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RELATIONS BETWEEN MATHEMATICS AND COMPUTER SCIENCE IN THE FRENCH SECONDARY SCHOOL: A DEVELOPING CURRICULUM

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In the last decade, French curricula for secondary school have included contents in Computer Science inside Mathematics curricula. We study this particular situation by questioning the history of the introduction of Computer Science in school in France, by analyzing the links between Mathematics and Computer Science in the curricula (based on epistemological considerations), and by enlightening the issues of this curriculum under development.

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COMPUTER SCIENCE AND MATHEMATICS IN FRENCH SECONDARY SCHOOL

In the last decade, French secondary school has gradually incorporated in its curricula contents in computer science. Before that, there were already contents relative to computer tools (use of software) in the curricula (like spreadsheets in mathematics, or word processing program in other disciplines), but from 2009 contents concern computer science as a specific discipline and not only as a tool. Most of these contents in Computer Science have been integrated in the Mathematics curricula and addresses algorithmics and programming. Some advanced contents in Computer Science have also been introduced in optional courses in upper secondary school and are often taught by mathematics teachers; indeed in France, there are no positions of secondary teachers in computer science. This situation leads to tumultuous relations between two views about computer science education: the first view consists in defending the necessity of an autonomous scholar discipline, and the second one consists in underlying the links with Mathematics and the fact that Mathematics teachers could be trained for teaching of Computer Science.

This specific situation questions the relations between Computer Science and Mathematics, as disciplines, but also inside the French curricula of secondary school. This issues clearly regards STEM education, with a special focus on the relation between Mathematics and Computer Science among other scientific topics. In this paper, we address the following issues we have been working on since 2009 (Modeste & al., 2010, Modeste & Ouvrier-Buffet, 2011, Modeste, 2012, 2015, Modeste & Rafalska, 2017): What do Mathematics and Computer Science share as scientific disciplines and what kind of interactions between them can be developed in secondary school? How does the French curricula deal with this issue and in which direction are they developing?

In this paper, we first present briefly the theoretical framework that shapes our analysis. Then, we explore briefly the history of the introduction of computer science in school in France and we analyze the relations between Mathematics and Computer Science in the current curricula, based on epistemological considerations about the nature of these relations. Finally, we examine the institutional situation in France, through the processes that lead the development of these curricula

and the actors who influence it. This will enable us to enlighten the issues of developing coherent curricula in mathematics and Computer Science.

A framework for analysing the curricula: ATD

In this paper, we will use some elements from the Anthropological Theory of Didactics (ATD) (Chevallard, 1992, Artigue & Winsløw, 2010, Bosch & Gascón, 2014). Indeed, ATD is relevant to analyze curriculum design and allows taking into account various levels of analysis such as society, pedagogy or discipline, as well as institutions involved in the process, which fits our purpose. We briefly describe the elements of ATD that are used below.

ATD considers unit blocks of activity called *praxeologies*. They permit to describe human activities and their organization in specific institutions. Here we are interested in Mathematics praxeologies and Computer Science praxeologies involved in secondary school curricula. Another concept linked with ATD is the *didactical transposition* (Chevallard, 1985, Chevallard & Bosch, 2014), which is the process through which knowledge (i.e. the praxeologies) is transposed from institutions where it is produced to institutions where it is taught. In the case of scientific knowledge (like Mathematics or Computer Science), the didactical transposition concerns the passage from scholarly knowledge to knowledge to be taught and then to the taught knowledge. This concept is closed to the notions of *intended* and *implemented curricula* but incorporates views on curricula as products and as processes. The didactical transposition of a piece of knowledge involves many actors and institutions, at a higher level than the one of the teachers, called *noosphere*. In the last part, we give example of it.

To understand how didactical transpositions occur or how curricula are designed and evolve, we will rely on the *levels of didactic codetermination* (Chevallard, 2002), which allow taking into account the context (in terms of conditions and constraints) in which praxeologies exist and develop. These levels, that interact with each other, are the following:

Civilization (9) ↔ Society (8) ↔ School (7) ↔ Pedagogy (6) ↔
Discipline (5) ↔ Domain (4) ↔ Sector (3) ↔ Theme (2) ↔ Subject (1)

In this article, we are interested mainly in *Society*, *School*, *Pedagogy* and *Disciplines* as levels that influence curricula, in particular on Mathematics and Computer Science and the way they interact.

Current situation in France: organization and design of the curricula

Currently, French secondary school is divided in two institutions. Lower secondary school (called *collège*) is mandatory and starts at grade 6 and finishes at grade 9, with a national assessment called *Brevet*. The next 3 years (grades 10 to 12) concern upper secondary school (called *lycée*). It has different streams (vocational, technological and general), and we will focus here on the general stream, which ends with a national assessment called *Baccalauréat*. The two national assessments, *Brevet* and *Baccalauréat*, have a strong influence on the way the intended curriculum is implemented by teachers.

Historically, France has a national curriculum elaborated by specialized committees. In mathematics, the curriculum is defined by different official documents. One is the *program* itself, describing contents and expectations about them, and the others are *accompanying resources* for helping teachers to implement the program, offering details about specific topics (propositions of

learning activities and related explanations). Until 2016, the programs for secondary school were presented for each grade. Since 2016, in primary school and lower secondary school, the curriculum for each subject is derived from a *common core of knowledge, competencies and culture* and organized by 3-years cycles (lower secondary school is concerned by cycle 4 – grades 7 to 9 – and by the last year of cycle 3 – grade 6). These changes are clearly related to international movement towards enhancing competencies. For now, curriculum for upper secondary school has not changed but very recently the Ministry of Education has launched a wide project for changing the Baccalauréat and the whole structure of upper high school¹.

Historical overview on computer science in French Secondary School

This section is based on a previous collaborative work (Gueudet & al., 2017) in which details about French curriculum's structure and evolution are presented.

In the 1980s, after a few experiments, the teaching of computer science in upper secondary school was introduced in France for the first time with an optional teaching called “Informatique des Lycées” (Computer Science for upper secondary school). This teaching was done by specially trained teachers, essentially mathematics teachers, and was centered on algorithmics and programming; the Ministry of Education invested a lot of effort into teacher training for this option. At this time, international work is already developing about the interactions between Mathematics and Computer Science, as attested by the first ICMI Study: *The influence of Computers and Informatics on Mathematics and its Teaching* (Howson & Kahane, 1986). However in France there was no social consensus on the finality of this teaching (Baron & Bruillard, 2011), and Computer Science as a scholar discipline, disappeared in the 1990s, replaced in the curricula by teaching how to use computers as tools in every discipline.

In the 2000s, the CREM² (Kahane, 2002) recommended in its report to “introduce some Computer Science in the teaching of Mathematics and in teacher education” and defended the importance of interactions between Mathematics and Computer Science. The report addresses many arguments summarized as follows: Algorithmic thinking, implicit in the teaching of mathematics, could be developed and enlightened with the instruments of algorithmics; Programming promotes formalized reasoning; Questions about effectiveness of algorithms involve mathematics; Data processing and digital computations are common in other disciplines; and finally, Computer Science transforms Mathematics, bringing new points of view on objects, bringing new questions, creating new fields in Mathematics that are growing rapidly, and changing the mathematician's activity with new tools.

Just after this report was published, algorithmics was introduced in mathematics at grades 11 and 12, but only for literature series, and in optional mathematics courses in the last year of the economics series (in an introduction to graph theory) and the scientific series (in an introduction to

1 A mission has also been given to the Fields medal awarded French mathematician Cédric villani on the teaching of mathematics at primary and secondary levels (<http://www.education.gouv.fr/cid126423/21-mesures-pour-l-enseignement-des-mathematiques.html>) but we will not analyze it here.

2 In 1999, the French education ministry appointed a commission, the CREM (National Commission for Reflection on the Teaching of Mathematics) for rethinking the teaching of mathematics for the new century headed by Jean-Pierre Kahane. Jean-Pierre Kahane is a famous mathematician, member of the Academy of sciences, and former president of ICMI (1983-1990). In 2002, the CREM published an important report on the teaching of mathematics.

number theory). Then, between 2009 and 2012 in new official programs, algorithmics was introduced as part of Mathematics into all series of the general stream (literature, economy, sciences) from grade 10 to 12 (French *lycée*).

Finally, in the 2010s, computer science as an autonomous discipline came back in the upper secondary school, together with algorithmics and programming as part of the contents in Mathematics. In 2012, a new optional teaching of computer science (called ISN, for *Informatique et Sciences du Numérique*) was proposed in grade 12 for students of the scientific series. These teachings are made by teachers from various scientific disciplines, including a lot of mathematics teachers. A similar option (*Computer Science and Numerical Creation*) has been created in grade 10 and tried in various schools since 2015. Since 2016, Computer Science is also taught in cycle 4 (grade 7 to 9), but divided between two disciplines: Mathematics and Technology.

Following this increasing need for teaching Computer Sciences in secondary school, a Computer Science option has been introduced since 2016 in the competitive exam for recruiting mathematics teachers for secondary school (CAPES), leading to the involvement of university scholars in Computer Science in the preparation of these.

We can already notice that the appearing of Computer Science in French curriculum is not a linear process, illustrating the tensions in the phenomena of didactical transposition, submitted to conditions and constraints that falls under different levels of codetermination: School, Pedagogy and Discipline, but also Society, inasmuch as the relationship with Computer Science, Mathematics and Sciences in the French society and French academic world clearly affects the curricula.

After this brief presentation of French curriculum structure and organization³ and this short historical perspective, we examine relations between Mathematics and Computer Science in the current programs for grades 10 to 12 in the general stream and in the new programs for cycle 4 (grade 7 to 9) of lower secondary school.

ANALYZING SECONDARY SCHOOL CURRICULA

Epistemological considerations on the relation between Mathematics and Computer Science

In our previous work (Modeste, 2012, 2015), we have developed epistemological considerations – in the sense of Artigue (1990) – on the relations between Mathematics and Computer Science. We have identified four aspects that we summarized here.

A1. Foundations, logic and proof. Mathematics and Computer Science share common logic foundations (Computer Science is born, in part, from development of logic) which guide the role of language in both disciplines. Proof, as a mean of validation, plays an important role in Mathematics and Computer Science, and is an important component of their epistemologies.

A2. Continuity and interfaces. The frontier between Mathematics and Computer Science is impossible to draw, and a lot of objects and fields live at their interface like cryptography, games theory, graph theory, combinatorics, etc. Many new Mathematical fields developed in response to Computer Science needs and many algorithmic and computing questions arose from Mathematics.

3 For more details about the French Mathematics curriculum, see (Gueudet & al., 2017) or the ministry website: <http://eduscol.education.fr/cid66998/eduscol-the-portal-for-education-players.html>

A3. Computer assisted mathematics and experimental dimensions. Computer Science permits to foster the experimental dimension of mathematics, allowing systematic exploration of various cases, or algorithmic solving of mathematical problems. Computer Science can bring complementary outlook on mathematical objects.

A4. Modeling, simulation and relation with other disciplines. Both disciplines offer means for formalization that permits to model and simulate (or compute) situations from other disciplines. Mathematical models can be computed and simulations often involve many mathematical models.

Based on these four aspects, we analyze below the curricula of French lower and upper secondary school in Mathematics and Computer Science. This provides an insight on the didactical transposition and informs us about the factors influencing the curricula and the levels of codetermination at which they intervene.

Computer Science and Mathematics in lower secondary school curriculum (French *collège*)

In lower secondary school, inside the Mathematics programs for cycle 4, one domain is *Algorithmics and Programming*. The main objective is developing pupils' skills on: "Write, elaborate, and execute a simple program". For this goal, the program enumerates various programming notions (loops, conditions) and programming paradigms (parallel, event-driven...) and suggests to use a programming language with specific properties, very close to the language *Scratch*⁴, which is, in fact, used in the accompanying resource (and, thus, used by all the teachers). This follows an international trend for introducing Scratch and block programming in curricula, but the specificity, in France, is its inclusion inside the Mathematics class (Modeste & Rafalska, 2017). This leads to two different kinds of activity in class: on the one hand, algorithmics and programming are widely used to solve Mathematics problems, particularly in algebra and geometry (this is A3); on the other hand, they are also used in projects which can be very far from Mathematics. A4 could be developed at this occasion, but neither the program nor the accompanying resource develop this aspect. A1 is not present (proof and logic have a small place in this curriculum); it is the same for A2 (not any element of mathematics used in Computer Science has been introduced when Computer Science entered the Mathematics curriculum). The epistemological reference remains unclear about the status of these Computer Science contents.

Besides the teaching of Computer Science within Mathematics, contents related to networks and to programming the behavior of objects, machines or systems are taught within Technology. For now, very few interactions exist between teachers of the two subjects and few elements are given for that in the curricula and resources.

We can see various processes involved here, at different levels. At the civilization or society level, international trends seem to have a strong influence, but the transposition is influenced at many other levels like *School* (there are no Computer Science teachers in French schools); *Pedagogy* (the pedagogy of project, suggested in *algorithmics and programming*, is likely to collide with habits in Mathematics teaching in France, despite the efforts made since the 2000s to change them), and *Disciplines* (the potential links between the two disciplines are superficially taken into account). Another element affecting taught knowledge is the national exam at the end of lower secondary school (the Brevet). The contents in the final assessment strongly influence the type of tasks that are

4 <https://scratch.mit.edu/>

proposed by teachers and which domains, sectors and theme are emphasized. The recent introduction of algorithmics and programming tasks, oriented towards completing or interpreting programs or algorithms because of the paper-and-pencil nature of the assessment, is likely to impact teachers practices and hence the implemented curriculum.

Computer Science and Mathematics in upper secondary school curriculum (French *lycée*)

The current curriculum of Mathematics at upper high school is the one introduced between 2009 (grade 10) and 2012 (grade 12). Algorithmics has been introduced in Mathematics through these programs. In 2017, the Mathematics program for grade 10, and in particular the algorithmic part, has been adapted, as algorithmics is not a new subject anymore for pupils at this level, and in order to make of the transverse content of algorithmics an authentic chapter untitled “algorithmics and programming”. The programming language Python has been introduced in replacement of Algobox, a language designed for French secondary school. This process will necessarily be followed by changes in grades 11 and 12 in the next years.

It is worthwhile to compare these two programs and the two corresponding accompanying resources, regarding the interaction of Mathematics contents with algorithmics. From 2009, algorithmics must be a tool for solving mathematics problems and contents (A3), but this role is often restrained to illustrate mathematical concepts and simulate random experiments (Modeste, 2012). There is also a collapsing between the notions of algorithm and program resulting in a collapse between input/output and typing/printing, and raising didactical issues (Modeste, 2012). In the 2017 program and accompanying resource, some of these issues have been settled, and a point of view on algorithms as functions is expected (in order to make this change effective, model subjects for the Baccalauréat have been published with an emphasis on the way algorithms must be structured). We interpret this change as a better consideration of some points of view of Computer Science in algorithmics, with a potential to develop also algorithmics for itself, but at the same time, the examples given in the new accompanying resource are strongly oriented toward application to calculus and numerical methods. This contradiction illustrates the tensions, at *school*, *pedagogy* and *discipline* levels, between teaching some elements of algorithmics for themselves and organizing the whole teaching of algorithmics around mathematics problems.

In 2009 as in 2017, A2 is not developed: although there is a strong potential to support interactions between mathematics or consistent algorithmic problem solving at secondary school (and namely the opportunity of being taught in the same class), very few contents shared by Mathematics and Computer Science are offered in the curriculum (for instance, arithmetic and combinatorics have remained negligible in the new curricula). For A1, although some contents of logic are present in upper high school Mathematics, there is no mention of their links with algorithmics. Finally, A4 is also very little present in these curricula.

Evolution of curricula: Actors, processes and debates. An insight of the noosphere

In the recent development of the curriculum of Mathematics and Computer Science, many actors have been involved or have influenced the situation. The academic societies in Computer Science have been, for a long time, lobbying for the introduction of Computer Science as a Scholar Discipline in France, associations like EPI⁵ have been campaigning for introduction of Computer

5 Enseignement Public et Informatique : <https://www.epi.asso.fr/>, association founded in 1971.

Science in School and have been contributing to the reflection on this for a very long time. In the 2010's, many opinion columns were published in French newspapers and the French Academy of Sciences (2013) published a report on the necessity to introduce Computer Science in school in France. Many of the actors of these institutions (mostly influential researchers) have also been invested in curriculum design (for ISN or the cycle 4 curriculum of Computer Science) but also in developing reflections on what should be and should contain a teaching of Computer Sciences, and in developing resources and textbooks.

The main debates about the future of teaching Computer Science are now about teachers and teachers' training, and the question of bringing together or not the different pieces of Computer Science present in the curriculum. The creation of a Computer Science option in the competitive exam for recruiting Mathematics teachers let think that we head towards a teaching of Computer Science by Mathematics teachers, or more likely Mathematics/Computer Science teachers. This debate is not closed at all and other hypotheses are also likely. In particular, some defend the close connection between Computer Science and Information Technologies (Tort & Bruillard, 2010) that would be likely to increase the distance between Mathematics and Computer Science. In any case, enhancing interaction between Mathematics and Computer Science in school will remain an important issue.

CONCLUSIONS AND PERSPECTIVES ON MATHEMATICS CURRICULUM REFORMS

Computer Science is still looking for its place in the curricula, and questions the territories of other scientific disciplines. As we have seen, the interactions with Mathematics are important in the scholarly knowledge. This leads to important curriculum design issues and questions the teachers' needs in order to handle the intended curricula. The perception of these changes in the curricula by Mathematics teachers could be enlightening for understanding their needs and representations of Computer Science, in order to understand the effects on the implemented curricula.

In the noosphere, many actors influence the didactical transposition of Computer Science which has a direct impact on Mathematics curriculum in the French educational context. In our view, an important issue is the place that a curriculum can let to the interactions between Mathematics and Computer Science (we have seen that these interactions are very limited at present). We have also seen that the French curriculum of Mathematics and Computer Science is influenced by two tendencies: international trends and French specificity.

We view the relation between Mathematics and Computer Science in French secondary curriculum as a prototypical example that illustrates the difficulties faced in STEM education to design curricula that take into account the disciplines themselves without neglecting their interactions (and reciprocally), and that address institutional constraints like the profile of the existing community of teachers.

To study the curriculum issues, we think that ATD and didactical transposition can be relevant.

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