FaSMEd Position Paper

The use of technology in mathematics and science education

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Reminder: Key questions of the FaSMeD project and formative assessment

The key questions of the project as established in the DOW are formulated in the following way:

- How do teachers process formative assessment data from students using a range of technologies?
- How do teachers inform their future teaching using such data?
- How is formative assessment data used by students to inform their learning trajectories?
- When technology is positioned as a learning tool rather than a data logger for the teacher, what issues does this pose for the teacher in terms of their being able become more informed about student understanding?

(DOW 1.1.3 Research questions)

Introduction

Improving the quality of teaching and learning by effective use of technology is a common goal that brings together teachers, researchers, students and, more widely, citizens. In the frame of formative assessment in mathematics and science, we are going to consider several perspectives:

- first, technology in a broad sense that allows new sources of information, new *re-sources*, new means of communication and storage of information,
- second, technology specifically linked to mathematics and mathematics education,
- and third, technology, science and science education.

The purpose of this document is to provide an epistemological approach to what ICT can bring in math or science education more than summarizing the state of the art of digital use in mathematics and science. *See "The use of technology in formative assessment to raise achievement" for another point of view about technology in FaSMEd.*

In formative assessment, Andrade, speaking of authors of the "Handbook of formative assessment" (Andrarde & Cizek, 2010) says: "*nearly every author identified the primary goal of formative assessment as providing feedback to students and teachers about the targets for learning, where students are in relation to those targets, and what can be done to fill in the gaps.*" (Andrade, 2010). So, one role of technology is to facilitate the collection of students' data in order to inform more quickly and surely about the students' activity in a particular situation. But it is far from being the only role and considering technology in the first perspective (above), it is also a source of documentation directly linked with the learning goal. For example, technologies used by students allow them to store and to share data that contribute to their learning trajectories. Thus documentation and available resources are a key element of self-regulating learning, where students control and augment their knowledge in a given or self-constructed goal. It is also the case that teachers develop formative assessment from their own set of resources and when technology is a tool facilitating collection of data and feedback to the learners or when technology is positioned as a learning tool, the availability of resources impact on their resources and behavior. In both cases, available resources play a central role for the students and teachers in the process of formative assessment. Consequently, this notion of resources and documents has to be clarified especially when the adjective "digital" is added.

The theoretical framework underpinning reflection about resources and documents is that of documentational genesis, described by Gueudet and Trouche as an extension of instrumental genesis: "*We introduce here a distinction between resources and documents, extending the distinction introduced by Rabardel (1995) between artifact and instrument." (Gueudet & Trouche, 2009). In this theory, resources become documents after a long process where the resource modifies the actor's behavior (instrumentation) and the actor modifies and shapes the resource (instrumentalization). The result of the process is called a document and can be described by the formula: "Document = Resources+Scheme of utilization*" (id. p. 205).

These two last points, which we believe also directly link to the third FaSMEd research question (above), lead us to consider the place of technology in mathematics or science education through the lens of a specific epistemology. The reason is that in science and in mathematics, learning tools are designed drawing on the objects, concepts and notions that can be described, depicted, manipulated, and combined within the given technology. For example, in mathematics, calculators are built to deal with numbers (most of the time a finite subset of the set of decimal numbers) and to manipulate these numbers through operations. In this case, mathematical objects are implicit in their digital representation. However, we believe that in science, there is a necessity for a clear distinction between objects and theory since modeling needs to distinguish between the world of objects and events and the world of theories and models (Tiberghien, 1994). As a consequence, we believe, the role of ICT in science is to help students to distinguish and to explore the relationships between these two domains rather than manipulating and combining objects. Thus the difference between a mathematical and a scientific approach to the use of technology in pedagogy depends on a fundamental epistemological difference between objects of mathematics and science.

In our discussion we are constraining our study to specific mathematics and science technology. In the first part of this document, we develop an epistemological viewpoint about mathematics and science education. We then describe the available tools that can be used in mathematics and science and the conclusion will focus on points that might be useful for the FaSMEd project.

Mathematics and mathematics education

One description of mathematics claims that the mathematical objects that mathematicians manipulate have various representations and mathematicians' work is about these representations: “the semiotic representations are productions made of signs belonging to a system of representation which has its own constraints of significance and operating.” (Duval, 1991, p.234). This defines mathematical objects as the equivalence class of their representations modulo the equivalence relation defined by: two representations are equivalent if they represent the same object.

This definition has two important consequences:

- a mathematical object can be mastered in a particular context and is difficult or unknown in another context,
- converting a register of representation to another is essential to understand a mathematical object.

This conversion requires a translation that both loses elements of meaning and adds others (tradurre e tradire: to translate is to betray). Changing the significant, that is to say the way to designate the object, modifies and enriches on the one hand and impoverishes on the other the signified, that is to say the designated object. The thesis of indeterminacy of translation (Quine, 1960) tends to explain that the translation between two languages cannot be complete. More precisely, Quine argues that it is always possible to build different interpretations, semantically coherent, of a given text. His famous “Gavagai”, word (or sentence?) said by a primitive seeing rabbits running away in the forest, is an example of holophrastic indeterminacy, that is to say, the indeterminacy of sentence translation; does it mean “rabbit”, or “stages of rabbits” or “rabithood”,...? “In each case the situations that prompt assent to ‘gavagai’ would be the same as for ‘rabbit’. Or perhaps the objects to which ‘gavagai’ applies are all and sundry undetachable parts of rabbits, again the same stimulus meaning would register no difference.” (Quine, 1960, p.47)

We argue that the issues raised by Quine are not restricted to translation between different languages but can also be present within a language, through the interpretation of a word or a sentence. They can also occur when different significants refer to a sole signified. This is the case where there are semiotic registers of representation of a mathematical objects. For example, in the Julia set known as the Douady's rabbit can be defined in a topological perspective as the closure of the set of repelling periodic points of f(z)=z^2+−0,123 + 0.745i. Or in an analytical (or algorithmic) perspective as: for all but at

most two points $z \in X$, the Julia set is the set of limit points of the full backwards orbit $\sum f^{-}$ or, in a graphical

perspective as shown on figure 1. And so on.

All these representations give information about the structure and the properties of Julia sets, but also lose information or properties. Thus, the graphical representation, even if it is not calculable, gives precious information about the dynamic of this set and it is not surprising that the work of Julia remained little known until computers allowed these representations.

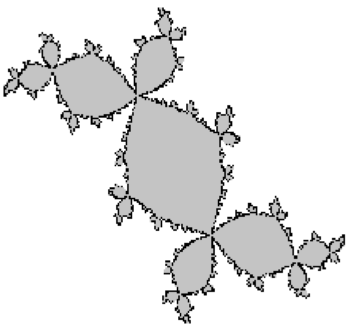


Fig. 1 Douady's rabbit

Multiple representations through digital technology

The assumptions that underpin our work are then that technology offers opportunities for multiple representations that facilitate the understanding of mathematical objects. Following the work of Arzarello and Robutti (2010), technology provides both an internal representation through multiple software representing the same object (spreadsheet, DGS, CAS,...) but also externally through communication, providing different approaches from different points of view.
The notion of multimodality emphasizes the many ways people experience and develop understanding and these two aspects of multirepresentation and multimodality can be seen as the two faces of the same coin: multirepresentation being the technological way and multimodality the cognitive way of understanding mathematics. “Instrumental activity in technological settings is multimodal, because action is not only directed towards objects, but also towards people” (Arzarello and Robutti, 2010, p. 718).

Thus, to study multiple representations offered by technology, it seems important not only to focus on the graphing and calculation properties, but also to consider the properties of organization of ideas, creativity and communication involved in the implementation of external representations of mathematical objects studied, that is to say, to include documentational properties within technology.

We believe that scientific phenomena or observable occurrence can be included within an experimental device (framework) only if they are considered as objects. Mathematics is not an exception and the relationships between mathematical objects and reality have to be clarified. From a Kantian perspective, mathematics is a human construction which builds and defines its objects *a priori.* In this perspective, its levels of reality include mathematical objects as elements:

perceptible reality which is perceived by the five senses; empirical reality which can be the subject of experiment and objective reality on which it will be possible to build mathematical experiments. The reality *per se* also called unattainable reality which remains inaccessible.

Thus, it can be argued that experience takes into account perceptible, empirical and objective reality and what can be called an experience in mathematics is work on naturalized representations of mathematical objects defined in a system of signs. The word “naturalized” is understood as the mastery of internal transformations within a register of representation or conversions from one register to another. Thus a mathematical experience allows us to define and explore the properties of a particular object in relation to a theory. Hence mathematical concepts, even if they are created in mind, are fully realized in the relationships with empirical phenomena: "Thoughts without content are empty, intuitions without concepts are blind.” (Kant, 1781, p. 51) [i]. We believe that these philosophical considerations on the nature of objects are of great importance for education and particularly when considering mathematical objects through their technological representations. Indeed, especially in a technological environment, the role of experience of mathematical objects seems to be a widely shared assumption. However, experiments are built not on objects which are fundamentally synthetic in nature but on representations of these objects that extend the studied concept to make it perceivable.

The dialectical relationship of media-contents and resource-document discussed above have to be put in relation with objects and representations. As well as a resource becoming a document in the documentational genesis, the understanding of a mathematical object is built through and by the experiments on some of its representations. As an example, we can consider the famous clay tablet shown on Fig. 2. The mathematical content is synthesized on the tablet with different representations of the same object: symbols of the sexagesimal Babylonian writing of numbers, a square and its diagonals. The Babylonian algorithm for the determination of the square root of two, even if not present on the tablet is also present through the result of the calculation: the side is 30 (<<<) and the diagonal is 30 times square root of 2 (I << IIII
<<<<< I <: $1+24/60+51/3600+10/60^3$ ⍰ 1.41421296) and the two approximate values, result of the algorithm, are written on the diagonal.

Fig.2 Clay tablet YBC 7289
Yale University
http://nelc.yale.edu/babylonian-collection

In this example, links between registers of representations bring to light the experiment that combined methods and concepts to create new knowledge. Even if no document described the calculation done by the scribe to reach this precision, we could imagine that the so-called “Babylonian algorithm” came from the combination of drawings and calculation; starting with a rectangle 1 x 2 of area 2, then replacing the side of length 2 by the mean of 1 and 2 and the side of length 1 by a side such that the area is still 2, and so on. When the rectangle becomes (almost) a square, the calculation gives the result (almost) written on the tablet as illustrated on figure 3. Extending to a register of analysis, it is interesting to notice that this algorithm can be described by the algorithm of Newton with the function $f : x \rightarrow x^2-2$: the sequence u0 = 2, un+1=un-f(un)/f'(un) gives as first terms: 2, 3/2, 17/12, 577/408, 665857/470832...

1	2
$\frac{3}{2}$	$\frac{4}{3}$
$\frac{17}{12}$	$\frac{24}{17}$
$\frac{577}{408}$	$\frac{816}{577}$
$\frac{665857}{470832}$	$\frac{941664}{665837}$

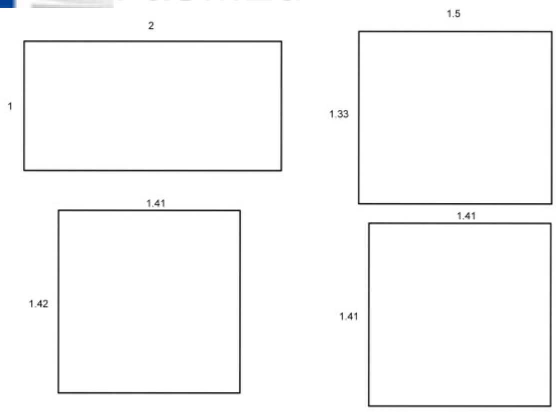


Fig. 3 Babylonian algorithm in two registers of representation.

Exploration, experiments with technology

The important part of the experimental dimension of mathematics in the processes of modeling, exploration, or practicing is facilitated by the use of technology. In both 'horizontal' modeling from an 'external' situation to 'internal' and 'vertical' modeling within mathematics, technology gives an opportunity to manipulate and to combine mathematical objects (or some of their representations) in order to produce a new knowledge. This experimental dimension of mathematics can be defined, following Durand-Guerrier (2007, p.17) as "*the back and forth between the objects that we try to define and to delimit and the test or the development of a theory, mostly local, in order to report on some properties of these objects".* This experimental dimension thus takes into account both modelling approaches and mathematical concepts and impacts on their learning. With a view to renewing the teaching of mathematics, the place and role of an experimental approach of mathematics in the classroom through modeling situations or problem solving approaches should be addressed, especially with regard to learning mathematical concepts. The question of the evaluation and transposition of skills that are involved in an experimental dimension of mathematics, to other frameworks of mathematical activity (appropriation and implementation of knowledge, of technique, communication and writing of results and proofs,...) is a crucial issue in the perspective of dissemination of teaching methods based on experiments with ICT.

Thinking of mathematics education in the twenty first century brings us to consider the relationships between students, teacher and knowledge and the subtle games played in the documentary process between resource and document as well as the dialectical relationship of representation-objects through mathematical experiments. This experimental part of mathematics can be considered as all that can be done with representations and media (including thought experiments) when the cognitive part joins the associated contents and the mathematical objects as illustrated on figure 2.

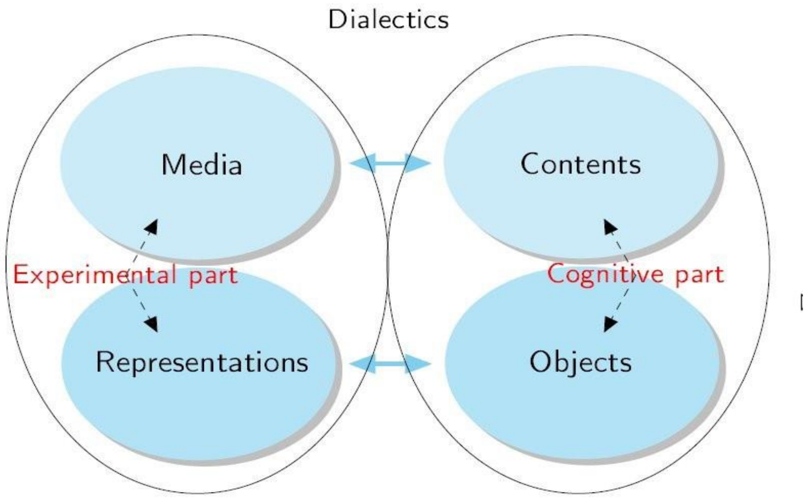


Fig 4. The experimental part of mathematics

Consequences for mathematics education

It is easy to introduce technology in mathematics education as a "new" kind of representation of mathematical objects with new potentialities, but introducing technology in a way that facilitates learning is quite an issue. The examples of dynamic geometry or computer algebra systems show these new opportunities for teaching and learning mathematics.

The example below comes from the EdUmatics project. Even if it has not been designed in the perspective of formative assessment, it is interesting to see the potentialities included within the mathematical situation in order to inform the teacher of the students' understanding of various mathematical knowledge:

- mathematical concepts (as for example, continuity, differentiability of a function)
- understanding of semiotic representations of objects (relationships between non differentiability at a point and curve representation of this function at that point, quadratic equation and conics,...),
- interpretation of geometrical properties within the field of analysis and reciprocally (relationships of distance to a point and function representation, symmetries...)

The problem[ii]

First, students have to find the curve describing the distance to the center of a square according to the walker's position on the perimeter. Synthesis allows the teacher to bring to light different properties of this curve: periodicity, continuity and non-differentiability on certain points.

Secondly, the curve was given as shown below, and students have to find the analytical expression of the function on a period of this curve. (The expression of the function was searched on the first period, that is to say on the interval [0,c], where c is the length of the square's side.)

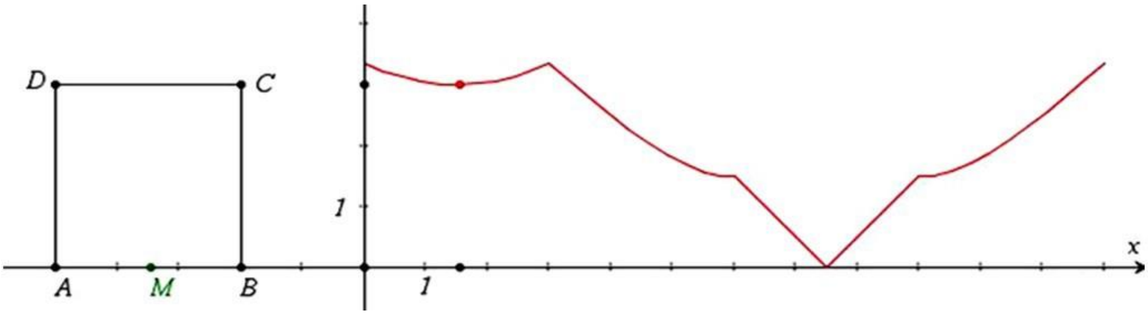


Fig. 4. Evolution of the distance to a point of a mobile moving along the perimeter of the square Where is the point?

The interactions between the geometrical problem and its representations are the departure point for exploration of different notions. Properties experienced in the geometrical environments are dynamically translated into the graphical register of representations, which lead to the characterization of these properties in the graphical domain. Conversely, properties seen on the curve can be interpreted in the geometrical domain:

- Periodicity: when the target point is the square's center, the function is c-periodic (c is the length of the square) whereas when the target point is not the center, the function is 4c-periodic; the geometrical situation (or the "real" situation) shows clearly this periodicity; conversely, a period on the curve represents the path along one side or along the perimeter of the square;
- Symmetry: the position of the target point on particular lines of the square (the diagonal, the perpendicular bisector, the sides) highlights local or global symmetries on the curve; conversely, possible symmetries of the curve give information about the position of the point; especially, it is possible to link symmetries on the curve and axes of symmetry of the square;
- Differentiability: observation of the curve corresponding to the position of a walker on a vertex of the square allows us to question the differentiability of the function and its graphical interpretation; this observation also occurs when the target point is on a side of the square.

Where is the target point? Graphical readings

Particular properties can be interpreted; for example:

- equivalence between "the target point is on a side of the square" and "the curve reaches the x-axis";
- three points of the curve are sufficient to draw the target point in the plane;
- when the target point is inside the square, the maximum of the function is less than the length of the square's diagonal; if the maximum is greater than this diagonal's length then the point is outside the square but the reciprocal is false;
- a supplementary question: what is the domain where the reciprocal is true?"

Digital technology in science and science education

This part is based on a book chapter reflecting CAT Course, wich is a product of CAT-project, supported by european commission (Comenius Program, registration number 141767-LLP-1-2008-DE-COMENIUS-CMP)[1].

Integrating ICT in a teaching sequence necessitates consideration of the knowledge to be taught, learning hypothesis and the actual context of teaching as integrated in an institutional context. We believe that questions stated nowadays with ICT are relatively close to those arising in the nineties concerning the role of practical work. As the effectiveness of practical work has been questioned, good ways to teach science with ICT activities are still fields for investigation. The role of ICT in learning science continues to be studied, in combination with other elements of the teaching-learning situations.

Different theoretical perspectives not developed here, arising from psychology of education, enabled science education research to improve the teaching-learning situation. Behaviorist hypotheses on learning, in vogue in the early seventies, evolved towards viewpoints taking account of the previous knowledge of students and later on, the role of social interactions in the classroom. It seems that, since the nineties, a general agreement in the science education research community has emerged concerning the socio-constructivist point of view on learning. Within this perspective, two main categories of elements should be taken into account when considering a teaching-learning situation:

- the material objects with which students interact. This category not only includes devices enabling experiments, but also written instructions, the available material resources such as textbooks, and the computer and software to be used;
- any other partners (mainly students and teachers) interacting with the student.

This last category has to be analyzed from a didactical point of view. A teaching-learning situation involves a series of actors or partners, mainly but not only students and teacher, interacting in the use of knowledge. Taking into account these two categories of elements (material objects and partners) allows ICT to be considered as an integrated element of the teaching-learning situation. Implementing new elements, such as new types of activities including ICT or not, in a teaching-learning situation disrupts the system, and the role of actors has to be carefully redistributed in order that learning objectives continue to be clear to everyone. Keeping this systemic point of view of a teaching learning situation in mind enables us to think of ICT not only as a tool for motivating students, but also for modifying relationships between teacher, students and knowledge.

Teaching and learning viewed with different time scales

The teaching learning situation can be analyzed with three time scales. These scales can make clear the way knowledge is used in the class.

- The longest time scale considered is called the *macro scale*. A good representation of this scale is the chapters or parts of a textbook. During a macro episode, the unit of knowledge is large, for example; acid base reactions, the chemistry of alcohols etc., or larger as “chemistry and health”, chemistry and sport”, etc. A macro episode lasts hours spread out over one or even several weeks.
- A smaller time scale is the *meso scale*. During a meso episode, the thematic unity is of smaller size. For example, the macro-episode “acid base reaction” can be divided into meso episodes such as “proton transfer (during a lecture)”, “proton transfer (during an exercise)”, “dissociation of acids (during an experiment)” etc. As far as knowledge is considered, a meso episode lasts 10 to 20 min. At this scale, knowledge is organized to enable the construction of the meaning by students.
- The smallest time scale to be considered on a cognitive viewpoint is the *micro scale*. A micro-episode is an interaction between teacher and students, or between students. An interaction lasts from few seconds to one minute. At this level, we believe, utterances bear information more than meaning.

Teachers work at the macro scale when they decide how long they would spend on such and such chapters. This division of time leads to the decision of when would work be spent in the chemistry laboratory or in the computer room etc. Even though teachers may not have previously heard about time scales, they are familiar with the macro scale where institutional constraints are often determinant.

The meso scale is of prime importance in teaching as meso episodes make possible the construction of the meaning of concepts. The length of these episodes should not be excessive as the students cannot focus their attention for too long to process information. It is the responsibility of the teacher to share his/her time into these episodes and a failure in teaching may arise from a bad partition of meso episodes.

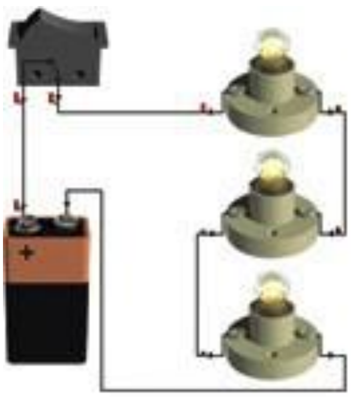
The micro scale can also be adjusted by the teacher. During micro episodes, information is exchanged between people in interaction. If the teacher uses long monologues, the interaction is no more efficient and learning is less likely to occur. Another aspect of the micro scale is to consider a situation where a small group of students (group 1) are interacting while the teacher works with another group of students (group 2). When the teacher arrives by group 1 and listens, s/he hears micro episodes, and not a meso one. S/he may therefore not be able to appreciate the meaning of the current students’ interaction from the little information that s/he has just grasped. Hence s/he is likely to interfere with only a partial understanding of what is being discussed in group 1. Thus his/her interventions may be at variance with the real meaning that was at stake. Such behaviour may damage the group 1 interaction that was occurring before s/he arrived.

Integration of ICT can be understood with these three time scales. ICT is rarely used at the macro scale. Such a use would mean that consecutive hours of teaching would be organized around ICT. Only specific schools with a long tradition of ICT teaching can afford such an organization, unless a long project using computers, and lasting for months, could be integrated in teaching. Most of the time, ICT is used at the meso scale. Introduction of laboratory work that would present the aim of the task to be performed by the student is clearly at the meso scale since it lasts a few minutes and the meaning of an idea is considered. The same argument can be proposed to defend the idea that ICT is used at the meso scale if it is used to conclude a teaching sequence, to simulate an experiment, to show an animation about the correspondence between macroscopic and microscopic representation. The use of ICT can also be considered at the micro scale, either during student-student interaction, or students-teacher interactions. At this scale, students and teacher may interact on how to use in information on the screen, how to make a graph or how to use ICT to make a prediction or to check a hypothesis.

Learning science as a modeling process

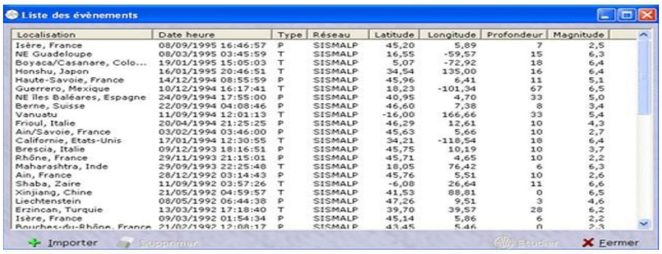
One hypothesis concerning learning science addresses the modeling process which makes meaning out of scientific concepts. The meaning of these concepts requires establishing links between two domains of knowledge: the first domain is related to perception and description of the material world and the second one comprises scientific theories and ways of thinking – not necessarily coherent with a scientific point of view. Establishing such links appears from research studies to be the main difficulty for students (Bécu-Robinault, 2004): indeed, students frequently make use of everyday knowledge that are unfortunately non-compliant with scienctific knowledge. They need to experience that knowledge they construct from direct observation on the material world (built on naïve theories) conflicts with knowledge constructed from scientific models enabling the interpretation and prediction of phenomena. Thus students must be helped in confronting their own ideas with scientific theories and models, and the use of ICT may be helpful to reach this goal. Hence, a purpose of ICT might be to contribute in helping students to distinguish and explore the relations between these two domains of knowledge, i.e. modeling. Modeling allows an analytic distinction between the "world" of objects/events and the "world" of theories/models (Tiberghien, 1994). According to this framework, establishing relationships between these domains of knowledge is a requisite for understanding and learning. For example, learning physics implies learning how to integrate both levels. Analyzing the learning process in this framework also enables support for both the personal knowledge of a learner and teaching.

ICT, coupled with traditional activities may favor these modeling activities if the teacher takes care to distinguish the two levels before asking for establishing relationships. For instance, while describing an experimental situation in electricity, such as a shining bulb and the way to connect it to a battery, students will be addressing the level of objects and events. While interpreting or predicting what occurs in terms of current or what object plays the role of the generator, they will be dealing with the level of models and theories. ICT applets, often used by teachers to simulate an experiment in electricity, should thus make it possible for the student to establish a clear distinction between the world of object and events and the world of theories. Thus, pictures of electrical circuit with the representation of the bulb alight are quite confusing for students, because they mix two levels and two types of information (functioning and phenomenon levels). A way to avoid such confusion is to use representations that make clear that there is a level for the objects and, separately a level for the model. The lightening of the bulb should be exclusively used on drawings of experiments.



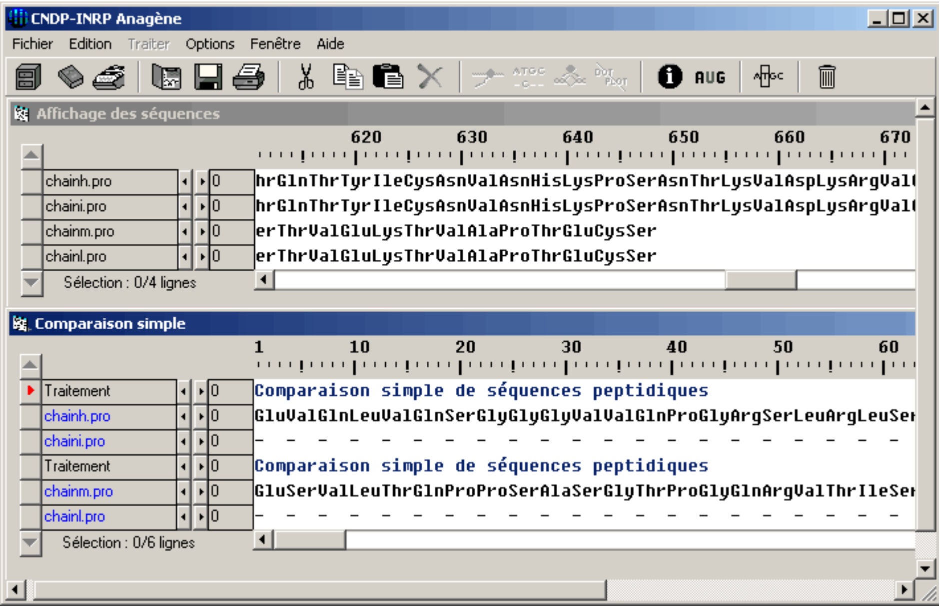
On this screenshot of a simulator (crocodile clips), the pictures of the battery, the switch and the lightening bulbs (real devices, corresponding to objects and events) are connected with lines (diagram of the experiment, which corresponds to the electrokinetic's model). In this case, the two levels are intertwined, which might be confusing for students.

Modelling activities can also be enhanced by software providing databases.



Localisation	Date heure	Type	Réseau	Latitude	Longitude	Profondeur	Magnitude
Isère, France	08/09/1995 16:46:57	P	SISMALP	45,20	5,89	7	2,5
NE Guadeloupe	08/03/1995 03:45:59	T	SISMALP	16,55	-59,57	15	6,3
Boyaca/Casanare, Colo...	19/01/1995 15:05:03	T	SISMALP	5,07	-72,92	18	6,4
Honshu, Japon	16/01/1995 20:46:51	T	SISMALP	34,54	135,00	16	6,4
Haute-Savoie, France	14/12/1994 08:55:59	P	SISMALP	45,96	6,41	11	5,1
Guerrero, Mexique	10/12/1994 16:17:41	T	SISMALP	18,23	-101,34	67	6,5
NE îles Baléares, Espagne	24/09/1994 17:55:00	P	SISMALP	40,95	4,70	33	5,0
Berne, Suisse	22/09/1994 04:08:46	P	SISMALP	46,60	7,38	8	3,4
Vanuatu	11/09/1994 12:01:13	T	SISMALP	-16,00	166,66	33	5,4
Frioul, Italie	20/04/1994 21:25:25	P	SISMALP	46,29	12,61	10	4,3
Ain/Savoie, France	03/02/1994 03:46:00	P	SISMALP	45,63	5,66	10	2,7
Californie, Etats-Unis	17/01/1994 12:30:55	T	SISMALP	34,21	-118,54	18	6,4
Brescia, Italie	09/12/1993 18:16:51	P	SISMALP	45,75	10,19	10	3,7
Rhône, France	29/11/1993 21:15:01	P	SISMALP	45,71	4,65	10	2,2
Maharashtra, Inde	29/09/1993 22:25:48	T	SISMALP	18,05	76,42	6	6,3
Ain, France	28/12/1992 03:14:43	P	SISMALP	45,76	5,51	10	2,6
Shaba, Zaire	11/09/1992 03:57:26	T	SISMALP	-6,08	26,64	11	6,6
Xinjiang, Chine	21/05/1992 04:59:57	T	SISMALP	41,53	88,81	0	6,5
Liechtenstein	08/05/1992 06:44:38	P	SISMALP	47,26	9,51	3	4,6
Erzincan, Turquie	13/03/1992 17:18:40	T	SISMALP	39,70	39,57	28	6,2
Isère, France	09/03/1992 01:54:34	P	SISMALP	45,14	5,86	6	2,2
Bouches-du-Rhône, France	21/02/1992 12:08:17	P	SISMALP	43,45	5,46	0	2,3

Sismolog is a software including a datase on seism (geolocalisation, depth, intensity, sismic wave velocity). These data help modelling boundaries of lithospheric plates.



Anagene is a molecular biology software including a database of molecule sequences (proteins, DNA, RNA), for instance allowing to study the relations between the structure and the functions of molecules.

Learning to represent scientific concepts

One characteristic of scientific concepts is related to their expression with multiple representations. These representations, expressed through several modalities, can be categorized on the basis of semiotic registers, such as: diagram, natural language, formula, drawing, and graphics… Kress et al. (2001) demonstrated that learning to talk about science at school goes beyond verbal aspects. Scientific discourse is multimodal and uses multiple semiotic registers (Duval, 1995). Learning science implies the appropriation of concepts, instruments, and cultural practices by a multimodal language (Lemke, 1990). Interactions in science classes are therefore organized with a plurality of multimodal resources, including gestures, glances, body postures, movements, and questions and answers from students and teachers alike, and also involve the handling of objects, texts, charts, sketches, diagrams, and lists of number, in addition to the use of simulations and other procedures.

Educational research has shown that students cannot easily connect the different scientific representations of a given concept. Combining these representations is seen as a good indicator of the student learning process. In the study of the kinetics of a chemical system

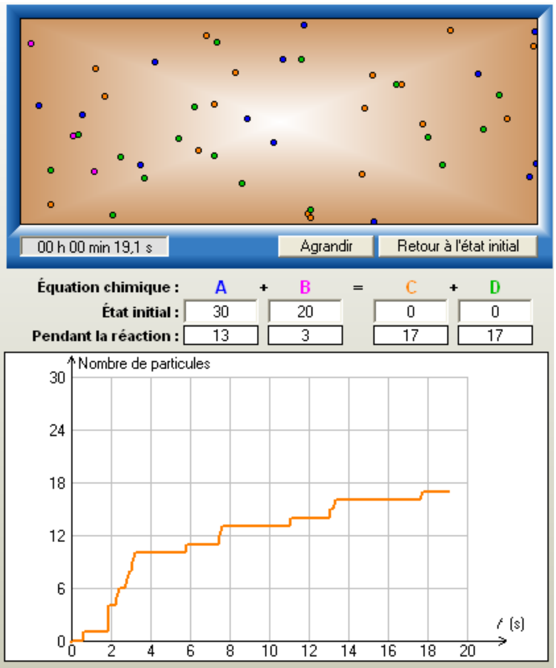
$A + B \rightarrow C + D$

the following representation can been used with students (see figure below):

- a dynamic animation of particles,
- a table of the progress of the reaction with the initial state and the current state
- a graph of the evolution of the number of the C particles

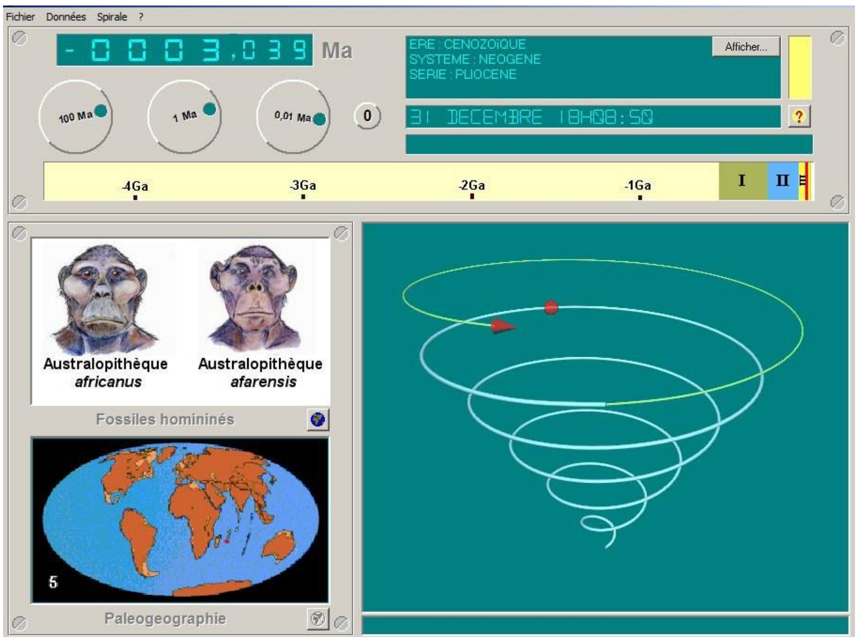
- and a table of the states can also be provided

Although the information represented on these different semiotic registers is the same for a chemist, going from one to the other requires real and lengthy work for students. It can be done step by step. Making meaning out of many details of the representations (colour change of particles, numbers in the table, variable represented in each axis of the diagram, steps of the diagram etc.) must be coordinated with bringing new vocabulary such as reactive collision, progress of the reaction etc. The new knowledge has then to be used in other contexts, especially in a "normal" class situation and exercises that do not involve ICT.



Learning physics also implies learning what part of information is missing or gained, what are the connections established between the concepts while using a different semiotic resource.

An example in geology



This screenshot displays a software including different representation of geological time[2]

- sagittal time (unidirectional time) : a frieze and a spiral ;
- relative time (older than, latest) connected to geological period (era, system, serie) ;
- absolute time with a counter ;
- the geological time based on the period of one year.

Some ICT tools used in mathematics education

Geometry software: dynamic geometry software (DGS) has been developed for more than thirty years and a lot of projects' papers have shown the impact of DGS on the representation of geometrical objects in mathematics education. At the same time, networks of users have spread on the web (Geogebra institutes, Cabri world conferences, Cinderella forums, The Geometer's Sketchpad® Resource Center, and so on). In the recent years, the appearance of tablets and interactive white board has been accompanied by new DGS taking into account the manipulation of objects directly with hands. (Geogebra, Cinderella, Cabri, Geometer Sketchpad, Dgpad,...)

Spreadsheets: mainly building a bridge between arithmetic and algebra, spreadsheets' use within mathematics lessons has been studied in several countries and in several curricula. (Libre Office Calc, Open Office Calc, Microsoft Excel,...)

Computer Algebra System: mostly used in high secondary levels and university, CAS software are available on handheld devices (calculator, tablets, or mobile phones). Their calculation potentialities as well as their complexity require specific work of teachers in order to orchestrate their use within the classroom. (TINspire, Maxima, Maple, Mathematica, Xcas,...)

Statistical software: apart from spreadsheets, statistical software gives tools allowing users to deal with large data sets and allowing the calculation of statistical characteristics. (R, Scilab, Statistical Lab,...)

Specific apps illustrating a particular property or allowing an interactive work regarding a particular object are also available at different levels of education.

Some ICT tools used in science education

Below is presented a list of ICT tools than can be associated to purposes and teaching contents. It might be interesting to analyze the way these tools are used in French schools, depending on the teaching level and content, and what specific learning objectives are tackled, and assessed when implemented in classrooms.

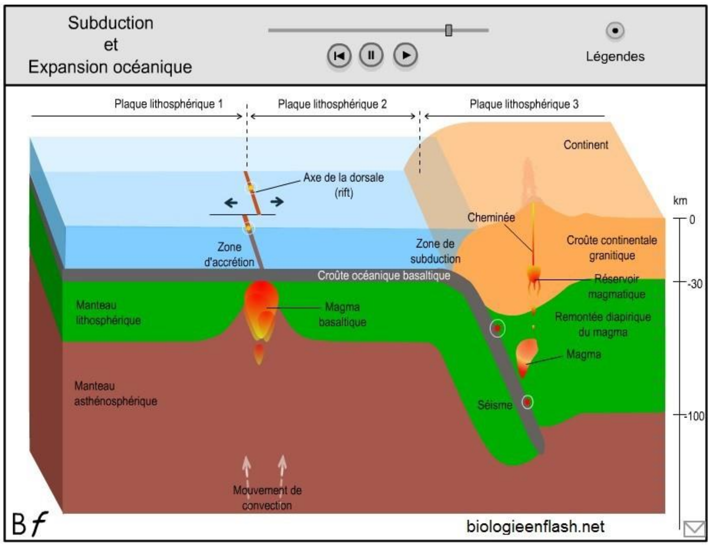
Microcomputer-based laboratory: biology, chemistry and physics. Those tools are combinations of hardware and software. They are used to collect, process data and to capture data that are not approachable with traditional devices. For instance, biology studies complex and changing objects. This leads to study a series of individuals, not a single one: calculus enabled by ICT tools help to process (statistically) huge amounts of data.

Models and modeling: biology, geology, physics, chemistry. As presented before, science education aims to help students to gain an understanding of scientific models. The aim of a scientific model is to simplify phenomena to build powerful explanations. Modeling ICT tools allow knowledge construction from a computational approach (which is different from the theoretical or experimental approach).

Spreadsheets: physics: let the students see how simple arithmetic is used to solve complex physics problems.

Simulation: geology, biology, chemistry, physics. These tools allow the manipulation of the model implemented in the software. It enables work on visible and non-visible aspects (electricity flow for instance), to accelerate or slow down time (acceleration in geology or in biology, slow-down in physics for instance), to reduce or increase observed objects and phenomena…

Visualization (3D or 2D): geology, biology, chemistry ICT shows the dynamics of change (a plant that grows, the movement of the Moon in relation to the Earth and the Sun), and articulated, differentiated micro and macro worlds. ICT tools allow the representation of objects whose dimensions are not accessible to human or experimental constraints in school context. Animating the representation of phenomena helps to display the whole process of short or long lasting phenomena (not compatible with teaching period: mountain formation, life cycle of a living being)



Biology and geology cannot be taught without a strong relation to the field: studying objects, collecting data are part of scientific activity and need to be articulated to the laboratory. Geomatique tool (virtual globes, digital model of the field, Global Positioning Systems) are tools that can help to localise, acquire, represent and process the data and therefore enhance modeling tasks.

Conclusion

The potential for learning of low attainers in mathematics or science is sometimes underestimated in activities that are usually offered in the classroom and which are often not problematized (or artificially problematized), favoring written feedbacks and dealing with formal concepts. Low attainers are often relegated to the position of solving routine tasks and therefore are deprived of significant tasks allowing them to reach a minimum level of understanding of the issues of these more academic tasks. So, even if knowledge is present (or in a process of understanding), the recognition by the teacher of these acquisitions can be deficient. Offering a technological environment taking into account the epistemological aspects of manipulated objects with a deep respect for scientific knowledge as well as students' potentialities is the main issue of the project. One goal is to design learning situations in which an adapted material environment offers tools (including technological tools) for experimenting with objects (mathematical or scientific) to anchor experience in a cultural dimension where the scientific knowledge will be pushed to the front. From that perspective, technology, when positioned as a learning tool, may be an interesting tool for becoming more informed about student understanding of learning objects with respect to the learning situation. In that sense, using technology and specialized software is not a precondition but the result of a process of designing tasks in which a particular tool may offer opportunities to facilitate the understanding of a particular concept or notion that is a learning concern. For theoretical levels, different notions might be helpful for analysis with regard to the theoretical frameworks that can be used and the notions of instrumental and documentational genesis as well as the notion of orchestration are surely important and should be taken into account.

1 Lavonen, J., Bécu-Robinault, K., Le Maréchal, J.-F., Stadler, H., Krzywacki, H. (2010). Views on teaching and learning. In Koistinen L. & al. (Eds) The effective use of computer aided teaching and learning material in science teaching. Plovdiv: Plovdiv University Press, p. 149-158.

2 Fuxa G., Sanchez E., Prieur M. (2006) Le Calendrier Géologique: un environnement informatique pour l’enseignement des sciences de la Terre. Biennale de l’éducation. INRP, L

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"Thoughts without content are void; intuitions without conceptions, blind. Hence it is as necessary for the mind to make its conceptions sensuous (that is, to join to them the object in intuition), as to make its intuitions intelligible (that is, to bring them under conceptions)." (Translation by J.M.D. Meiklejohn; http://www.gutenberg.org/files/4280/4280- h/4280-h.htm)

i http://www.edumatics.eu