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(Research Article)

Teaching Newton's second law in final year science classes: Exploring practical bridging-in-action

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Abstract

When teaching a subject, all of the teacher's work must be part of a learning process for the student, i.e., bringing knowledge closer to the student so that they can effectively assimilate it and truly enter into the culture of the discipline. Therefore, in physics, the development of student activity materials, right up to their implementation in the classroom, must take into account a number of criteria, including the functioning of the discipline, in order to successfully bridge the gap between the subject matter and the learners. An analysis of the activity materials used by three teachers to teach Newton's second law in the final year of high school science shows that the work instructions (tasks or types of tasks) and the systems put in place do not allow students to move between the real and theoretical worlds using appropriate models. The work produced on the board only reinforced this observation, and the discourse concocted by these three teachers does not allow for the establishment of efficient interconceptual (or inter-concept) relationships that could promote a good understanding of the law.

Keywords: Newton's Second Law; Bridging-In-Action; Interconceptual Relationships; Discourse Analysis

1. Introduction

1.1. Research problematization

1.1.1. Theoretical and conceptual framework

Inclusion of this research in the dual didactic and ergonomic approach

In this paper, we examine certain aspects of the construction and assessment activity materials developed by teachers, as well as their discourse during classroom practice. The teacher's work, before and during the activities, is aimed at helping students better understand the law, which is the subject of learning, so that they can apply it when solving problems that require its implementation, from both a qualitative and quantitative perspective. Based on the assumption that "everything that is decided a priori feeds into the cognitive component, and the corresponding choices in terms of implementation are part of the mediative component " (Robert, 2007), we can say that this study is anchored in the cognitive and mediative components, two of the five components from which teaching practices are studied and reconstructed according to the theory of the dual didactic and ergonomic approach (Robert and Rogalski, 2002, 2005, 2008). In this approach, the materials used for construction and assessment activities, as well as the teacher's discourse, can be considered as aids provided to the student in order to bring them closer to the knowledge they are learning.

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However, for these aids to be effective, they must be located within the student's zone of proximal development so that they can be easily grasped and used as a springboard to access knowledge.

1.1.2. The concept of bridging

In his developmental theory of children with learning difficulties, Vygotsky (1934/1997) developed the concept of the “zone of proximal development,” which is an area where students have certain resources and, with help, can perform the task assigned to them.

It is in this zone, located between the zone of autonomy, i.e., where the student can perform the task without help, and the zone of disruption, i.e., where, even with a lot of help, the student may with difficulty complete the task. It is in this zone that all forms of assistance provided to the student by either the teacher or their peers during a teaching/learning situation should take place.

It should be noted that, in relation to the zone of proximal development, the acts of teaching and learning evolve in opposite directions. These developments in this zone of these two acts are easily justified when we realize that the teacher's work during the teaching act consists of transforming knowledge and gradually moving it from the zone of disruption to the zone of proximal development, while the student, during the learning act, is led to move out of their zone of autonomy with their supposed knowledge “already there” to discover and acquire knowledge in the zone of proximal development.

Since the zone of proximal development is a zone of interaction, within which the student can consolidate or modify their representations of a concept, fact, or object, we believe that this notion can also be applied to adolescents, always in the school context where teaching/learning continues to contribute to their development.

We refer to any form of assistance or attempt to assist aimed at moving out of the zone of disruption and/or bringing knowledge (a notion, concept, law, etc.) that is being learned by the student closer, explicitly or not, to their zone of proximal development as “rapprochement-en-acte” (act of rapprochement). This bridging allows the student, with some effort, to encounter knowledge (discover and appropriate it) in this zone. During the teaching/learning of a subject in physics, this bridging is possible when the teacher actually moves the student between the empirical and theoretical worlds through appropriate modeling and interpretation.

The difference between the concept of proximity-in-action developed by Robert and Vandebrouck (2014) and that of rapprochement-in-action is that the former focuses on "...*proximities between what is intended and what students do* " (Robert and Vandebrouck, 2014), while the latter includes the help of the teacher and other students in order to bring the student closer to the knowledge at stake.

In a classroom setting, the entire teaching/learning process must therefore take place within the students' zone of proximal development. It is true that this is a zone whose boundaries are difficult to define because they are not explicitly accessible. This raises the issue of mastery of the teaching profession, and therefore places heavy demands on the teacher's expertise.

2. Literature review

Newton's laws occupy an important place in the physics curriculum for senior science students in Benin. The explanation or interpretation of the motion of a solid or a particle whose speed does not approach that of light in a vacuum () is based on Newton's second law, also known as the center of inertia theorem (constant mass). In this paper, we will use both terms “law” and “theorem.” This is justified, on the one hand, by the fact that Newton's proposition is "*the mathematical expression of a repeatable correlation, constant behavior, or statistical frequency observed among a set of facts. It is deduced from a number of observations and generalizes them, retaining their stable character*" (Sagaut, 2008). It is therefore a scientific law. On the other hand, it is based on logical elements and is scientifically proven by other propositions that are already considered to be true. This is what also gives it the status of a theorem.

We generally find that when solving physics problems requiring the application of this theorem, students have considerable difficulty using it efficiently. Since this law combines dynamic and kinematic concepts (force, mass, acceleration), research has identified multiple difficulties students have in using these concepts, as well as their reasoning when applying this law.

Thus, even in their final year of high school, students still have difficulty making a comprehensive assessment of the external forces applied to a body, as well as representing them appropriately (Viennot, 1989; Brasquet, 1999; Ménigaux, 1986). To remedy this situation, Dumas-Carré and Goffard (1997) suggest that the concept of force be approached through a study of interactions, using an appropriate technique. For Brasquet (1999), this proposal can help students avoid confusion between the balance of applied forces (Newton's second law) and the study of interactions (Newton's third law).

When students are asked about the role of friction, they say that it always opposes motion, even though some types of friction are propulsive (Besson et al., 2007). The way in which the concept of mass is often approached with students does not allow them to later realize that the mass in Newton's second law opposes the setting in motion or change of motion of a body, since it is an inertial mass (Givry, 2003; Rosca, 2005). These are concepts that, in part, obscure Newtonian concepts for learners.

Reif and Allen (1992) and Shaffer (1993) also noted difficulties experienced by students and even some experts with qualitative questions relating to the nature of the acceleration vector and its schematization in given situations.

The center of inertia theorem gives rise to a purely vectorial relationship. This raises the question of the use of vectors in a physics context. On this point, Knight (1995) and Flores et al. (2004) found that both pupils and students experience considerable difficulty.

All these observations were made when learners were presented with problem-solving situations requiring the application of the aforementioned law. In these situations, Viennot (1978) noted that learners' reasoning was not solely due to the effects of the formalism taught. Continuing her investigations, she found that the intuitive system acts as a barrier to academic knowledge. By studying textbooks through their developments and recommendations, Viennot (1982) highlights a reinforcement or teaching of intuitive reasoning devoid of physical meaning by certain textbooks. It should be noted that students' difficulties with Newton's second law are both qualitative and quantitative. From the point of view of the statement of the law, Nguessan (2016) noted that learners did not master the dominant syntactic structure or its conditions of applicability.

2.1. Research question and hypothesis

All these difficulties and modes of reasoning observed in students in the research cannot be attributed solely to the students or teachers, as Lefèvre and Allevy (1998) found in their research that there is always a gap between the model taught and the model actually learned by students. To this end, we asked ourselves the question: how does the teacher go about bringing students in science classes closer to Newton's second law? Our aim here is to characterize the choices teachers make to help students construct Newton's second law, i.e., to examine the choices teachers make in mobilizing the concepts involved and the interconceptual relationships established that enable students to effectively appropriate the law and its application in given situations. We postulate that the activity materials developed and the teacher's discourse are designed to give meaning to Newton's second law. With this in mind, we will analyze the activity materials used to construct and assess knowledge related to this subject, as well as the discourse used by the teacher during class.

3. Méthods

3.1. Sample and corpus composition

In this study, which is part of a thesis, we focused on certain aspects of physics teachers' classroom practices. We worked with three teachers of the subject in classroom settings. To ensure that they had all received the necessary academic and professional training to enable them to perform their job efficiently, all three teachers were certified.

The students' activity materials were collected and their work on the board was photographed for analysis. Similarly, the lessons of the three teachers were filmed to examine the oral organization of each of them during the teaching/learning sessions on Newton's second law.

The first teacher, whom we have named T1, taught the law in a 1 hour 32 minute session, while the second, named T2, did so in two sessions lasting a total of 3 hours 9 minutes. The third teacher, named T3, devoted two sessions with a total duration of 2 hours and 43 minutes to the topic. The teachers' speeches and exchanges with the students were transcribed in full.

3.2. Data processing and analysis

In order to bring a subject closer to students, its teaching/learning must follow, more or less, the same logic as the discipline to which it belongs. Physics operates between the empirical world (the world of objects and events) and the theoretical world (the world of laws, theories, paradigms, theorems, etc.) through models (Gaidioz et al., 2004; Gaidioz and Tiberghien, 2003; Borromeo, 2006). The antithetical polysemy of the concept of a model (Béziau, 2011) has prompted scientists and philosophers of science to reflect on it. Among the definitions proposed, one in particular catches our attention: "a structure is a model of a formal theory if all the axioms of that theory are validated for that theory" (Badiou, 2007, p. 107). Taking this definition into account, we see that the model cannot be housed solely in one of the two worlds (the real world or the theoretical world) nor can it be completely separated from both, because the model can be abstract or real. To characterize the variability of the model between the two worlds, Béziau and Kritz (2000) developed the concepts of "*model of*" and "*model for*." These two concepts have allowed us to understand that a representation (diagram, model, drawing, etc.) derived from reality is a *model of* that reality, while the latter is a *model for* the representation. In this sense, there are not only models belonging to the real world or very close to it, which we can describe as physical models (Rey, 2010) or model-realities (Béziau, 2011), but also models in the theoretical world that are described as mathematical models (Borromeo, 2006).

The following diagram presents the teaching/learning of a knowledge object related to the functioning of the discipline.

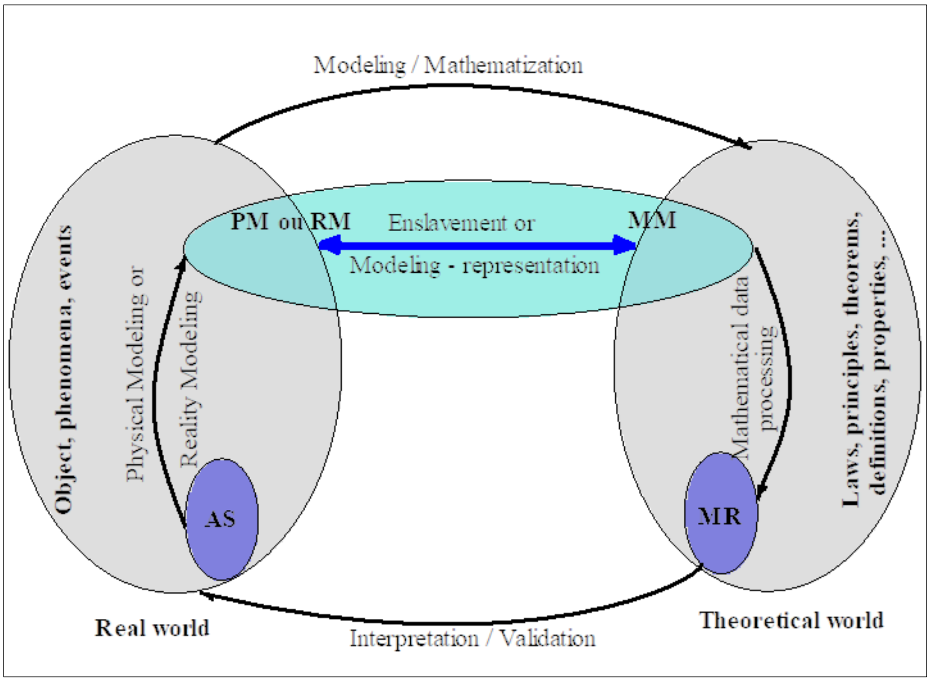

Figure 1 Scheme for teaching/learning a subject related to the functioning of physics

- SR: actual situation
- PM: physical model
- RM: reality model
- MM: mathematical model
- MR: mathematical result

The analysis of construction and assessment activity materials will be based on this diagram. This will enable us to see whether the teaching of Newton's second law by each of these teachers is consistent with the logic of how the discipline works, as any connection with a subject that students are learning must fit into this perspective.

As for the oral organization of each teacher, we extracted their discourse from the whole transcribed during their ordinary classroom practice.

The teacher's discourse is often improvised. However, we postulate that this discourse is always concocted in such a way as to bring the knowledge at stake closer to the students so that they can appropriate it and invest it effectively in other situations, for problem solving. This generally requires accommodations on the part of the students. In this sense, the mobilization and articulation of different concepts by the teacher in his or her discourse is not random. They are well-directed because, in principle, they should enable the student to make sense of the knowledge at stake. These concepts, mobilized by the teacher through his or her discourse in order to give meaning to the law and promote effective learning on the part of the students, are in fact lexies, i.e., meaningful functional units. Teaching practices are complex and require modeling in order to characterize them. In this study, we also pay particular attention to the teacher's discourse when teaching Newton's second law, and its lexicometric analysis (de Hosson et al., 2018) leads us to modeling. We create these models by developing concept maps (Manrique et al., 2016) of each teacher's filmed discourse.

The concept map allows us to understand the meaningful functional units of the teacher's discourse and how they relate to each other in order to bring the law, the subject of teaching, closer to the students. This concept map also allows us to approach the teacher's methodological profile through the mobilization of the concepts directly at stake in the law, how they give meaning to them in the network, and also how they move students through the different elements of the real and theoretical worlds through models. Certain applications of old and new knowledge (Robert, 2007) can also be seen, to the extent of the data we were able to collect and our means of investigation, through the articulation of interconceptual relationships manipulated by the teacher during the teaching/learning session on the law in question. The concept map allows us to grasp all of these connections in action.

4. Results, interpretation and discussion

4.1. Interpretation and discussion of the activity materials proposed to the pupils by teachers P1 and P3.

Teachers P1 and P3 proposed the same activity materials to their pupils, even though they did not work in the same schools. However, they both work in the commune of Comé. When asked why they were so uniform, they all told us that they meet up from time to time to work on the sheets together.

Table 1 Compilation of cognitive activities proposed to learners by teachers P_1 and P_3

Consignes	**Work to be done content**	**Potential cognitive activities involved**	**Situation in relation to the discipline's operating cycle**
4.4B1 Using the fundamental relation of dynamics, establish the centre of inertia theorem.	Write the logical-mathematical ($\sum \vec{F}_{ext} = \frac{d\vec{p}}{dt}$) expression of the fundamental relation of translational dynamics from its statement. Introduce into this expression that of the momentum vector ($\vec{p} = m\vec{v}$) and then, mass being a constant, derive the velocity vector $\vec{v}$ with respect to time to obtain the acceleration vector $\vec{a}$ in order to find the logical-mathematical ($\sum \vec{F}_{ext} = m\vec{a}$) relation of the centre of inertia theorem.	Modelling a law by its logical-mathematical relationship. Passing from one logical-mathematical relationship to another: using mathematical skills.	Mathematical model (MM)
4.4B2 Write the vector relation expressing the relative equilibrium of a solid in a non-galilean reference frame.	Write down the logical-mathematical relationship expressing the relative equilibrium of a solid in a non-galilean frame of reference, based on a translation of d'Alembert's theorem and the explicit expression of the corrective force.	Modelling a law using a logical-mathematical relationship: using mathematical skills.	Mathematical Model (MM)
4.4B3 Show that the motion of the solid S is rectilinear and uniformly accelerated.	List the prerequisites for applying the centre of inertia theorem. List the external mechanical actions exerted on List the external mechanical actions exerted on the material system whose motion is being studied and represent them by force vectors. Write the contextualised logical-mathematical relationship of the centre of inertia theorem applied to the semi-modelled system presented. Solve the vector equation obtained to derive the algebraic value a. index x of the acceleration along the track modelled by the right-hand segment left $[AB]$ Associate the "straight" aspect of the track with that of $a_x > 0$ to give the explicit nature of the motion of the solid.	- Mathematical modelling: modelling mechanical actions using the concept of force, then modelling the latter using the concept of vector. - Contextualisation of the logical-mathematical relationship of the centre of inertia theorem. - Use of mathematical skills to solve the vector equation.	Physical Model – Mathematical Model – mathematical result (PM-MM-MR)
4.4.4 Deduce the characteristics of the velocity vector $\overrightarrow{v_B}$ at B and the duration t of the path AB.	Identify the point of application, the direction and the sense of the velocity vector $\vec{v}_B$ then, Either write the contextualised logico-mathematical relation of the kinetic energy theorem and solve the algebraic equation obtained to derive the value of the norm v_B; Or write the relation independent of time between points A and B to derive the value of the norm v_B . Write the hourly equation of motion of the solid on the inclined plane and set $x = AB$ for $t = t_{AB}$ to derive the value of the latter.	- Contextualisation of the logical-mathematical relationship of the kinetic energy theorem. - Use of mathematical skills to solve the algebraic equation obtained and to establish and then exploit the equation of time.	Mathematical Model – Mathematical Result (MM-MR)

According to the title of the activity, "What are Newton's second and third laws? Since the two laws are not used in the same way, insofar as the second law requires a balance of forces whereas the third law is more a study of interactions, such a grouping could lead to confusion as to their applicability (Viennot, 1989). The first instruction, "from the fundamental relation of dynamics, establish the theorem of the centre of inertia", means that by starting from a relation, we can directly establish a theorem (or a law). Returning to the latter, starting from its logical-mathematical relationship (Oké and al, 2019), requires an interpretation to reconstitute certain parameters that were rendered mute during the mathematical modelling (or simply the mathematisation) of the theorem.

The second set of instructions, "write the vector relation expressing the relative equilibrium of a solid in a non-galilean reference frame", is a pure and simple reproduction of what is stated in the support because it does not require any adaptation of knowledge. This is what Robert (2007) calls a "simple, isolated task". In reality, this type of task does not allow students to put old and new knowledge to work for effective learning. The learning of Newton's third law, although not the subject of our work, was announced in the title of the activity and reduced to a simple reading of the statement in the support without any further development, as no instructions were given. To assimilate the knowledge taught, each pupil has to work individually to decode, memorise and adapt to the situation. Such a way of teaching a scientific law can only increase the gap between the knowledge taught and that actually learnt by the pupils (Lefèvre and Allevy, 1998).

The last two instructions give rise to more or less complex tasks requiring some adaptation of knowledge.
An analysis of the content of the actual work to be done in relation to each instruction shows that the teaching of Newton's second law in the science final year as proposed by these two teachers did not at all respect the appropriate methodology for the subject: the scientific approach. Since this is a scientific law designed to explain phenomena (in the real world), we believe that its teaching should start with a few observations that give rise to questions, followed by the formulation of hypotheses leading to experiments (reality or physical modelling) with the collection of data (mathematical models and/or mathematical results), which will be analysed and/or interpreted to conclude with the formulation of the law in question. It is only after this stage that we need to return to the conditions of applicability of the law and the meaning and/or role of each of the "pivotal" concepts it contains.

The knowledge activity relating to Newton's second law proposed by the teachers (P1 and P3) is practically a pure and simple mathematisation.

4.2. Interpretation and discussion of P_1 and P_3 productions on the blackboard

The first thing P_1 noticed was that the title of the activity had been changed on the board during the teaching session. On his teaching sheet we read "What are Newton's second and third laws?" whereas on the blackboard the teacher wrote "What is Newton's second law?

As for teacher P_3, it was the number of the activity that was changed on the blackboard (4-3B instead of 4-4B on the sheet we recovered).

In relation to instruction 4-4B1, Teacher P_1 had the students establish the expression $\sum \vec{F}_{ex} = M\vec{a}_G$ without any other precision (written on the board) whereas after having done the same thing ($\sum \vec{F}_{ext} = m\vec{a}_G$), with one difference in notation, P_3 added that "*this is Newton's second also called the theorem of the centre of inertia*". As we pointed out when we analysed the activity support, this is the logical-mathematical relationship translating the centre of inertia theorem and not the theorem itself.

As far as instruction 4-4B2 was concerned, since it was simply a question of writing down a vector relationship, the two teachers remained practically the same, except that P1 included the notion of driving force, but without any other details.
In the development of instruction 4-4B3, at the level of the balance of the external forces applied to the solid we read:

- " - the weight $\vec{P}$ of the solid (P_1 and P_3),
- the normal reaction $\vec{R}_n$ of the inclined plane (P_1 and P_3),
- the friction force $\vec{f}$ of the solid (P_1) or the friction forces $\vec{f}$ (P_3) »."

By remaining within the same scientific logic according to which a force is the modelling of a mechanical action of one body on another, the rhetoric "force of a body" is not part of a Newtonian vision (Viennot, 1989). A body on its own does not, on the whole, possess force. In order to help students to engage in a scientific discourse on the concept of force, we think it would be better to say:

- " - the force $\vec{P}$ modelling the attraction exerted by the Earth on the solid,
- the force $\vec{R}_n$ modelling the normal reaction exerted by the inclined plane on the solid,
- the resultant f $^{\rightarrow}$ of the forces modelling the friction between the inclined plane and the solid".

In relation to the first part of instruction 4.4B4, the characteristics of the velocity vector $\vec{v}_B$ in B, the use by the two teachers of the time-independent relationship (in the case of uniformly varied rectilinear motion) to calculate the norm of $\vec{v}_B$ can be understood insofar as they have devoted an entire activity to the theorem of kinetic energy but not yet tackled. However, taking into account the fact that this theorem has already been learned by the students in the first science class and that scientific knowledge is cumulative, they should not be forced to refrain from also using this theorem to calculate the norm of $\vec{v}_B$ as P1 said in the following terms:

P_1 : " We know the speed at B and we also know the distance between A and B, so we can use the time-independent relationship. It's true that using the kinetic energy theorem will give the same result, but we haven't seen the theorem yet, so it's better to use it given that the motion is uniformly varied and we know everything involved in the time-independent relationship except v_B, so it's better to go that way."

With regard to the second part of the instructions, i.e. the calculation of the time t_{AB}, P3 and P_1 used the time equations for speed and uniformly varied rectilinear motion respectively. At this level, only P_1 specified the origin of the dates and the origin of the spaces. Teacher P3 did not mention this explicitly on the blackboard, even though the use of time equations necessarily requires such details.

The developments made by teachers P_1 and P_3 confirmed the pure mathematisation of Newton's second law during its teaching/learning in the final year of secondary school. This does not allow the students to properly grasp the law and apply it efficiently in given situations. On the whole, this is an unsuccessful attempt to bring this law closer to the students.

4.3. Interpretation and discussion of the activity materials proposed to the pupils by the teacher P2

Table 2 Compilation of cognitive activities proposed to learners by teachers P_1 and P_3

Consignes	Work to be done content	Potential cognitive activities involved	Situation in relation to the discipline's operating cycle
C.1- By replacing the expression for the momentum vector in the relation $\frac{d\vec{p}}{dt} = \sum \vec{F}_{ext}$, show that $\sum \vec{F}_{ext} = m\vec{a}$. Deduce from this the statement of the centre of inertia theorem (Newton's 2nd law).	- Introduce into the logico-mathematical expression ($\frac{d\vec{p}}{dt} = \sum \vec{F}_{ext}$) of the fundamental relation of dynamics, that $\vec{p} = m\vec{v}$. Derive the velocity vector $\vec{v}$ with respect to time to obtain the acceleration vector $\vec{a}$ in order to find the logico-mathematical relation $\sum \vec{F}_{ext} = m\vec{a}$ of the centre of inertia theorem. - Formulation of centre of inertia theorem from $\sum \vec{F}_{ext} = m\vec{a}$.	- Implementation of mathematical skills (when going from $\vec{v}$ to $\vec{a}$. - Reconstructing the syntactic structure of the centre of inertia theorem from its logical-mathematical relationship.	From a mathematical model (MM) to a mathematical result (MR) then to another mathematical model (MM) followed by interpretation.
C.2- Apply Newton's 2nd Law to a solid material whose centre of inertia is moving in a uniform circular motion. - Name the resultant of the forces applied to it and deduce its characteristics.	- Write the expression for the acceleration vector in the case of circular motion of a material point $= a_\tau\vec{\tau} + a_n\vec{n}$. Find what this expression is worth in the case of uniform circular motion ($\vec{a} = r\omega^2\vec{n}$). Replace this expression in the logical-mathematical relation of the centre of inertia theorem to have $$\sum \vec{F}_{ext} = mr\omega^2\vec{n}$$ - Assign a name, in this case, to the resultant (($\sum \vec{F}_{ext}$) forces applied. Then identify the characteristics of this resultant.	Use of mathematical skills (when moving from the logical-mathematical relationship of the centre of inertia to its contextualised relationship).	From a mathematical model (MM) to a mathematical result (RM) then to another mathematical model (MM) followed by interpretation.
C.3- Translate the relative equilibrium of a solid in a non-galilean reference frame using a corrective force $\vec{F}_i$ (force of inertia).	Express or represent in mathematical language the state of relative equilibrium of a solid in a non-galilean reference frame, with the introduction of a corrective force $\vec{F}_i$.	Mathematisation of a physical model: using physical and mathematical skills.	From a reality model (RM) to a mathematical model (MM) and then to the mathematical result (MR).
C.4- Recall the principle of action and reaction (Newton's 3rd law).	Reconstruct the principle of action and reaction (simple, isolated reconstruction).	Mathematisation of a physical model: using physical and mathematical skills.	From a reality model (RM) to a mathematical model (MM).

Table 3 In relation to the formative assessment topic proposed to the students by the teacher P_2.

Consignes	**Work to be done content**	**Potential cognitive activities involved**	**Situation in relation to the discipline's operating cycle**
1- Show the forces applied to the solid on parts AB, BD and DE of the track.	- List the major external mechanical actions exerted by the immediate environment on the solid. - Schematisation of the solid by a point and mechanical actions by force vectors.	Modelling the concept of a solid by that of a point. Modelling mechanical actions using the concept of force, then modelling the latter using the concept of vector. This is a mathematisation of mechanical actions: use of physical and mathematical skills.	From a physical model (PM) to a mathematical model (MM) and then to the mathematical result (MR).
2- Use the kinetic energy theorem or the centre of inertia theorem to: - Determine the acceleration of solid (S) along AB and its velocity V_B at point B. - Show that the solid arrives at D with zero velocity. - Express the intensity of the reaction of the track on the solid at point M as a function of m, g and θ.	- Recall the prerequisites for applying the kinetic energy theorem or the centre of inertia theorem. Write the contextualised expressions of the logical-mathematical relationship of the centre of inertia theorem and then solve the vector equation obtained to derive - The algebraic value of the acceleration of the solid on the AB portion of the track. - The expression for the intensity of the reaction of the track on the solid at point M. - Write the contextualised expressions of the logical-mathematical relationship of the kinetic energy theorem and then solve the algebraic equation obtained to derive: - The value V_B of the velocity of the solid at point B. - The conclusion that the velocity V_D is zero. - The value V_M of the velocity of the solid at point M.	Vector and algebraic equations followed by solving: mathematical skills are strongly called upon.	From the mathematical model (MM) to the mathematical result (MR).
3- Write the time equation for the motion of the solid on AB and calculate the duration of the path AB, the distance CD, the speed VE and the intensity RE of the reaction of the track DE on the solid at point E..	Reconstruct the general form of the equation of time for uniformly varied rectilinear motion and incorporate the initial conditions and the algebraic value of the acceleration on part AB of the track in order to find the equation of time for the motion of the solid on this part..	ector and algebraic equation formulation followed by resolution: mathematical skills are heavily relied upon..	From the mathematical model (MM) to the mathematical result (MR).

	Use the equation of time to calculate the journey time AB. After the prerequisites for applying the kinetic energy theorem, write down its contextualised logical-mathematical relationship: - on the CD part of the track to draw the distance CD; - on the DE part of the track to draw the speed value V_E. - After the preliminaries for the application of the centre of inertia theorem, write its logical-mathematical relation contextualised on the DE part and then solve the vector equation obtained in order to derive the intensity RE of the reaction of the track on the solid at point E.		

The sequence in which Newton's second law is inserted by teacher P2 is entitled "Newton's second and third laws - kinetic energy theorem" and is part of a sub-activity (4-3) entitled "how to apply Newton's laws and the kinetic energy theorem". In the first part of the sequence, the pupils are provided with certain elements of knowledge such as: the definition of a Galilean reference frame followed by a few examples, the statement of the fundamental relation of translational dynamics as well as its logical-mathematical relation modelling it, the steps to follow to apply the theorem of the centre of inertia and that of kinetic energy. According to the title, this sequence aims to develop at the same time not only Newton's last two laws of motion but also the kinetic energy theorem.

The first part of instruction C1 namely "by replacing the expression for the momentum vector in the relation $\frac{d\vec{p}}{dt} = \sum \vec{F}_{ext}$, shows that $\sum \vec{F}_{ext} = m\vec{a}$ " is a simple application without any knowledge adaptation. This precisely resembles what Robert (2007) refers to as a "simple, isolated task". The second part of task C1, i.e. "deduce from it the statement of the theorem of the centre of inertia (Newton's 2nd law)", requires an interpretation of the logical-mathematical relationship obtained and a reconstruction of certain parameters.

The first application of this law begins with instruction C2. However, as it is formulated, i.e. "apply Newton's 2nd law to a solid material whose centre of inertia is animated by a uniform circular motion", the instruction does not have a precise final aim, which does not make the anticipations explicit. The second part of the same instruction asks you to name the resultant of the forces applied to the solid. We wonder whether it's really a name that the teacher wants, or a qualifier? Instruction C3 asks you to "translate the relative equilibrium of a solid in a non-galilean reference frame by involving a corrective force $\vec{F}_i$. (force of inertia)". In the support, no reference is made to any real situation involving the notions of relative equilibrium and non-galilean reference frame. Under these conditions, even if the teacher oratorically describes some real situations involving these concepts, the pupils' memory of a probable link between the knowledge taught and these situations is likely to be precarious. Through this instruction, we wonder whether it is really the translation of the relative balance that the teacher is aiming for or the relationship translating (or modelling) it? En ce qui concerne la troisième loi de Newton, la consigne C_4 a demandé juste le rappel de son énoncé.

In short, for this teacher, the teaching/learning of Newton's second law in the final year of secondary school boils down to establishing its logical-mathematical relationship and its statement. To support the learning sequence, teacher P_2 planned a situation for reinvesting (or assessing) the students' knowledge. We note that this situation is the contextualisation of a purely mathematical model, i.e. a situation that is almost totally modelled, and therefore disconnected from physical reality. The instructions for the work (tasks or types of task) all call for mathematical results, without any other interpretation.

4.4. Interpretation and discussion of productions on the P_2

The first part of instruction C.1 asked to show that $\sum \vec{F}_{ext} = m\vec{a}$ whereas the final result obtained on the board is instead $\sum \vec{F}_{ext} = M\vec{a}_G$ without any other precision. This lacks a little scientific rigour, if only from the point of view of form. It is written under the established logical-mathematical relationship ($\sum \vec{F}_{ext} = M\vec{a}_G$) framed after the statement: "this is Newton's 2nd law". Is this part of the sentence related to the box or to the statement? The question is justified by the fact that, referring to Vergnaud (1990, 2007), a theorem-in-act is not a theorem, and the box alone is not yet the centre of inertia theorem or Newton's second law. As for the second part of the same instruction, i.e. the deduction of the statement of the theorem, we note that from the logical-mathematical relationship ($\sum \vec{F}_{ext} = M\vec{a}_G$) to the statement, there was no interpretation, whereas a mathematical formula alone is mute in physics.

As for the first part of instruction C.2, i.e. "apply Newton's 2nd law to a solid material whose centre of inertia is in uniform circular motion", we found that it was the logical-mathematical relationship modelling the said law in the case of uniform circular motion that was established on the blackboard. If this is the case, then the instructions lack precision, as they could simply have asked what the relationship established in C.1 is for the case where the centre of inertia of the solid is moving in a uniform circular motion. For the second part of the same instruction, $\sum \vec{F}_{ext} = \vec{F}_c$ is given to arrive at $\vec{F}_c = Mr\omega^2 \cdot \vec{n}$ in order to give the name "centripetal force" to $\vec{F}_c$. This is not a noun but rather a qualifier. If this is the result intended by this part of the instructions, the teacher could ask you to say, with justification, how to qualify the resultant of the forces applied to the solid in this case. As far as the characteristics of this resultant are concerned, there is a lack of precision as to what is meant by the terms "radial" and "centripetal" for the direction and sense respectively.

In response to instruction C.3, which asks us to "translate the relative equilibrium of a solid in a non-galilean reference frame by using a corrective force $\vec{F}_i$ (force of inertia)", we read on the board :

Sometimes it is convenient when studying the motion of a solid to refer to its immediate environment (non-galilean reference frame) rather than to the earth's ground (galilean).

The solid is then in relative equilibrium thanks to an imaginary force $\vec{f}_i = -m\vec{a}_G$ *that we bring into play.*

In this relative equilibrium, we have : $\sum \vec{F}_{ext} + \vec{f}_i = \vec{0}$

$\vec{f}_i$ *is called the centrifugal force of inertia.*

This is not a translation, but rather a commentary on the relative equilibrium of a solid in a Galilean frame of reference. A commentary that did not even explicitly highlight, in writing, the significance of the phenomenon.
In response to instruction C.4, i.e. "Recall the statement of the principle of action and reaction (Newton's 3rd law)", here is part of the answer that we read out on the board :

Two-point solids of masses m_A *and* m_B *placed respectively at two points A and B exert directly opposite attractive forces on each other.*

The common intensity of these two forces is proportional to the product of their masses and inversely proportional to the square of the distance separating them...

The first thing to emphasise in this answer is that the forces of interaction can be attractive or repulsive. Thus, the emphasis cannot be placed solely on the attractive aspect of these forces. The second part of the answer is specific to gravitational interactions and is a special case of the principle of reciprocal actions. Such a far-reaching principle of physics cannot be reduced to a special case when it is institutionalised. In this case, the response to the instruction is really not in line with it.

Let's also take a look at the blackboard relating to the response elements of the formative evaluation situation (SEF) 1.6. During the assessment of the forces applied to the solid, in the first set of instructions, the statement "force of a body" remained the same as for the other teachers (P1 and P3).

In the first part of the second task, the vector relation given by the theorem of the centre of inertia-in-act is also projected only onto the axis (Ax). The "why" of this relationship is not also projected onto the axis (Ay) is nowhere specified, even though on the diagram it is a two-dimensional reference frame $(A, \vec{\imath}, \vec{\jmath})$ which is inscribed there. We believe that the determination of the acceleration of the solid should not stop at its algebraic value but rather should go as far as its norm, even if in the present case the two values keep the same sign.

τ

During the establishment of the expression of the intensity of the reaction of the track on the solid and that of the tangential acceleration (instruction introduced during the correction), it is not specified in the table why in the first case the vector relation given by the theorem of the centre of inertia-in-act ($\vec{P} + \vec{R} = m\vec{a}$) is projected onto $(M, \vec{n})$ while in the second case it is rather onto $(M, \vec{\tau})$. In relation to the latter, on the board, it's about projection onto τ instead of $\vec{\tau}$ since we cannot make a projection onto τ which is a norm, and therefore a scalar.

Regarding instruction 3, when establishing the time equation of the motion of the solid, the origin of the dates as well as that of the spaces was not explicitly specified in the written notes.

However, we found that teacher P_2 explicitly made more remarks and provided more of the necessary details on the blackboard, especially during the correction of the formative assessment situation.

All the development done by teacher P_2 also remained practically confined to a single world: the theoretical world. He was unable to move the students around the elements of the different worlds by means of appropriate modelling to enable them to better grasp Newton's second law, both qualitatively and quantitatively.

4.5. Results of the analysis of teachers' speeches

A quick analysis of the three teachers' speeches shows that they are well supplied. The teachers made sufficient use of the concepts involved in Newton's second law, which is indicative of their methodological profile. And as P1 was able to point out to his pupils: "...mastery of science is not limited to writing down a formula, you have written down the formula but the quantities involved in the formula each have their own meanings, their own names and what they represent...", so a simple conceptual mobilisation by the teacher in his speech may not lead to systematic learning on the part of the pupils. For our part, it would also be necessary to see how the teacher activates and plays on, on the one hand, the inter-conceptual relations and, on the other hand, the relations between the two real and theoretical worlds, in relation to the concepts mobilised in his discourse. In the law whose teaching is the subject of this study, the concept of movement, for example, is one of the 'pivotal concepts' (Dufour, 2011). The relationships between this concept and others in the network, which are directly related, should therefore be made sufficiently explicit by each teacher, particularly those, for example, between the concepts of motion, force and momentum vector. A more in-depth analysis of the cards shows that, in the discourse of the teachers filmed, there are practically no clearly defined relationships between the concept of force and that of motion, or between the latter and that of the momentum vector of the system under study. In particular, the change in the state of motion of a body caused by the variation of its momentum vector, which in turn is caused by a mechanical action, modelled by a force applied to the system. During the teaching process, and this in Newtonian mechanics, none of the three teachers explained why a whole solid is represented by a point, what is gained from this, or what is lost.

All three teachers did their utmost to network the concept of force sufficiently, i.e. they highlighted enough of the relationships between this concept and others in their speeches. However, nowhere did they consider whether these connections alone could bring about an entry into a scientific culture (Grancher et al, 2014), specific to physics, and consequently encourage systematic learning on the part of the pupils with regard to this concept in a Newtonian context. From the point of view of the link between the real and theoretical worlds, i.e. on the modelling side, we note, in P2 alone, an attempt to initiate modelling when he notifies the pupils that the solid will be represented by a point for the sake of simplifying the task. Here again, what this simplification of the task concretely consists of by reducing the solid (element of the real world) to a point (element of the theoretical world), what is gained and what is lost, nothing is explained. And this is what justifies the expression "attempt to begin modelling" which we used to describe the teacher's discourse on this subject.

Despite the fact that the concept of a frame of reference was widely evoked by the three teachers, the relativity of a movement in relation to a frame of reference was not mentioned explicitly, or at least not at all, by them in their speeches.

Assuming that in the course of teaching, relationships between concepts also constitute a kind of rapprochement-en-acte, then in the discourse of these teachers, these potential rapprochements-en-acte are more confined to the theoretical world. Here again, it remains to be seen whether they are effective or missed. These are some of the shortcomings in the inter-conceptual relationships revealed by the concept maps and which could have a negative impact on the conceptualisation and implementation of Newton's second law by the pupils.

4.6. Inter-teacher regularities in discourse

Following the modelling of the discourse of the three filmed teachers using concept maps, we now seek to highlight some invariants in the oratory organisation of these teachers during the teaching of Newton's second law in the science final year class. From a lexicometric point of view, we refer here to these invariants in the oratory organisation of the three teachers as inter-teacher regularities in the discourse. It is not our intention to try and determine whether these regularities are conscious or unconscious, or whether they are improvised or not. Having highlighted them, however, we can examine some of their potential impacts on the pupils' learning of the law.

We are following the logic that "a theorem-in-act is not a theorem" (Vergnaud, 1990). Thus, knowledge of Newton's second law, also known as the theorem of the centre of inertia (in the case of a material point or a solid of constant mass), cannot be reduced to the use of the logical-mathematical relationship $\sum \vec{F}_{ex} = m\vec{a}$, for only purely computational purposes. Unfortunately, this is what it's noticed in the speeches of the three teachers filmed. Speeches, often synthetic, with an invocative connotation of conceptual sets without functional relational cohesions, sometimes under the guise of a truncated devolution, contributing to a reduction in the capacities to activate the students.

In this law, which is the subject of our study, the concept of force also constitutes a "pivotal" concept, the sufficient networking of which could help the pupils to avoid certain confusions, for example: the maintenance of a movement by a force, friction forces as and only resistance to movement (Givry, 2003; Besson et al, 2007). None of the teachers filmed attempted to do this. When teaching this law, the teacher, through his or her discourse, should make the pupils understand that force does not maintain movement but that, being the model of a mechanical action, it modifies the body's quantity of movement, which thus causes the body to set in motion or modify its movement. Friction is a particularly important category of force in this law, and one that needs to be emphasised. What teachers say on this subject does not give pupils an understanding of the types of friction. For pupils up to the final year of secondary school, friction is always opposed to movement For this purpose, the interconceptual relationship between the concept of frictional force should also be an opportunity for the teacher to develop the notion of the topography of contact surfaces between solids and the mechanisms producing friction, as well as the typology of the concept of friction, leading to static friction (which contributes to maintaining the equilibrium of a body), propulsive friction (which contributes to the evolution of movement) and resistive or repulsive friction (which opposes movement).

The study shows that the difficulties pupils encounter in interpreting friction during the movement of a body are partly related to teachers who, in their teaching, make no mention of the typology of the concept. In fact, they reinforce students' misconception that friction "always opposes movement".

In the relation $\sum \vec{F}_{ex} = m\vec{a}$, none of the teachers were concerned about the nature of my mass which here represents a coefficient of proportionality between force and acceleration and which therefore ensures the transition from kinematics to dynamics (Givry, 2003)). When, during the teaching of this law, the teacher does not explain to the pupil the difference between gravitational mass and inertial mass, while pointing out that it is precisely the latter that is mentioned in the law, the pupil will never realize that it is such a mass which, by its very definition, opposes the setting in motion as well as the change in motion of a body (Givry, 2003; Rosca, 2005).

This study highlights that teachers only focus on deduction, based on the fundamental relationship of dynamics., the logical-mathematical relation translating the theorem of the centre and its applications for purely quantitative purposes. The students were not given any explanation about the content of the assignment. This tends to explain the difficulties students have not only with the syntactic structure of the law but also with the conditions of applicability (Nguessan, 2016). There is also a lack or even absence of counterintuitive examples that could promote a gradual conceptual shift towards effective learning of the law by students. All of this helps to reinforce their intuitive reasoning at the expense of the scientific reasoning conveyed by the Newtonian formalism taught (Viennot, 1978).

Newton's second law can be used to explain, interpret or predict certain phenomena relating to the movements of material systems. It is therefore a law whose efficient implementation requires a constant back-and-forth between the real and theoretical worlds, using appropriate models. The study highlighted, on the one hand, that the activity supports developed by the teachers and the materials used by them to teach the Newton's second law do not allow the students to move between the two worlds in accordance with the way physics works. Furthermore, the discourse of these teachers during class sessions on Newton's second law is practically all confined to the theoretical world. In other words, this way of teaching does not make it easier for students to appropriate and apply the law.

5. Conclusion

The teacher's job is to ensure that student effectively appropriates the knowledge. However, very often, the resources used by the teacher do not meet expectations. As physics operates between two worlds (real and theoretical) through the intermediary of models, the teacher's work must enable the student to move back-and-forth between these worlds to get closer to the object of knowledge, in order to appropriate it and be able to apply it efficiently in given situations to solve problems. The activity materials proposed by the three teachers, and their development, do not follow this logic. The teaching of Newton's second law is reduced to a simple mathematization.

The analysis of the teachers' discourse using concept maps revealed lexicometric connections that were either missing or insufficient. This does not allow the various parameters (kinematic and dynamic) involved in Newton's second law of motion to be made operational. From an oratory point of view, the help given to students by teachers is practically all focused on quantitative aspects, thus creating difficulties in accommodating the qualitative aspects that could promote proper appropriation. The teaching of Newton's second law of motion showed a lack of inter-conceptual relationships in the discourse of the teachers.

Effective learning of Newton's second law requires appropriate adjustment of curricula, appropriate training of teachers, and the development of good teaching methods. level, with good instructional engineering as the key, since the didactic gaps in the physics, chemistry and technology syllabus and guide open up a Pandora's box to a cacophony of teaching practices fuelled by discourse on science.

Compliance with ethical standards

Disclosure of conflict of interest

All four authors acknowledge that there is no conflict of interest. They all agree with what is written in this article. In accordance with the requirements of transparency and scientific integrity, we, the authors of this study, declare that we have no conflict of interest, whether financial, commercial or otherwise, that could influence the results or interpretations of our research on initiation rites in Benin, thus guaranteeing the independence and objectivity of our work and ensuring the credibility of our conclusions.

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