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Mathematical modeling, ICT and collaborative work in Moroccan high schools: From ModLe^t to ModL2^t, experimentation of a semiotic set[1] in the teaching and learning of the radioactive decay law

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Abstract: *In 2nd year of the Moroccan baccalaureate SLE (Sciences of Life and Earth) and PC (Physics and Chemistry) branches, ModLe^t (the official analytical model of radioactive decay law) obstructs its teaching-learning. As an alternative, we propose a model of this law that we call ModL2^t (model of radioactive decay law of base 2 powers), allowing pupils to build an intelligibility framework that easily links concepts of the space of reality to their mathematical modeling. Thus, exploratory and preliminary studies were carried out with a sample of sixteen pupils (17 to 20 years old). The activities were an alternation between collaborative work, individual work, and mobilization of ICT's part, especially, CSRDP200 (Checkerboard Simulation of Radioactive Decay of Polonium 200), the one we developed. The validation study was done with an LSE and a PC classes separately taken.*

The results show that the difficulties of experimentation have been alleviated through the use of ICT, with the help of which pupils have listed various models of radioactive decay. In intergroup with rotating members, pupils established the expected analytical model, with a success going from 37.5% in individual work, to 71.43% in collaborative work. On the calculation of the powers, the pupils showed their mastery going from 84.38% of success, until reaching 100%. The validation study confirms the pupils' unblocking between reasonable mathematical passages under ModL2^t. These unblocking increased from 0% until beyond 77.33%.

Keywords: *Radioactive decay law, Mathematical modeling, Collaborative work, ICT, Frame of intelligibility, Model of radioactive decay law of base 2 powers (ModL2^t).*

I. Introduction

On the one hand, the use of information and communication technologies in education (ICT) significantly improves the teaching-learning [1]. F.Zellweger shows that same results have been linked to the fact that teachers have changed their traditional practices by developing new teaching methods that incorporate any technological progress [2]. Also, the combination between the use of ICT and collaborative work greatly improves the understanding of the photoelectric effect [3]. Whereas on its own, the collaborative work in intergroups with rotating members, increases the success of teaching and learning [4], by the fact that it opens the channels of communication between all the actors in a class [5]. However, the teaching-learning of physics is still far from the conjugation of the efforts toward the use of ICT structures available to high schools, with those to the homes of Moroccan pupils [6].

On the other hand, once the modeling process of the radioactive decay law passes into the mathematization phase, a fracture occurs, at the level of the semiotic and semantic registers [7], and at the level of the frame of mathematical rationality [8]. Indeed, the introduction into the classroom of physics, mathematical concepts of linear differential equation of the first order and of its resolution, logarithmic and exponential functions, of probability [9], is operated even before they are discussed in the mathematics class [10]. Thus, these notions are outside the scope of intelligibility of pupils, as it was defined by F.Moungabio et al *"One of the objectives of physics teaching is to promote the construction of a frame of intelligibility to give pupils access to the type of knowledge which, in the eyes of physicists, makes the world intelligible, that is the ability to relate the material world to the world of theories and models."* [11]. Similarly, the work of D.Mallafosse and A.Lerouge [12], raised the breaks and continuities between physics and mathematics in the

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[1] Set : an ensemble of similar objects for the same use.

case of the characteristic of linear electric dipoles. They proposed a model based on the notions of "frame of rationality" and "semiotic register".

II. Problematic

In the course of physics, the analytical modeling of the law of radioactive decay in the 2nd year of the scientific baccalaureate, branches SLE and PC, involves the calculation of the probabilities, the linear differential equations of the first order and their resolution, and the logarithmic and exponential functions (p 79, 87, 88 for SLE branch, and p 112, 121, 122 for PC branch) [9]. These notions are still untreated in mathematics class, while they are at the heart of almost all physics lessons. Thus, their reprogramming is to be discarded. While on the mathematical side, these same notions are programmed in the 2nd semester, answering to a pedagogical and didactic logic of the discipline (p 93, 94, 95, 98, 99 for baccalaureates SLE and PC) [10]. This situation imposes on pupils the dilemma of manipulating relationships, based on rote learning, and not on the normal path of intelligible mastery of required mathematics. Hence the clearly perceptible blocking of teaching-learning that are related to the law of radioactive decay.

In a frame of intelligibility ensuring, at the same time, the adequacy between the registers, the frames of physical and mathematical rationalities, and the space of reality, we propose the ModL2^t as an analytical model of the radioactive decay law. In the light of which, we have scripted our intervention while basing ourselves on both ICT and mathematical notions represented in the usual semiotic and semantic registers for pupils.

III. Methodology

The level targeted in our research is the 2nd year of the scientific baccalaureate of the branches SLE and PC. This is where the teaching-learning of the phenomenon of radioactive decay poses a problem on the side of the mathematical formalism currently adopted.

Our intervention includes an exploratory study, a preliminary study, and a validation one. The first two studies were conducted separately with three groups of a total of sixteen pupils from two high schools. These pupils were all the volunteers, with whom the work was programmed according to their free time, in the premises of their high schools that the corresponding administrations put at our disposal. The activities were organized in collaborative work situations using the intergroup technique with rotating members [5]. They were alternated by individual works, and by the diffusion of simulated parts in support, as it was clearly highlighted in our study of the dependence between ICT and the teaching-learning of physic [13]. Especially, the ICT resource we developed [4], which we called Checkerboard Simulation of Radioactive Decay of Polonium 200 ‘’CSRDP200’’.

Our validation study was conducted separately, with two classes of the 2nd year of the baccalaureate: one class from the SLE branch, and another one from the PC branch. Both of them are from the high school Mohamed AJANA of Meknes. The sequences of this study were filmed, transcribed and analyzed, as were the exploratory and preliminary studies. As part of the validation study, all the pupils made anonymous copies, on which their individual productions are carried. These copies were the subject of a qualitative study, and a quantitative one.

IV. Theoretical frame

1. Research paradigm

The teaching-learning of the analytical modeling of the radioactive decay law, as officially proposed, testifies to the major difficulties for all the actors (pupils and teachers). To contribute to the proper functioning of its teaching-learning, a didactic engineering [14] was built, while being based on the theoretical notions: semiotic register and semantic register; frame of rationality; intelligibility framework; and reality space.

In terms of interpreting the difficulties encountered by pupils during transitions between semiotic registers and semantic physical-mathematical registers, we focus on the identification of signs and their meanings in the physical setting and in the mathematical framework. While in terms of a break in rationality, our analysis interprets the difficulties observed in pupils for four elements: proportionality, dimensionality, the reality space, and the intelligibility framework.

2. ModL2^t semiotic set

2.1. Expression of N(t) the radioactive population number

The law of evolution of a radioactive population is written as:

$$N(t) = N_0 e^{-\lambda t} \quad \text{and} \quad \lambda = \frac{\ln 2}{t_{\frac{1}{2}}} \tag{1}$$

$$\Rightarrow N(t) = N_0 e^{-\left(\frac{\ln 2}{t_{\frac{1}{2}}}\right)t} \Rightarrow N(t) = N_0 e^{\left(\ln \frac{1}{2}\right)\left(\frac{t}{t_{\frac{1}{2}}}\right)} \tag{2}$$

$$\Rightarrow \ N(t) = N_0 \left(e^{\ln \frac{1}{2}}\right)^{\left(\frac{t}{t_{\frac{1}{2}}}\right)} \Rightarrow N(t) = N_0 \left(\frac{1}{2}\right)^{\left(\frac{t}{t_{\frac{1}{2}}}\right)} \quad (3)$$

$$\Rightarrow N(t) = N_0 2^{-\left(\frac{t}{t_{\frac{1}{2}}}\right)} \quad (4)$$

Knowing that $ln2 \approx 0,69$ therefore:

$$N(t) = N_0 2^{-\left(\frac{\lambda t}{0,69}\right)} \quad (5)$$

For the particular case where $t = nt_{1/2}$ with n∈IN:

$$N(t) = N_0 2^{-n} \quad (6)$$

2.2. Expression of the time t

We have:

$$N(t) = N_0 2^{-\left(\frac{t}{t_{\frac{1}{2}}}\right)} \quad \Rightarrow t = t_{\frac{1}{2}} \frac{Ln\left(\frac{N_0}{N(t)}\right)}{Ln\,2} \quad (7)$$

Knowing that whatever the number of populations N_0 and $N(t)$, there exists p and p_0∈R, such that the data can be written in the form:

$$N(t) = 2^{p} \quad \text{et} \quad N_0 = 2^{p_0} \quad (8)$$

The expression of time becomes:

$$t = t_{\frac{1}{2}}(p_0 - p) \quad (9)$$

Or:

$$t = \frac{0,69}{\lambda}(p_0 - p) \quad (10)$$

For the particular case where $N(t) = \frac{N_0}{2^n}$ with n∈IN :

$$t = nt_{\frac{1}{2}} \quad (11)$$

V. Experimental frame

1. Exploratory study

1.1. Statement

We ask you to comply with the instructions in the following test on the calculation of the powers:
- 1st instruction: that each pupil works alone.
- 2nd instruction: *a, b, p, q, x, y* ∈IR. Write differently $a^p \times a^q$ and $(b^x)^y$.
- 3rd instruction: let x be the unknown such that a ∈ IR+* and *x*, y ∈IR.

Propose a solution of the following equation: $a^x = a^y$.

1.2. Expected answers

- The expected answers for the 2nd instruction are:

If a, b, p, q ∈IR, so $a^p \times a^q = a^{pq}$. And if x, y ∈IR, so $(b^x)^y = b^{xy}$.
- The expected answers for the 3nd instruction are:

If x is the unknown such that a ∈ IR+* and x, y ∈IR, and if $a^x = a^y$, so $x = y$.

1.3. Results

Regarding the 2nd instruction, all pupils, all branches combined (PC: 7/7 and SLE: 9/9), have produced correct answers.

Regarding the 3rd instruction, all pupils in the PC (7/7) branch gave the correct solution. While for pupils in the SLE branch, four out of nine pupils found the requested solution (4/9).

1.4. Conclusion

Pupils show that they have undeniable skills in mastering the calculation of powers. Overall, their success averaged 84.38%. In fact, the pupils gave correct answers ranging from 44.44% to 100% per item. While in terms of comparison between the two branches, all items combined, 100% of correct answers is to be attributed to pupils in the PC branch, against 68.75% for pupils SLE branch. This finding shows that pupils in the SLE branch, compared to those in the PC branch, do less well on mathematically reasonable passages.

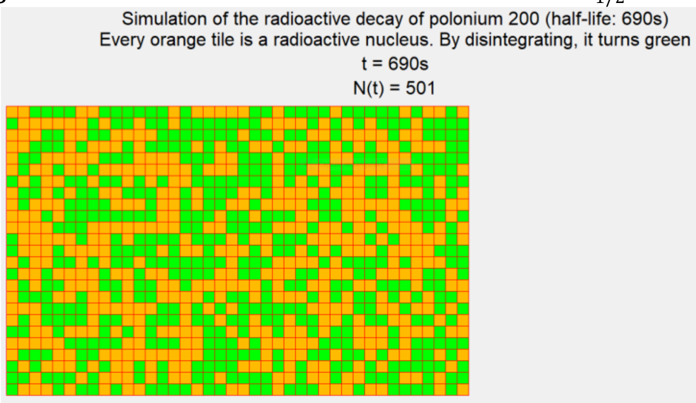
2. Preliminary study

2.1. Presentation of our created ICT resource and organization

CSRDP200 is an ICT resource whose acronym is derived from its full name: " the Checkerboard of the Simulation of the Radioactive Decay of Polonium 200". This ICT resource [4], was developed by our team using the Python language. This language is placed online under a free license (https://www.python.org/psf/). Indeed, after having installed this software on five pupils' laptops, in addition to the teacher's laptop, its interface offers the possibility to create code files, in this case, the code of CSRDP200. Once properly written by our team and saved in pupils' laptop computers, each file become ready to use because it has the same distinctive logo and a name it has been given.

We explained to the pupils that using CSRDP200 consists of a simple click on their file previously saved on their laptop desktops. Its interface appeared. They discovered that it has the shape of a checkerboard of tiles (40x25), all initially oranges. We told them that each orange tile plays the role of a nucleus of ^{200}Po not yet disintegrated. But once disintegrated, its color becomes green. The built-in clock in the interface displays time t. While another counter displays the number of remaining radioactive nucleus N(t).
Example of CSRDP200 interfaces:

Figure no 1: shows the screenshot of CSRDP200 in $t = t_{1/2} = 690s$.



Our intervention consists of an alternation between individual work and collaborative work [15]. In fact, during the individual work, the pupils record the values from the only display of CSRDP200 activated by the teacher. While in collaborative work, intergroup of pupils with rotating members, manipulate this ICT resource to their guises on their other five laptops.

2.2. Pre-test 1

Statement

We propose to study the evolution of N(t) the number of a radioactive population, using CSRDP200, our ICT resource. Thus, we propose a simulation of the evolution of an initial population of N0=1000 radioactive nuclide of polonium 200 (^{200}Po) whose half-life is t1/2=690s [16]. Please respect the following instructions.

1st instruction: visualize carefully the first part of CSRDP200. Identify the physical quantities in play, and possibly their signs and meanings.

2nd instruction: each pupil draws up a table of measures with the values he/she has been able to note.

3rd instruction: from your observations on the simulated evolution of the polonium 200 sample (^{200}Po) and from your observations on the table that you have drawn up, provide the values for the other empty boxes of this table.

4th instruction: by working in intergroups with rotating members, repeat the activities requested in the 2nd and 3rd instructions.

5th instruction: now, visualize the second part of CSRDP200. This is the table of experimental measurements whose values are the ones we asked you to predict. Make the necessary corrections, and then go back to the individual work.

6th instruction: pick up your observations on a possible relationship linking N(t) to time t.

7th instruction: from the measurement board, draw the curve N(t).

8th instruction: knowing now the shape of the curve N(t), establish the analytical expression of N(t).

9th instruction: working in intergroups with rotating members, repeat the activities requested in the 6th, 7th and 8th instructions.

Expected answers and results

Following the instructions, pupils finished to draw up Table 1 and then Table 2 as follows:

Table no 1: shows 1000 kernel evolution of ^{200}Po during the first four seconds (t≤4s)

t(s)	0	1	2	3	4
N(t)	1000	999	998	997	996

Table no 2: shows evolution of 1000 kernel of ^{200}Po during the first eight seconds (t≤8s)

t(s)	0	1	2	3	4	5	6	7	8
N(t)	1000	999	998	997	996	995	994	993	992

In individual work as in collaborative work, all pupils were able to develop acceptable tabular models, and then their corresponding graphical models. On the basis of which, pupils ended up proposing forms of mathematical expressions of affine functions. A non-mastery of mathematical contents is displayed, when the mathematical form y=ax+b, spontaneously expressed by the pupils, is passed to the explicit form of the constants " a " and " b " in the physical context. This is also observed at the level of the transposition of the variables x and y to the studied physical quantities t and N(t). Only the four PC pupils of the Lycée Ibn Roumi group proposed a fair final expression:

$$N(t) = N_0 - at \text{ with } [a] = s^{-1}.$$

Analyze grid

We have transcribed the recordings made during the modeling initiation sequences, and the sequences of the analytic modeling of N(t) over a very short time interval, to be in a usual mathematical case.

Based on pupil activities, we found some elements of analysis. The results of this analysis are given in the following table 3.a:

Table no 3.a: shows the results of the qualitative study of pre-test 1

Elements of responses analysis	Yes	No	Clue among pupils' activities
model concept		X	-Sir, what does model mean? -How is real experience a model example? -How is the graph a model example?
Pick up of values and development of a tabular model	X		-The pupils have drawn up different forms of the table of values they fill from the interface
highlighting the phenomenon of decay radioactive	X		-There is radioactive decay because the values N(t) decrease
development of a mental model of the law of radioactive decay by each pupil	X		Pupils offer values without hesitation even after the teacher has voluntarily stopped the simulation
elaboration of graphic model	X		-In groups of pupils N(t) were represented by straight lines
elaboration of analytic model	X		-Almost all pupils proposed affine functions as analytic models of a(t) and/or N(t)
imensionality respect		X	-Without being meticulous with respect to dimensionality, the pupils in groups, make explicit false analytic models
proportionality highlighting		X	-During all activities, no pupil referred to the proportionality

In the configuration of intergroups with rotating members, the satisfaction of the pupils is great, and the time allotted to the execution of the instructions becomes short. The relative statistics are in the following table 3.b:

Table no 3.b: shows the results of the quantitative study of pre-test 1

Analysis elements	branch	Proportion of individual work acceptable		Proportion of acceptable intergroup work with rotating members	
Curve productions as the form of affine functions	PC	6/7=85,71% (3 pupils from Ibn Roumi and 3 pupils from Ajana)	13/16 = 81,25%	9/9=100% (8 groups from Ibn Roumi and 1 group from Ajana)	21/21 = 100%
	SLE	7/9=77,78% (7 pupils from Ajana)		12/12=100% (12 groups from Ajana)	
Expressions proposed for N(t) in t≤8s	PC	4/7=57,14% (2 pupils from Ajana and 2 pupils from Ibn Roumi)	6/16 = 37,5%	8/9=88,89% (7 groups from Ibn Roumi et 1 group from Ajana)	15/21 = 71,43%
	SLE	2/9=22,22% (2 pupils from Ajana)		7/12=58,33% (7 groups from Ajana)	

Conclusion

Collaborative work greatly increases pupil learning, as it happens with the concept of models of radioactive decay. It took shape in the pupils, under the manifestations: the natural model, the tabular model, the graphic model, and the analytical model. Indeed, all pupils have been able to develop acceptable tabular models, both in individual work and collaborative work. While their success in drawing the corresponding graphical model, increased from 81.25% to 100%, during the shift from individual work to work in intergroups with rotating members. On the basis of this, pupils eventually came up with forms of mathematical expressions of affine functions that were successful at 37.5% for individual assignments and 71.43% for intergroup work with rotating members. It remains to be noted the omnipresent manifestation of the lack of mastery of the transpositions of mathematical contents towards their physical context studied.

2.3. Post-test 1

Intervention modalities

We asked the pupils to work in an individual configuration. The professor proceeded to the presentation of ModL2^t, giving the expression of N(t) of the evolution of a radioactive population, specifying that it describes exactly the radioactive decay, by:

$$\mathrm{N(t)} = \mathrm{N_0} 2^{-\left(\frac{\mathrm{t}}{\mathrm{t}_{\frac{1}{2}}}\right)}, \text{ or also } \mathrm{N(t)} = \mathrm{N_0} 2^{-\left(\frac{\lambda \mathrm{t}}{0,69}\right)}$$

With: $\mathrm{t}_{\frac{1}{2}}$ the half-life of the radioelement and λ its radioactivity constant.

Statement

We enunciate the expression of N(t) by: $\mathrm{N(t)} = \mathrm{N_0} 2^{-\left(\frac{\mathrm{t}}{\mathrm{t}_{\frac{1}{2}}}\right)}$ or also $\mathrm{N(t)} = \mathrm{N_0} 2^{-\left(\frac{\lambda \mathrm{t}}{0,69}\right)}$, and we suppose that N(t) and $\mathrm{N_0}$ are written in the form:

$\mathrm{N(t)} = 2^{p}$ and $\mathrm{N_0} = 2^{p_0}$, with p and p_0 are real integers that exist.

Rewrite N(t) using the base 2 powers, and then establish the analytical model of time t.

Expected answers

The expected answers are:

- The expression of N(t) using the base 2 powers, is:

$$2^{p} = 2^{p_0} \times 2^{-\left(\frac{\mathrm{t}}{\mathrm{t}_{\frac{1}{2}}}\right)} = 2^{p_0 - \left(\frac{\mathrm{t}}{\mathrm{t}_{\frac{1}{2}}}\right)} \quad \text{or} \quad 2^{p} = 2^{p_0} \times 2^{-\left(\frac{\lambda \mathrm{t}}{0,69}\right)} = 2^{p_0 - \left(\frac{\lambda \mathrm{t}}{0,69}\right)}$$

- The analytical model of time t is:

$$\mathrm{t} = \mathrm{t}_{\frac{1}{2}}(p_0 - p) \quad \text{or} \quad \mathrm{t} = \frac{0,69}{\lambda}(p_0 - p)$$

Results

All pupils, have correctly rewritten N(t) using the base 2 powers (PC: 7/7 and SLE: 9/9).

All pupils (7/7) in the PC branch have normally produced the requested analytical model of time t, such that $\mathrm{t} = \mathrm{t}_{\frac{1}{2}}(p_0 - p)$. While for pupils in the SLE branch, seven out of nine pupils (7/9) have established it correctly.

Conclusion

During the presentation of the first part of the ModL2^t by the teacher, or during the establishment, by the pupils, of his second part, the satisfaction has been growing, explaining the growth of the successes which reached an average of 93.75%. So, we can conclude that during the process of developing models in physical science, the success of any teaching-learning with pupils, at the secondary level, requires that their concentrations must be about the modeling process and its experimental and conceptual constraints, the occurrence, those of the specific factor "space of reality" [17]. As well, the concentration of pupils should not be dispersed in the face of factors described as epistemological obstacles [18], in this case, the mathematical registers and their framework of rationality not yet treated in the course of mathematics.

3. Validation study

3.1. Organization

With the support of the administration of the high school Mohamed AJANA Meknes, the field of the study of validation was two whole classes of the second year of the baccalaureate, of the school year which followed that of our exploratory and preliminary studies. The study was conducted on a class of 38 pupils of the PC branch,

then on another class of 37 pupils of the SLE branch. In their respective classes of physical sciences, these pupils have already finished the courses on the phenomenon of officially programmed radioactive decay.
Throughout our validation study, we relied on ICT resources prepared in advance by the teacher. At the end of this study, each pupil made an individual work on an anonymous sheet.

3.2. Introducing the ModL2^t

On the basis of logical mathematical passages, for any radioelement, the law of radioactive decay can be written in the form:

$$N(t) = N_0 2^{-\left(\frac{t}{t_{\frac{1}{2}}}\right)} \quad \text{, or also} \quad N(t) = N_0 2^{-\left(\frac{\lambda t}{0,69}\right)}$$

With: $t_{1/2}$ the half-life of the radioelement and λ its radioactivity constant.
The establishment of the expression of time is retained for testing.
The data on the quantities N(t) or m(t) or a(t) are provided in a form such as:

$$N(t) = 2^p \quad \text{and} \quad N_0 = 2^{p_0} \text{ , with } p \text{ and } p_0 \in \mathbb{R}$$

Example:
At the moment t, researchers took pieces of charcoal, from a prehistoric cave. This sample contained a population of ^{14}C at $N(t) = 2{,}6.\,10^{11}\,1 \approx 2^{37,92}$ and radioactive activity $a(t) = 0{,}7Bq \approx 2^{-0,51}Bq$.

3.3. Pre-test 2

Statement

For a half-life radioelement $t_{\frac{1}{2}}$ and radioactivity constant λ ($\lambda = \frac{0,69}{t_{\frac{1}{2}}}$), we can always write N(t) the population number of one radioelement in the form:
$N(t) = 2^p$ and $N_0 = 2^{p_0}$, with p and $p_0 \in \mathbb{R}$
Establish the expression of time t, starting from one of the expressions given below:

$$N(t) = N_0 2^{-\left(\frac{t}{t_{\frac{1}{2}}}\right)} \quad \text{or} \quad N(t) = N_0 2^{-\left(\frac{\lambda t}{0,69}\right)}$$

Results

The results are given in Table 4 below:

Table no 4: shows the results of pre-test 2

Elements of analysis of the responses with ModL2^t	branch	Under ModL2^t			Total
		frequency of unblocking		frequency of blockages	
		admited responses	responses not admitted		
Establishment of the expression of time t	PC	65,79%	31,58%	2,63%	100%
		97,37%			
	SLE	54,05%	24,33%	21,62%	100%
		78,38%			
	PC and SLE	60%	28%	12%	100%
		88%			

Conclusion

Under ModLe^t, both in mathematical development relative to the establishment of the expression of N (t), or that of the establishment of the expression of the time t, the pupils' unblocking frequency was null (0%). While under our model ModL2^t, their unblocking situations in the passages between mathematical contents went till 88%. Moreover, the success of 60% of pupils in the establishment of the analytical model of time t, in the account of ModL2^t, testifies that this model is mathematically affordable. Nevertheless, the fact that 40% of the pupils have not succeeded in making the answers expected, attests that the scripting of the teaching-learning of the ModL2^t must be revised, or these pupils still cumulate a weakness in mathematics in the control of the calculations of the powers. This last cause appears tangible, because it is the third of the pupils, among those who have experienced a situation of unlocking, who have not made admitted answers. According to this view of the degree of mastery of mathematics in the usual frame, pupils are to be classified into three categories: 60% of pupils master the required mathematics, 28% do not master it, and 12% do not retain any notion of this mathematics. We can, cautiously, conclude that the failure to complete 40% of teaching-learning situations in the physical sciences, including mathematical contents in the usual setting, is attributable to the difficulties pupils have in mastering these mathematical contents.

3.4. Post-test 2

Statement

Bone scintigraphy is based on imaging after fixation of the phosphated molecules labeled with technetium 99 (^{99}Tc) called tracers. Indeed, intravenously, the tracer is injected into the blood, and its uptake by the skeleton is maximum after a while.

At the time $t_0 = 0s$, an injection containing ^{99}Tc of radioactive activity a_0 was administered to a patient. At time t1, an image was taken of the examined bones, in which the radioactive activity of ^{99}Tc reached $a(t_1) = 2^{-0,74}a_0$.

Calculate the value of t_1 in h. We give: the half-life of ^{99}Tc is $t_{1/2} = 6h$.

Results

The results are given in Table 5 below:

Table no 5: shows the results of post-test 2

Analysis elements / Branch	Under ModL2^t				Total
	frequency of unblocking		frequency of blocages		
	with successful development	with unsuccessful development	with start of response	no response	
PC	52,63%	26,32%	0%	21,05%	100%
	78,95%		21,05%		
SLE	51,35%	24,32%	8,11%	16,22%	100%
	75,68%		24,32%		
Total PC and SLE	52%	25,33%	4%	18,67%	100%
	77,33%		22,67%		

Conclusion

As a check of our hypothesis on the 40% of the pupils who failed to render the answers expected, during the pre-test 3, this post-test is distinguished by a higher degree of mathematical difficulty, explaining its resolution by 52% among all pupils. And for the rest of the pupils, it is shared between 25.33% and 22.67%, respectively unsuccessful use of the ModL2^t, and blocking situations. We conclude that the non-achievement of the rest of the pupils is explicable by their weaknesses in the mastery of mathematics.

VI. Conclusion

In the 2nd year of the Moroccan baccalaureate, scientific branches SLE (Life Sciences and Earth) and PC (Physics and Chemistry), the teaching and learning of the phenomenon of radioactive decay knows difficulties related to the mobilization of mathematical contents, as it happens, when introducing the analytical model of the radioactive decay law. Our contribution is the ModL2^t, a model of this law. It allows all the actors of the class (teacher and pupils) to carry out their activities in the registers and usual frame. Indeed, together with the use of ICT, ModL2^t facilitates mathematical modeling. It allows pupils (between 17 and 20 years old) to relate the concepts of the space of reality and the construction of a frame of intelligibility.

Our experiment consisted of studies: exploratory, preliminary and validation. The validation study was conducted with one SLE class and another PC. The first two studies were conducted with a sample of sixteen pupils from two high schools in the city of Meknes. The activities were an alternation between collaborative work, individual work, and distribution of parts of ICT resources.

The results of the exploratory and preliminary studies show that in collaborative work, the satisfaction of the pupils has been growing, as long as they have seen their contributions to the different models grow. Indeed, during the exploitation of the first eight seconds of an ICT resource of the radioactive decay, the pupils' success relative to the establishment of its tabular model was 100%. Then, they established graphical models in the form of a decreasing affine function, with a performance ranging from 81.25% to 100% between individual work and that of intergroups with rotating members. Likewise, their successful proposals for the analytic model jumped from 37.5% to 71.43%. While on the basic knowledge of the calculation of the powers, the pupils showed that they master them with 84.38%. On the other hand, after the presentation of the ModL2^t, the pupils' success in stopping the release in mathematical passages reached the very significant average of 93.75%. The usual ModL2^t registers have allowed pupils to overcome their blockages in mathematical sequences, known as ModLe^t (the official model of teaching the law of radioactive decay). These results are due to the mobilization of the ICT resources, as it happens with the simulation of the radioactive decay of the ^{200}Po, especially with

CSRDP200, our developed ICT resource. This ICT resource was used too, to mitigate the difficulties of experimentation and modeling. At the end, the validation study was conducted with two whole classes taken separately. It confirms the pupils' unblocking in the passages between contents considered mathematically reasonable. These unblocking made by the pupils went from 0% under ModLe^t, to jump very significantly beyond 77.33% under ModL2^t, thanks to elements compatible with the reality space, namely: the registers of ModL2^t, its frame of intelligibility, and its usual mathematical framework. This observation shows that a good part of the difficulties of teaching and learning of the physical sciences is attributable to those that pupils encounter when mastering mathematical contents in their usual frame.

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