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RESEARCH ARTICLE

PHYSICS TEACHERS' PEDAGOGICAL KNOWLEDGE OF THE CONTENT ABOUT NEWTON'S SECOND LAW IN THE FINAL YEAR OF SECONDARY SCHOOL: DIDACTIC PERSPECTIVES

Ahodegnon Zephyrin Magloire Dognon[1], Danhinaimecomlan Kanffon[1] and Coovicyriaque Sessou Ahodekon[2]

1. Discipline Didactics Laboratory, University of Abomey-Calavi.
2. Research and Expertise Laboratory for Sport, Education and Social Interventions, National Institute of Youth, Physical Education and Sport, University of Abomey-Calavi.

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Abstract

The difficulties encountered by learners in applying Newton's second law during problem solving have led us to take a closer look at teachers' pedagogical knowledge of the content of this law. This exploration, carried out in the light of Shulman's theory, reveals that teachers are not only somewhat unfamiliar with the recommendations relating to the aforementioned law in official texts, but also have a very poor conception of the teaching/learning of this law from a training perspective. This contributes greatly to the difficulties that learners have in learning and assessing this law. For a betterenrollment of students in a culture of physics, specifically about Newtonian mechanics, teacher training needs to be rethought, particularly in terms of physics pedagogical content knowledge (PCK).

Introduction:-

Theoretical and conceptual framework of the research:

The model developed by Shulman (1986, 1987), taken up by Grossman (1990) and Magnusson, Krajeik and Borko (1999) (1999) was used as a framework to explore the physics teacher's knowledge of Newton's second law, enabling him to teach it efficiently.Indicators that can be used to describe a teacher's PCK include knowledge of teaching strategies, knowledge of the curriculum, knowledge of assessment, knowledge of pupils' difficulties, science teaching guidelines, ways of representing and formulating the subject that make it comprehensible to others (the most useful forms of representation of ideas, the most powerful analogies, illustrations, models, examples, explanations, demonstrations) (Shulman (2007), knowledge of the textbooks recommended by the school, etc.)..

Literature Review:-

The appropriation of Newton's laws and the reasoning of pupils and students when using them to solve problems have preoccupied many researchers in physics didactics.Like Newton's other two laws of motion, the second law was formulated in very specific contexts, using specific vocabulary.Understanding this law requires a mastery of the language used to formulate it. Unfortunately, in a study carried out with undergraduate and postgraduate students, Nguessan (2016) showed that they do not generally master not only the dominant syntactic structures of the

Corresponding Author:- Ahodegnon Zephyrin Magloire Dognon
Address:-Discipline Didactics Laboratory, University of Abomey Calavi.

foundations of Newton's laws of motion but also the constituent elements of their domains of validity.This raises the question of the adaptability of these laws to given situations, as well as the effectiveness of their implementation in problem solving.To explore some of the causes of the discrepancy between the models taught and those actually learnt by pupils and students, Lefèvre and Allevy (1998) examined the reasoning of pupils and students in the application of Newton's second law when solving problems relating to the inclined plane.They have found that most learners have difficulty instantiating knowledge schemas (Rumelhart, 1978) in "exotic" situations, i.e. situations that are far removed from the prototypes used as monstrations.This leads these researchers to put forward the hypothesis that "it seems that the mental model formed at the point of instantiation does not cope well with alternative situations" (Lefèvre and Allevy, 1998).

In examining the understanding and models underlying the reasoning of student teachers and high school students, Saglam-Arslan and Devecioglu (2010) found, especially among student teachers, significant weaknesses in understanding the fundamental knowledge terms of Newton's laws of motion. When they went on to explore some of the causes of these weaknesses, they came to the conclusion that this finding is due to the fact that Newton's second law of motion is generally linked to theoretical knowledge rather than everyday applications.Viennot (1978), analysing the reasoning of learners when solving problems requiring the application of Newton's laws of motion, noted that this reasoning was not part of a Newtonian vision.She then hypothesises that learners' reasoning is not due solely to the effects of the formalism taught. Pursuing her investigations with a view to verifying her hypothesis, she found that the intuitive system acts as a screen for school knowledge. Following the same logic, Viennot (1982) studied a number of school textbooks in terms of their development and recommendations. This study highlights the fact that some textbooks reinforce or teach intuitive reasoning that makes no physical sense.

The development of an explanatory model of the logical-mathematical relation $\sum \vec{F} = m\vec{a}$(Oké, Kanffon&Kelani, 2019) was the subject of a study conducted with high school students by Robardet (1995). He has shown that by teaching/learning through progressive conceptual change based on solving problem situations and gradually developing explanatory models, the majority of students manage to make more sense of Newton's second law. The author also noted that this conceptual change is all the more effective if it takes place through a coherent set of problem situations in a progressive modelling approach during which the pupils' conceptions are made to function as pre-models in the sense of Johsua (1989).Newton's second law of motion brings together a number of concepts whose conceptualisation by learners has not left physics didactics researchers indifferent. They have highlighted certain difficulties faced by pupils and students.
About the movement

Saltiel and Malgrange (1979) have shown pupils to have a space linked to the earth, a single timeless, geometric space of finite dimension, in which the movements of any object are identified. This leads them to a principle of non-equivalence between rest and movement (Viennot, 1996). Hestenes, Wells and Swackhamer (1992) and Viennot (1996) have shown that, for some students, force remains the cause of movement.About the reference frameResearch by Saltiel and Malgrange (1979) and Viennot (1996) tends to show that pupils do not take the reference frame into account when describing certain parameters of movement such as trajectory and speed. This leads them to consider speed as an invariant and to give only a geometric meaning to the trajectory of the moving body.

About strength:
For Koffi (2014), the influence on pupils' conceptualisation of the objects, events and phenomena used in the statements of the situations leads to pupils' misconceptions of the concept of force varying from one situation to another. A study by Ménigaux (1986) shows that the "pictorial" schematisation of interactions during the teaching process causes persistent errors in pupils, such as the transposition of a force and the transmission of weight. Dumas-Carré and Goffard (1997) show that some students tend to consider that forces are transmitted through objects, even in the case of interactions at a distance. Other students consider force to be an intrinsic property of an object by reasoning in terms of "the force of the object" and not in terms of "the force exerted by ... on the object" (Viennot, 1989).

About the mass:-
As Givry (2003) and Rosca (2005) have shown, students do not differentiate between gravitational mass and inertial mass. What's more, they don't realise that the inertial mass in Newton's Second Law is opposed to motion.About the acceleration vector Reif and Allen (1992) have highlighted qualitative questions relating to the nature of the

acceleration vector and its schematisation among students and even some experts. In their reasoning, they only consider the normal or tangential component (Shaffer, 1993). Students have difficulty finding the approximate direction of the acceleration vector in conventional situations. They also have difficulty linking net force and acceleration vector in the application of Newton's second law of dynamics (Knight, 1995; Flores et al, 2004).This state-of-the-art shows that research into the teaching and learning of Newton's laws of motion is for the most part focused on the learner, i.e. on his or her conceptual difficulties and modes of reasoning. Only Robardet (1995) has developed and tested a kind of didactic engineering based on problem solving leading to the progressive development of an explanatory model of the logical-mathematical relationship modelling Newton's second law. Before a teacher can reach this level, he or she must have pedagogical knowledge of the content related to this law. This is what justifies the interest of this research.

Question and hypothesis:-

There is generally a gap between the models taught and those actually learned by learners (Lefèvre and Allevy, 1998). The question arises as to whether the reasons for this gap can be attributed solely to the students in the case of the teaching and learning of Newton's second law. An exploration of physics teachers' pedagogical knowledge of Newton's second law would provide an answer to this question.To teach an object of knowledge, the teacher must have several types of basic knowledge. Some of this knowledge is crucial to the teaching of an object of knowledge in a given discipline (Shulman, 1986, 1987, 2007). This is precisely the PCK. For example, do physics teachers have the necessary pedagogical knowledge of Newton's second law to teach and learn it effectively?The teaching profession cannot be integrated without a minimum of academic, professional and/or initial training. Given the years of experience of the teachers interviewed for this research, it is hypothesised that physics teachers have sufficient pedagogical knowledge of Newton's second law to facilitate its teaching and encourage learning.

Methodology:-

Data collection and corpus composition:

This study took place in the department of Borgou in Benin. It is part of a process of exploring certain categories of physics teacher knowledge, more specifically pedagogical content knowledge (PCK). To compile our corpus, we conducted semi-directive interviews with Physics, Chemistry and Technology teachers working in science final year classes. In order to ensure that these teachers had received the necessary training, both academically and professionally, six (06) certified teachers, including two educational advisors, were interviewed in class situations in final year classes. Two (02) teachers are on duty at the Lycée Mathieu Bouké, one at the Zongo General Education College and one at the Private College Academia, three establishments located in the town of Parakou. The other two are working at the PrytanéeMilitaire de Bembèrèkè, a sub-regional school for young soldiers located around a hundred kilometres from Parakou in the northern Borgou region.A questionnaire including thirteen (13) questions relating to PCK was drawn up for the purpose of conducting these interviews. The interviews with the six (06) teachers were audio recorded and transcribed in full. The corpus to be analyzed is made up of all these transcriptions.

Data processing and analysis methodology:-

For the analysis of the corpus resulting from the transcriptions of the interviews, we first drew up indicators of the elements of the expected responses to serve as references for the analysis. With regard to the recommendations in the official texts concerning the teaching of Newton's second law in the final year of science, we found them in the program guide.For each question, the responses of the six teachers are compared with the references developed for this purpose. By comparing the teachers' answers with those we produced, we can see whether or not there are any differences or similarities. These are then analyzed and discussed in order to examine their relevance to effective learning of this law.

Results:-

In all their work and at every level, teachers always refer to documents known as official texts, i.e. syllabuses, guides and textbooks recommended by the educational establishment. When we wanted to know whether these texts, through their recommendations, take account of the way the subject operates, the answer was unanimously yes for all the teachers interviewed.Learning an object of knowledge at a given level requires a certain amount of prior knowledge, which can be called prerequisites. In the case of Newton's second law in the final year of secondary school, we asked the teachers to present the prerequisites that the learner needs to know.For P1, it is sufficient to know the principle of inertia and the projections of forces (force vectors) on the different axes of a reference frame.

In addition to Newton's first law, P2 added that the learner should be able to "manipulate vectors mathematically". P3 also emphasized the principle of inertia before mentioning the definitions of certain concepts, namely external and internal forces, isolated or pseudo-isolated system, speed and acceleration.On the other hand, P4 only emphasized the mathematical concepts: "the prerequisites, I see that he still has to master vectors first, the mathematical concepts about vectors, the derivative as well, the derivative and the notion of primitive, projection and scalar product as well". CP1 mentioned the different natures of movement, the concepts of force, kinetic and mechanical energy, barycenter and center of inertia.

CP2 also talked only about the concepts of internal and external forces, force balance, motion, reference frame and momentum.On this question, the points of view do not converge because some dwell practically only on the physical concepts (CP1, CP2 and P3), others almost only on the mathematical concepts (P1, P2 and P4).Pour une bonne appropriation par les élèves d'un objet de savoir, lors de son enseignement l'enseignant insiste généralement sur certains points essentiels. The teachers were asked which of these they emphasized in the case of Newton's Second.In his answer, P1 only emphasised the projection of the force vectors onto the different axes of the reference frame and what the instructions required. For P2, these essential points are: the definition of the system, knowledge of the working reference frame, the external forces applied to a solid and the projection of the vectors into a reference frame. P3, on the other hand, focuses only on the statement of the law, the projections of the vectors and the conditions for using the law. On this question, P4 is only concerned with the mathematical formula.

During the teaching of this law, CP1 states that it will emphasize: the notion of internal and external forces, the definition of a system, the reference frame and the nature of motion. CP2 added to this list the notion of the balance of external forces acting on the system under study and their representation. During the teaching of this law, the two pedagogical advisors are practically unconcerned with the mathematical aspects involved in its development.In order to check the consistency of the answers to the last two questions, we wanted to know what mathematical concepts might make it easier to learn Newton's second law in the final year of secondary school.In this connection, P1 mentions angles, trigonometric functions and the projection of vectors. P2 only emphasised the manipulation of vectors in physics. Teacher P3 agreed with P2. As for P4, he talked more about the notions of derivative, primitive, scalar product and projection of vectors.CP1 covers trigonometric concepts and equations. CP2 looks at the derivative of a function with respect to a variable, trigonometry, the projection of a vector and the algebraic value.

Learning knowledge involves carrying out a number of tasks. With this in mind, we asked teachers what tasks they usually set themselves during teaching and learning sessions on Newton's second law.On this question, the task given by P1 was to determine the Cartesian equation of the trajectory of a moving body in a force field. P2 said that he proposed work to be done individually, in groups and then collectively. P3 partially agreed, proposing work to be done individually and concepts relating to the aforementioned law. P4 tells us that he refers learners to the mathematical concepts they need to learn about the law.As for CP1, it is purely documentary work that he organizes with his learners. He offers learners documents from which they must extract the answers to the instructions.CP2 says that it offers learners a learning activity based on a concrete fact that enables them to find the relationship translating Newton's second law and then apply it in other situations. We note that some teachers confuse tasks and forms of work.

In physics, the teaching of an object of knowledge is generally done with appropriate materials, so we asked these teachers which materials they used to teach Newton's second law.According to his answer, P1 only uses graphic aids to get his message across. P2 said that apart from the traditional activity sheets, he had only once used the inclined plane system for this course. Teacher P3 said: "The materials we use to teach Newton's second law are the documents on the syllabus, even the guides and programs, so I think that's what I use at this level" (P3-60). P4 said that he used documents and some videos to visualize and describe some movements of solids.CP1 felt that the inclined plane system would be a good way of demonstrating the law, but because his school did not have a fully-developed laboratory, he used only teaching materials. The only problem was that what he put in the latter was not explained. CP2 mentioned that he did not use any laboratory equipment and that he relied solely on documentary material and a real-life situation for the classroom sessions on Newton's second law.

From the development of course materials to their implementation in the classroom, teachers constantly refer to institutional prescriptions. To check whether teachers actually use these as their 'dashboard', we asked about those relating to the teaching and learning of Newton's second law.For P1, these requirements boil down to recognition of the forces applied to the system, a dynamic study and application of the center of inertia theorem. P2 talks about the activation of certain prerequisites, including the manipulation of vectors and Newton's first law. He adds that we use all this "...to really establish the notion of Newton's second law through the other notions that remain, in particular the application of the law, its meaning and then its exploitation now in a theoretical way and through concrete cases". As for P3, the knowledge to be taught in relation to Newton's second law in the final year is the notion of acceleration, speed and position before returning to this law. Despite our reminders, P4 said: "To be honest, I don't see what I can contribute in this respect". CP1 referred us to the guide and the program.CP2 tells us that the aim is to establish the relationship that translates Newton's second law, to help the learner to master it and to know how to apply it in different situations.

Teachers do not master the knowledge prescribed and to be taught in relation to Newton's second law in the final year of secondary school.The aim of any training course is always for learners to acquire a certain number of skills. Teachers were asked what skills they expected learners to have when learning Newton's second law. For P1, these skills were reduced to knowledge and application of this law to solve an exercise, a problem, etc. In P2's response, we can see that the learner must be able to recognize the characteristics of the resultant of the forces applied to a solid and the nature of its movement. According to P3, at the end of learning this law, the competence expected of the pupil is "to develop an explanation of a fact or a natural phenomenon specific to his/her environment".Teacher P4, for his part, said: "The expected skills, I think, are to be able to use this law to explain facts". As for the skills expected of the learners, CP1 replied "it's that they appropriate this theorem to know what it says, what the theorem says concretely, now to know how to exploit this theorem to calculate forces, speeds and acceleration..."He added that "we can use this theorem to appreciate the nature of a movement". CP2 agreed with teacher P3, except for one difference, when he talk about facts or phenomena of natural or constructed life.

According to P3, P4 and CP2, appropriation of the content of the law through reformulations was not one of the expected skills, but rather only its use to explain facts. For P1 and P2, learning about this law was simply for calculative purposes through problem solving. CP1 tried to partially address both aspects.The teachers were asked about their knowledge about the difficulties frequently noted among learners when studying Newton's second law in the final year of secondary school. P1 said that learners did not know how to calculate the external forces applied to a solid and their projections onto the axes of an associated reference frame. According to P2 and P3, learners have difficulty manipulating vectors (force vectors). P4 and CP1 concurred, saying that students' difficulties were always linked to the mathematical tools needed in science to explain phenomena properly. CP2 told us that the learners had difficulty identifying the frame of reference for the study, delimiting the study system with the forces inside and outside the system. To all this he also added difficulties in handling force vectors.

It should be noted that the difficulties are often not only on the learners' side; teachers also encounter them when teaching the law. On this subject, P1 said that he had difficulty in getting students to understand the law and its concrete applications. In P2's response, he said: "The general difficulty we have is the lack of materials available at the time for the work, because each era has its own materials, so what was appropriate yesterday is not necessarily appropriate today".He added that there was not enough practical training to teach the law easily. P3 also mentioned the lack of materials for experiments to help learners understand the law. As for P4, he left aside his own difficulties and returned to those of the learners linked to mathematical concepts. In his answer, CP1 thought that the main difficulty he encountered in implementing Newton's second law was the difficulty of introducing the concept and bringing learners to apply it because of their mathematical deficits. For CP2, the difficulty is that no practical work is available to implement this law, which involves a concept as abstract as the concept of force.

Learning takes place according to given strategies. Teachers were asked to describe the strategies used to learn Newton's second law in the final year of secondary school. A cette question, P_1 répond qu'il n'a aucune idée des stratégies. For P2, these strategies are nothing more than teaching the learner how to take account of the external forces applied to a solid and the operations on these force vectors. P3 thinks that this means first of all reminding learners of mathematical concepts and the concept of speed. In terms of strategies for learning Newton's second law in the final year, P4 said that individual, group and collective work were the strategies to be used. Apart from the three forms of work, CP1 said that learners should be presented with activities and then formatively assessed. CP2 thinks that "the notion of an experimental approach based on documentary research" is the right learning strategy for implementing Newton's second law, in addition to the forms of work mentioned by his colleagues.

All the teachers in our corpus teach Newton's second law in the final year ofsecondary school. However, they have not mastered the strategies involved in learning this law.Newton's second law in its restriction to a solid, that is to say the center of inertia theorem, is modelled by a logical-mathematical relationship that expresses the proportionality between the resultant of external forces applied to a solid and its acceleration vector. We wanted to find out how teachers get their students to establish such a relationship. According to P1, to establish this, we consider the momentum vector, which must be derived to obtain the relationship between force and acceleration. P2 ensures that his students are first able to take stock of the external forces applied to the system and determine the characteristics of their resultant. He then leads them to establish the proportionality between the resultant and the acceleration vector.It should be noted that the steps leading to the establishment of this proportionality are not explained. P3 had nothing concrete to say about this question.

P4, for his part, believed that to establish this law, it was first necessary to apply the kinetic energy theorem without listing the main stages in his approach. To establish the law, CP1 said that we had to start from the principle of dynamics and the restriction of the concept of a solid to establish the theorem of the centre of inertia. When we asked him what he meant by "restriction of the notion of a solid", he replied that a solid is non-deformable and therefore its mass is a constant..." CP2 partially echoed CP1, but with the addition of "the fundamental relation of dynamics".Apart from the CPs, none of the other teachers mentioned the fundamental relation of dynamics as a starting point for establishing, in the final year, the relation linking force to the acceleration vector. Despite the fact that the educational advisers were able to mention this, the actions to be taken or the stages necessary for this work were not specified.

Discussion:-

The official texts represent, as it were, the teacher's compass through their recommendations. In the context of the physics, chemistry and technology syllabuses currently in force, the recommendations in these texts do not take into account the fact that the subject operates between two worlds (real and theoretical) via the appropriate models, which these teachers do not know how to take into account in their teaching. These epistemological and didactic gaps can lead to a cacophony of teaching practices, further distancing the teaching of the subject from its objectives.Newton's second law implies, in its implementation, both physical and mathematical concepts, some of which are learnt prior to the sequences dealing with the teaching of the said law and which would favor the learning of the latter. We consider these concepts to be prerequisites that the final-year student should know before these sequences.When it came to the prerequisites that the final-year student should know before the lesson on Newton's second law, some teachers mentioned only physical concepts, while others mentioned only mathematical concepts. But when it came to the essential points they emphasized when learning about this law, some teachers mentioned both types of concepts, including prerequisites. What's more, when asked about the mathematical concepts that could make learning about the law easier, they cited a whole host of mathematical concepts, most of which predated the course sequences on the law and which they had not mentioned in the prerequisites. This suggests that there is a lack of consistency in what teachers say about certain aspects of their classroom practice in relation to Newton's second law. They therefore need to improve their knowledge of the concepts involved in implementing Newton's second law.

Some teachers confuse the tasks to be performed by learners when learning Newton's second law with forms of work. This is also evidence of a lack of pedagogical knowledge about this subject.Physics is an experimental science. As such, most of its laws are demonstrated using appropriate materials. In the case of Newton's second law in the final year of secondary school, of all the teachers interviewed, only one said that he had used the inclined plane system once to demonstrate this law during his eighteen years of service. The teaching and learning of Newton's second law is limited to a study of documentary material.Even if experimentation alone is sometimes insufficient, theorizing the course to this extent will not encourage learners to take the law on board. It may also contribute to increasing their accommodation difficulties in problem-solving situations requiring the implementation of this law. Experimentation and commentary are essential.The institutional requirements relating to the law, which should form the teacher's dashboard for teaching/learning, are not well understood by some, and not at all for others. In these circumstances, what do they focus on when teaching this law? From this state of affairs, it emerges that teachers lack knowledge of the knowledge prescribed and to be taught in relation to this law. This can lead to intuitive teaching of the law, thus distancing these teachers' actions from objective practices.
Among other things, learning Newton's second law enables students to appropriate its content and use it to explain facts relating to body movements. These skills, which are the ultimate aim of learning the law, are not clearly identified by some teachers, or not at all by others. Some are right to think that learning this law is only for calculative purposes. Without having a prior idea of what the student is learning, it is difficult to know how to help them learn.

In the course of learning, the learner is often confronted with difficulties:-

In the case of Newton's second law, the difficulties noted by teachers among learners are many and varied. This is perhaps proof that teachers have knowledge of the learning assessment process that enables them to easily identify learners' difficulties. Once these have been identified, they can be the subject of targeted remedial action.Teaching is a profession like any other, and those who practice it often encounter difficulties. The difficulties encountered by the teachers interviewed for this study were generally of two kinds: a lack of materials for practical work and a lack of manipulatives for teaching the law. When they say that there are no manipulatives planned for this purpose, this is easy to understand since they themselves are really unaware of the institutional prescriptions concerning the teaching of Newton's second law, since it is clearly mentioned in the revised program guide: « the experimental illustration of this relationship will be done using a few examples such as free fall, the inclined plane, the conical pendulum, etc. » (DIP T^{les} C et E, 2011, p.27). The relationship in question is, of course, the one modelling Newton's second law, i.e.$\sum \vec{F} = \frac{d\vec{p}}{dt}$. This proves that the lack of knowledge of the recommendations in the official texts sometimes leads teachers to blame their difficulties on the didactic gaps in the program and its guide.

Learning an object of knowledge is generally done according to given strategies. Despite their experience in the final year of secondary school, these teachers really don't know what strategies to use to teach this law. They do not seem to know how the law should be taught in the final year for effective learning. It will therefore be difficult for them to take into account, in the development of activity materials, a good problem-solving approach leading to the progressive development of an explanatory model of Newton's second law (Robardet, 1995) for a better appropriation.The law taught in this study, in its restriction to a solid, gives rise to the theorem of the center of inertia, whose logical-mathematical relationship emphasizes the proportionality between force and acceleration, with the coefficient of inertial mass.This relationship, in accordance with the recommendations of the program guide, is established by starting from the fundamental relationship of translational dynamics $\sum \vec{F}_{ext} = \frac{d\vec{p}}{dt}$by replacing the momentum vector by its expression ($\vec{p} = m\vec{v}$) and moving on to the derivative with respect to time with the mention of mass m equal to a constant.This relationship is always established when we come to the teaching/learning of Newton's second law. We are unable to understand what might be preventing teachers from expressing this practice. One wonders whether it was routine that acted as a barrier to the language artefact or a lack of knowledge about how to establish this relationship in the final year of secondary school.It is clear from all the above that the teachers interviewed have quite a few shortcomings, not only in terms of subject content knowledge but also in terms of pedagogical content knowledge. We are therefore tempted to think that the difficulties encountered by learners, whether conceptual or from the point of view of reasoning when implementing this law, do not emanate solely from the learners themselves but also from the quality of the teaching they receive.

Conclusion:-

A lot of research has shown that learners find it quite difficult to apply Newton's second law to explain or interpret the movements of non-relativistic solids or particles.In order to ascertain whether this finding is not partly due to an induced effect of teachers' pedagogical knowledge of this subject, we conducted semi-structured interviews with these players in an attempt to understand how they see the teaching and learning of this law.The results of the interviews show that physics teachers are seriously lacking in pedagogical knowledge of the content relating to Newton's second law. One of the consequences of this state of affairs is that they will not be able to transform the physical and mathematical knowledge of the content of the law into representations that can help pupils to understand the concepts involved, with a view to effective learning. For better enrollment in a culture of physics and, more specifically, Newtonian mechanics, teacher training will have to be rethought, particularly in terms of pedagogical content knowledge (PCK).

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