers and future teachers. These examples in turn can only be meaningful if they are strongly anchored in the school subjects taught by the teachers in question (S&T and M in our case). Teacher education must also introduce teachers to the structures of the other subjects than those they teach or will teach. In current teacher education programs in Quebec as in many other countries, secondary teachers undergo training in the subjects associated with their specialty (biology, physics, chemistry, etc.) and in how to teach them (didactics, pedagogy, etc.), but they are not introduced to the logics of the other school subjects. Even when teachers are open to interdisciplinarity, as our research results show, this

lack of an even cursory knowledge of the structures of other subjects constitutes an obstacle to successfully implementing interdisciplinarity.

3) In addition to the theoretical and practical conditions described above, the success of interdisciplinarity in schools also depends on political and organizational choices. Among other things, teachers need to be allocated specific time for consulting and working together, and other recognition mechanisms than the currently prevailing ones need to be put into place (given that teacher recognition is now primarily based on expertise in teachers' respective subjects, rather than their competence in helping students to approach complex problems that exceed disciplinary boundaries), etc.
4) These suggestions also, and perhaps above all, require an egalitarian and complementary conception of each school subject. It is important for teachers to understand that the subjects they teach are neither more nor less important than the others in the curriculum. The respective educational functions and contributions of each school subject must consequently be underlined in order to convey the need for an interdisciplinary approach.
5) Since these interdisciplinary concerns relating to S&T and M characterize most of the OECD countries, comparative studies and the sharing of teachers' training experiences pertaining to this issue would constitute an important avenue for research and for teaching.

In this article we have analyzed the curriculum and results associated with a study of Quebec teachers in order to understand how specific school subjects, namely STEM subjects, are used in interdisciplinary (or more accurately, supposedly interdisciplinary) approaches at the secondary school level. However, the questions posed, the analytical framework developed, and the methodology used, as well as the results obtained, also apply to all other school subjects that might be integrated into interdisciplinary work. Consequently, this article should allow all actors (decision-makers, practitioners, and researchers) concerned with interdisciplinarity, whether in secondary school or beyond, to reflect upon the best ways to facilitate implementation of this approach.

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