

COMPUTER SCIENCE IN MATHEMATICS' NEW CURRICULA AT PRIMARY SCHOOL: NEW TOOLS, NEW TEACHING PRACTICES?

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Abstract: Based on the observation of a teacher incorporating a programming language for the first time in his teaching, and on previous research centred on the development of teaching practices in mathematics, we highlight here the importance of didactic “landmarks”, functioning as references in the dynamics involved along the development of teaching practices with ICT.

Keywords: teaching practices, Scratch, computer science, didactical landmark, instrumental distance

1. INTRODUCTION

In France, since September 2016, new mathematics curricula ask primary schools teachers and secondary mathematics teachers to integrate computer science, algorithmic, programming, using robots or new software such as Scratch. This latter is referred to all along the different school levels, pointing computer science knowledge but also more or less traditional mathematics notions such as the “location in space” (6/7 years-old, MEN 2015, p.86), the “production of simple algorithms” (8 y.o, *ibid.*), or the “notions of variables and functions” (from the age of 12, *ibid.* p.378). Yet, the difficulty for ICT to penetrate mathematics classrooms is not new, explained in many research by the “teacher barrier”. Will it be different this time? How will practices using these new tools for new curricula develop over time?

We present here a case-study from the on-going ANR research project “DALIE” (Didactics and learning of computer science in primary school), where 24 ordinary teachers (with no training), volunteered to use robots and/ or Scratch software. We focus on the first sessions of René, a primary school teacher, who uses for the first time Scratch. As most primary school teachers and mathematics teachers, René is a beginner in both the functioning of this tool, in the knowledge that it embeds, and *a fortiori* in its didactic uses. How does Scratch become a teaching tool for René and for which aims? What knowledge and practices does he develop? What can be learned from this study for the teacher training to be set up but also the resources to support teachers?

The section 2 details the theoretical tools we use to analyse René’s practices, based on our previous researches, and the section 3 our main results of observations. We end by a discussion in section 4.

2. THEORETICAL FRAMES FOR THE STUDY

Inscribed in the field of didactics of mathematics, our analyses are framed by two theoretical frames that we briefly present next: the Double Approach and the Instrumental Approach in didactics.

Components of practices and instrumental approach in didactics

The Double Approach frame (didactic and ergonomic) of Robert & Rogalski (2002) models teaching activity with five components (institutional, social, cognitive, mediative and personal). The institutional and social ones constraint the choices the teacher makes when organizing the students’ work: at cognitive level (as choices of contents, of tasks...) and mediative one (space and time organization). Decisions are taken according to the teachers’ own person (history, representation of teaching, of education, of mathematics, of learning, etc.). To explain here why teachers act such as

they do, we take this personal component as crucial, supposing that daily cognitive/ mediative choices, are imprinted of several didactic knowledge, which pre-exists in this personal component. In other words, we think that the personal component *contains knowledge on the cognitive and mediative ones* themselves. This diversified knowledge acts as didactic landmarks guiding the subsequent activity, which refers to it in order to perform the cognitive and mediative choices.

To specify this general approach to the case of instrumented situations, we turn towards the Instrumental Approach in didactics (Artigue 2002, Guin, Ruthven and Trouche, 2004, Lagrange 1999), which borrows two of the key ideas from the theory of instrumentation developed in cognitive ergonomics by Vérillon and Rabardel (1995 of): the process of instrumental genesis with its artefact/instrument distinction, and the fact that this is not a one-way process. Rather there is a dialectic between the subject acting on her personal instrument (*instrumentalization*: the different functionalities of the artefact are progressively discovered, eventually transformed in a personal way) and the instrument acting on the subject's mind (*instrumentation*: the progressive constitution of the cognitive schemes of instrumented actions). So, human activity transforms an artefact into an instrument across a long individual process of instrumental genesis, which combines these two interdependent mechanisms. Both point out that instrumentation is not neutral: instruments have impacts on conceptualizations. For example, using a graphic calculator to represent a function can play on student's conceptualizations of the notion of limit. This idea of not neutral "mediation", which exists (and always existed) between mathematics and instruments of mathematical activity, was used in several studies, first on symbolic calculators, then on other software as dynamic geometry or spreadsheets. In what follows, we introduce in more detail the notion that will be used from this frame: the distinction personal/professional instrumental genesis.

Double instrumental genesis

Applying the notion of instrumental genesis to the teacher entails to divide it into a *professional* genesis and a *personal* genesis. To briefly present here this idea of *double instrumental genesis*, we go back to the research context, which gave birth to it: the study of the spreadsheet integration in mathematics classroom; more recent details can be found in (Haspekian, 2014).

For a person (the students, the teacher), an instrumental genesis (IGpe) can lead the artefact spreadsheet to become a personal instrument of mathematical work. In addition, for the teacher, the same artefact spreadsheet has to progressively become a didactic instrument serving mathematics learning, along a process of a professional instrumental genesis (IGpro). These are, for teachers and students, two different spreadsheet instruments, from the same artefact. In this "splitting in two" instrument, the important point is that they both exist on the teacher's side. The teacher has to organize the students' work, and accompany their instrumental genesis with the spreadsheet, a tool of students' mathematical work. This accompaniment evolves through the teacher's various experiments, along a professional genesis where the spreadsheet becomes an instrument for her professional activity: teaching mathematics. Unlike the students, the teacher thus faces two instruments, one personal (possibly ancient as in the case of pocket calculators for which a IGpe process has generally taken place, former to any teaching context), and a professional one, based on the transforming of the new artefact or already personal instrument (as the pocket calculator) into an instrument to teach mathematics. The example of the pocket calculator as didactic instrument is rather telling if considering the many (and now classic) situations of "broken machines" (in display, in use...) provided in educational resources and developed in this aim of mathematics teaching ("broken key", "defective machine" [1]). This calculator, as a didactic instrument, is quite different from the personal "pocket calculator" instrument, which is ordinarily neither defective, nor with broken keys...

IGpro and IGpe interfere one on each other. Haspekian (2014) shows these interferences in the case of a teacher integrating the spreadsheet while discovering it herself. But even when the IGpe is well advanced, we claim that the process of IGpro is far from being evident. More, it also has to take into account the student's instrumental geneses. Schemes has to be built aiming at organizing the ' work, accompanying their own instrumental geneses with the tool. This piloting role is necessary for Trouche (2004), who speaks about the teacher's *instrumental orchestration* (configurations and mode of exploitation of the tool in class) [2]. The figure 1 shows the relations between this teacher's double instrumental geneses interfering also with those of the students.

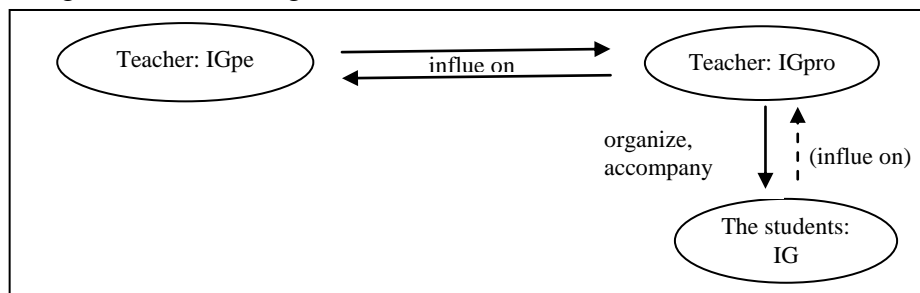


Fig 1 • Instrumental Geneses of the teacher (personal and professional) and the '

Scratch puts René in this complex case. His personal schemes of action with Scratch are evolving simultaneously, non-independently, with its professional schemes that aim students' learning. An additional difficulty comes in his case: knowledge to teach (computer science) is also new...

3. USING SCRATCH WITH FOURTH GRADE (9 YEARS OLD)

Methodology

Collected data consist of videos of the Scratch sessions and pre/ post interviews of the teachers. In these data, we try to understand the activity of the teacher with Scratch, the way instrumental geneses develop, particularly the links between IGpe (teacher and students) and IGpro (teacher). The sessions we focus here are situated at René's very beginning of IGpro: it is his 2nd session with Scratch, the first one consisting of a "free" discovering of Scratch by the students. What did René plan next? What knowledge does he aim at (mathematics? computer science? instrumental only?), through which functionality, in which order and under which modalities? In other words what are René's cognitive, mediative and instrumental choices? Another point makes this second session interesting: the class is divided into two groups with whom René repeats the same 1,5h session on two consecutive slots. We thus directly access to an instant of development of the teacher's IGpro, who's reinvesting with the 2nd group the marks taken with the first. It is interesting to see, in real time conditions, what types of marks he can he reinvest on the spot and why.

Main observed results

A detailed presentation of this session and its repetition is provided in Haspekian & Gélis (to come). We present here a synthesis of the two main results: on the one hand an IGpe too little advanced to efficiently support René's IGpro, on the other hand, despite the difficult situation, an evolution nevertheless of the IGpro, visible in the session repetition.

An IGpe too little advanced: consequences on the IGpro

In the session planed by Rene, the students were to answer two instructions [3] that, considering their own IG advancement with Scratch and their mathematical knowledge at this school level, were rising three foreseeable obstacles: first, the students did not yet meet the coordinates in Scratch, an

instrumental knowledge (a) necessary here to both locate, control moves of objects, and give them an initial position. This relates to mathematical knowledge of this school level clearly mentioned in the curricula (location in a plan or space). Then, they did neither meet the necessity (b) to define a starting position with certain movement commands used (with absolute and nonrelative positions, like “Going to...”). This instrumental knowledge is not obvious, insofar as an incompleteness of the program is only visible if run twice (the object does not move anymore). Third, the students do not either know the existence (c) of “scripts of scenario” associated to each object, which is again non-intuitive (only one page of scripts is displayed at once) but necessary to control two or more objects.

Did René’s task aim at making this knowledge emerge? The videos and interviews show that Rene did not prepare his session in this approach, having little identified himself these 3 points. Classroom interactions show René having the same interrogations as the students and discovering (a), (b) and (c), more or less realizing their importance on the spot. But René’s personal knowledge of Scratch features, even if beginning, far from putting him in discomfort, is on the contrary utilized to show students the importance of seeking solutions, carrying out tests, not discouraging...

This too little advanced GIpe of Rene has two consequences on his GIpro: in the management of the students’ GI, and in the definition of the learning objectives with Scratch. Indeed, having not himself anticipated knowledge (a), (b), (c), René could not effectively support the students’ difficulties, nor help their IG advance with Scratch. At several moments, in the two sessions, Rene is looking for the origin of the problem. Sometimes he succeeds on the spot (it is the case for the knowledge (b) but in an incomplete way: for the objects moved by translation but not by rotation), but more often he blames Scratch features, saying they do not function well, or dismiss the problem without more explanation, the dysfunction remaining thus not understood by the students. Lastly, Rene does not manage Scratch like a didactic tool of learning mathematical concepts nor informatics concepts, which are not identified at this stage (for example, his vocabulary is unstable: “*coordinates*” is sometimes said “*codes of the character*” or “*codes of movement*”). Yet, René has two other objectives instead. In the interviews, he states aiming at the learning of the French language (reading and understanding of the commands, project of writing a novel, importance of the chronology of a story, of sequencing the actions...) and of transdisciplinary objectives (to seek, to try and adjust, to develop interactions between pairs).

Finding of landmarks and development of the IGpro

Observing Rene at the first stages of his GIpro with Scratch, we see the teacher taking reference points with the first semi-group, and immediately reinvesting part of them with the second.

If the knowledge (c), a bit identified in mid-session 1, is never mentioned again, René clearly evolves on (a): the interactions show that he discovers at the beginning of the group 1 session the display of coordinates on the screen. At the end of this session, he points them directly (yet without seeking the coordinate system that generates them): *"If you don't see it anymore, it means that the x and y coordinates you put are outside of the page. (...) look, there you have the coordinates of the pointer. If you move, the coordinates change"*. Then, with group 2 session, he anticipates and this time mentions (a) during the beginning collective exchange: *"I will save time compared to the previous group: see if we put the pointer here..."* The interview confirms that he discovered knowledge (a) during the session: *"the coordinates of the pointer were displayed on the screen!"*; *"Look here, there, here: x zero! y zero! I had not seen it but in fact when you move you have the exact position!"*

In the same way, but at a later stage (in session 2), René becomes aware of knowledge (b). Once this landmark taken, he immediately identifies the students’ difficulties related to uninitialized positions

and in a dialogue with a student, he clearly express regrets of not having specified it collectively: "*I see very interesting things but there is a point that you, uh, a point that, besides, we did not specify in common...*". If the initial position problems in programs with displacements are thus well identified, the similar need to initialize a starting "orientation" in programs with rotations remains unidentified, leaving the students who encounter it blocked.

The table 1 summarizes René's evolution on (a), (b), (c) knowledge, along the consecutive sessions:

Knowledge	Group 1 session	Group 2 session
a : - Coordinates - Existence of a coordinate system	Coord : NO at the beginning, then awareness all along the session System : NO	Coord. : YES and beyond (asking a start and final point different) System : NO
b Initialize (if necessary) the starting position/ orientation	NO	NO at the beginning, then awareness all along the session for the displacements. No for the orientations.
c Scripts per object	NO at the beginning, then YES	YES and NO

Table 1 • Evolution of René's GIpe/pro along the 2 groups

Levers to manage the sessions while finding landmarks in parallel

René is 14 years experienced. His teaching practices are rather stabilized and coherent (Robert & Rogalski, 2002). The irruption of this new tool in the classroom destabilizes these equilibriums until evolving towards a new stability, which maintain the teacher's coherence in his professional activity. What is in the core of this process of evolution? The above analysis shows at least one thing: the teacher is taking landmarks on the utilization of Scratch. Here, this *constructive activity* (Samurçay and Rabardel, 2004) is occurring in the very time of the sessions, then how does Rene manage his sessions for the time duration needed to find landmarks? He reports himself needing time: "*I think it is necessary to redo a week more exercises of uh..., to discover a little because uh...*" But in spite of these difficult conditions (non-specialist, untrained, new tool and with unidentified underlying knowledge, be it algorithmic, mathematics or computer science), René remains at ease in the observed sessions, at no time in difficulties, neither at the macro level of its progression with Scratch, nor at the meso level of each session. What levers does he use?

Our hypothesis is that René has sufficient other landmarks (brought by his experience outside of tools as Scratch) to engage on innovative sessions without being toughly shaken, sessions that will provide him new landmarks. However, his use of Scratch does not lead him to use the tool with a mathematical or computer learning goal; he relates to transversal learning or French language learning. We make the hypothesis that these levers are not fortuitous choices, on the contrary they could be explained, again, in terms of landmarks acquired by the teacher, minimizing the distance that the software introduces to his everyday practices: René knows very well the teaching of French, and choosing transdisciplinary aims (group work, students' socialization, construction of a class project) also provides well-known landmarks, easily transferable because without underlying concepts.

4. DISCUSSION ET PERSPECTIVES FOR RESEARCH AND TEACHER TRAINING

Distance and landmarks

In earlier work, we have encountered two other cases, as René, of teachers minimizing the distance embarked by "newness" in old practices: the introduction of the spreadsheet into algebra teaching, which led to the idea of instrumental distance (Haspekian, 2014), and that of algorithmic into high school, where we observed similar phenomena to those of instrumental distance: tensions and resistances, practices of juxtaposition (homework, not integrated activities) or setting up of situations minimizing the "distance" that we then extended to a "distance to usual mathematical practices"

(Haspekian & Nijimbéré, 2016). The didactic landmarks appear as another hyphen to all these cases, like another face of the distance. If there is distance (to former practices), disturbing the teacher, not simply innovation, added without making waves on the current practices, it is because some didactic landmarks have been already built and the newness moves the teacher away from them, causing a loss feeling. New marks are to be created, either brought by training, resources, or by imagining them oneself or still accepting trying the experiment after all, in a blind manner. A first trial creates new reference marks which can lead to quite a different teaching activity at the second attempt. At a longer scale, several such experiments can supply the teacher with sufficiently robust landmarks enabling him to act in brand-new situations since they're not too distant on what was lived up, or since the teacher manages to bring it closer to what he knows. We saw these on-going processes happening in the case of Rene, but also with the spreadsheets. In other words, an enough experienced teacher will not only have more reference marks but may also be able to transpose, adapt old reference marks to create new ones more quickly and more easily than a beginner. In the same way, when we note phenomena of reduction of the distance, this translates the teacher's attempt to approach a situation in which she finds back didactic references. The distance is problematic when these landmarks are too much disrupted and/or without new ones being considered. For example, the factor making the spreadsheet instrumental distance too large had been analyzed as epistemological. The spreadsheet drops too much references on this dimension; letting the teacher with not enough didactic landmarks particularly in mathematical praxeologies. Thus, speaking of "distance" supposes the existence of an upstream referential to which new practices are compared. Whatever the term to name it, this referential serves the teacher to navigate in her daily practices by carrying a number of preexistent didactic landmarks (which can thus be disturbed, modified, searched, built, rebuilt...). The definition includes this idea of guidance of the teacher's later activity: a didactic landmark is a professional knowing, guiding the teacher in her action. The term "didactic" is taken in a very common sense, to specify that the elements of knowledge in which we are interested are those linked to the teaching-learning (including class management for instance).

The factors identified here and in our former research as contributing to create distance allow a categorization of the didactic landmarks, theoretically structured by the components of the Double Approach where we specifically isolate in the personal one: teachers epistemology and representations:

Even if legitimacy institutional (and social) is given and accepted, the teacher can still feel difficulties on the levels of:

- The disciplinary knowledge embarked by the tool: a too long distance to the usual objects of teaching (for example in the case of the spreadsheet in algebra: distance to the discipline and importance of "epistemological" legitimacy). This level where the epistemology of the teacher plays relates to the personal component of the Double Approach (representations on a discipline, on its teaching, its learning)
- Mediative knowledge of teaching: too large distance compared to the usual didactic landmarks (example of Scratch here). This level relates to the mediative component of the DA.
- Knowledge on the learning of the concepts by the students, on the possible situations, their potentialities, the classic difficulties/ errors, the possible remediation...: the new object must present a cognitive legitimacy but this is not enough. Even if the teacher recognizes it, she can feel its implementation too distant from its current knowledge. This level relates to the cognitive component.
- Knowledge on the curricula: the distance can be too large compared to the usual institutional landmarks. This level relates to the institutional and social component of the DA

Table 2 • Factors contributing to distance in general (instrumental in particular) hampering integration of newness (tool, domain or entire discipline)

From this, it comes out the following organization, which opposes legitimacies supporting newness integration to the tensions "landmark-distance" which slows it down:

	Legitimacy of the "newness"	Tension landmarks-distance
I: institutional	- legitimacy given by curricula, inspection, assess-	Require an appropriation on the part of the

S: social	ments, schoolbook; and by societal developments, fully immersed in technology	teacher: new landmarks are to be constructed here, even if curricula give some
Didactic: - C: cognitive - M: mediative	Research studies, professional training and literature, legitimize the contributions and benefits to cognitive levels (eg dynamic geometry for the notion of geometric figure, spreadsheets for entry into algebra ...) and mediative (saving time in the drawing of geometric constructions, in obtaining a large number of data, in the simulation of random experiments, in automated calculations, curve plots, illustration, etc.)	A priori, for an ordinary teacher: → loss of cognitive marks here → loss of mediative marks here Instrumental professional geneses are to develop in terms of orchestration, particularly to manage students' IG
P: Personal: - E: Epistemology of the teacher) - R: Representations	Legitimate/ foster or hinder (variable according to teachers): Depend on the person, her very knowledge of the disciplines at stake - Epistemology of the teacher on the impacted disciplines (epistemology of the discipline and of its teaching and learning) - Representation, in general, on teaching and learning (not specifically disciplinary)	
		Is function of the distance introduced by the "newness" regarding the disciplines usually taught

Table 3 • Legitimacies, landmarks and distance to ancient: the distance to current school practices is problematic if too few landmarks remain (I, C, M) (negative factors). This loss is counterbalanced on one part by the perceived/ conferred legitimacies at the levels (S, I, C, M) (positive factors), on the other part by the personal component, particularly the teachers' representation and epistemology in the concerned domain (P: R/ E) (factor positive or negative according to the person).

In conclusion, the quantity and the quality of the integration of a new object (in a broad sense) depend on two conditions on each one of the 5 components I, S, C, M, P: a condition on legitimacy and a condition on the didactic landmarks:

1. Legitimacy perceived/conferred by the teacher to this object at the institutional (I, S), didactic (C, M) and personal (E and R) levels
2. This legitimacy alone is not enough, the "newness" should not create (on the level of each components I, C or M) a too big distant situation to the usual practices where the teacher has landmarks (I, C or M), i.e that the integration of new can be done on landmarks close to the already acquired ones. A too large distance (for these components) hinders integration.

Finally, integration/or not, and its qualitative characteristics, depend on balance for each teacher between these various landmark-distance tensions (I, C, M) on one hand and the perceived/ conferred or not legitimacies (I, S, C, M and P) on the other.

Perspectives for rese arch and teacher accompaniment (training and resources)

The study of the case of Rene put in perspective with other research brings elements of comprehension of the practices in cases where the context "moves away" the teachers from their usual practices, either by the introduction of a new artifact, or by the introduction of a new field within mathematics, or by the introduction of a new discipline like informatics at elementary school. That led us to introduce the idea of "didactic landmarks" to speak about these common situations, idea that turns out to be the "counterpart" of that of distance. Defining and studying these are both objects of our current researches (with a theoretical link certainly necessary with the notion of *schemes* (concepts and theorems in acts, here professional; thus related to the Activity theory), but also with that of *beliefs* or Anglo-Saxon research on professional knowledge of the teachers: PCK model of Shulman (1986) and its later developments whose models are not based on the framework of the Double Approach). But if the didactic landmarks prove to be crucial, several interrogations upraise: how to facilitate their acquisition? Are some easier than others? Can some be more easily acquired in autonomy than others? In particular can we reasonably bet on the only experiment to develop didactic landmarks concerning the teaching of computer science concepts? The teachers in DALIE project (with Scratch or with robots) do not appear in a difficulty thanks to strategies of "substitution", why would they turn towards a new knowledge that they did not even identified and what could help

them acquire the necessary associated landmarks? These reflections indicate ways for the resources and more generally for needs in teacher training, to work out new didactic landmarks, supporting former and new situations, taking into account various dimensions of these landmarks:

- knowledge disciplinary of the fields, possible praxeologies,
- didactic knowledge in link with these fields (cognitive, mediative, instrumental, including class management in general at mediative level, but also at instrumental one with the orchestrations),

These dimensions should not be separated if one wants changes in practices according the Double Approach frame (Robert & Rogalski, 2002). We assume that if certain didactic landmarks can be more or less quickly acquired through the development of the teacher's Gipro/pe, undoubtedly there is a need to accompany, through training and resources, some conceptual didactic landmarks.

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1 see for instance MEN 2002, or Caron, F. (2007). Au cœur de « la calculatrice défectueuse » : un virus qu'on souhaiterait contagieux ! *Petit x* 73, 71-82, or also online resources, as for example: <http://emmanuel.ostenne.free.fr/arras/rallye/rallye8.html> or: <http://calculatrice.ac-lille.fr/calculatrice/spip.php?article60>

2 regarding Robert & Rogalski frame(2002), they are part of the teacher's personal component

3 with only one initial command, move two characters at the same time, then in a successive way