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Difficulties Facing Students in Transition to Newtonian Viewpoint: Newton's Third Law Case

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Abstract: Students' alternative frameworks and prior conceptions about interactions forces and/or Newton's motion laws have been largely investigated. The various investigations clearly show that students very often fail to apply Newton's laws of motion in general to everyday situations and third law in particular. Using a conventional notation for representing forces on diagrams, students were presented with questions on the interaction between two objects. and asked to represent in terms of Newton's third law the two interacting forces in a variety of situations. The results show that complete understanding of Newton's Third Law of motion is quite rare, and that some problems related to misunderstanding which force acts on each body. The use of the terms 'action' and 'reaction' in this specific context, compared with their general use, was also found to be misleading... This study highlights some of the serious difficulties students undergo with reciprocal interaction. It suggests that we should be more anxious about the teaching/learning process and the students overall understanding of this principle and that this understanding is underpinned by an understanding of the force concept. Suggestions were proposed for promoting conceptual change based on Posner et al proposal (1982). For this purpose, we propose in our work to analyse the difficulties of high school students in learning the reciprocal interaction principle, locate and identify the obstacles to overcome when dealing with real physical situations. To achieve this task, we have elaborated a questionnaire used to locate the fields of students' difficulties and identify possible causes. We carried by means of this questionnaire a survey (paper-pencil) by requesting a samples of (102) students in different high schools through the country. The analysis and the exploitation of investigation results have shown that students encounter serious difficulties in in dealing with this law.

Keywords: Force, Notation, Conceptions, Interactions, Representations

1. Introduction

Students generally start to learn early in their physics course how to represent forces using arrows, letters, points and lines, etc. The preliminary study discussed in this article attempt to introduce and evaluate this method (conventional notation of force, or CNF) as a rapid and effective technique to pinpoint students' misconceptions, namely those manifested through force notation or verbally expressed by students themselves. A sample of 102 students in their final year of secondary school age between (17, 18) belonging to various high schools in different parts of Algeria were given a paper-pencil-questionnaire comprising a variety of physical situations in which two objects interact with each other. The students were then asked to represent the two interacting forces, using the usual notation $\vec{F}_{A/B} = -\vec{F}_{B/A}$ as followed by teachers and used in textbooks (points of actions, lines of actions, directions and qualitatively compared magnitudes). At the end of each situation, space was provided for students to include an argument or a reason for their responses. Subsequent analysis of the participants' responses revealed the following misconceptions:

1. Mutual interaction is understood as a sequence between two forces.
2. A tendency to misuse letters indicating objects.
3. Action and reaction are not always equal in magnitude.
4. A tendency to restrict mutual interactions to resting objects only.
5. Difficulty in localizing points of application of forces, especially in contact situations.

6. The word 'reaction' used in its colloquial form, rather than in the scientific usage of reaction as simultaneous, exerted force, equal and opposite.
7. Informal explanation in which the word 'force' does not appear at all.

''Pozzer and Roth [15] argue that '*pictures seem to be an extension of nature into* the *pages of the book'*.'' One may follow this point of view and say that representing mutual interaction forces on those pictures may be an extension of the students' internal world (their knowledge and understanding of physics) to the external world. The idea that methods could be used to elicit students' understanding was inspired by Paivio's [13] dual code theory. According to this theory, human cognition employs two different channels for processing and storing information: non-verbal (primarily the visual modality) and verbal. Consequently, the learner constructs the meaning of the concept, its mental representation, using both channels. Therefore, in order to elicit what students hide in their minds regarding certain concepts, one has to urge them to show what is stored in both of the perceptual channels. The CNF method requires students to show their alternative conceptions representatively (by symbols) and/or verbally (in the space provided after each situation). And since the method requires the participants to represent the two interacting forces in each situation, this may force them to show their misconceptions "voluntarily" themselves. In fact, one source of students' misconceptions is the erroneous concepts propagated by teachers themselves Yip, [22]. Indeed, many studies have concluded that teachers have misconceptions as well (for example, in physics: Galili and Hazan, [4]; in physical chemistry: Gopal et al., [6] 2004; in biology: Yip,

Newton's Third Law Misconceptions:

Misconceptions related to Newton's Third Law have been the target of many studies; they are known and well documented. It should be noted, however, that the present study aims at introducing and testing the CNF method rather than exploring students' conceptions. Focusing on Newton's Third Law serves this purpose because it is a well-documented subject and, therefore, a good reference point. Moreover, the Third Law is suitable for the purpose of this research since, on the one hand, it can easily be represented visually using pictures of daily situations and, on the other hand, it is not a trivial law, as so many learners think. In fact, there is no doubt that Newton's Third Law is difficult to understand compared with other laws and is even known to hide some of the last misconceptions to be overcome in the transition to a Newtonian viewpoint (Hestenes, Wells and Swachamer, 1992). People often admit doubt about the validity of Newton's Third Law in all circumstances Gauld, [5]. The Third Law is fundamental and essentially defines what counts as a force: a force is always involved in interaction between two objects. Brown [1] explains that understanding Newton's Third Law requires one to understand that forces arise from interaction. There are at least five ideas that should be taken into account when dealing with Newton's Third Law:

1st A body cannot experience a force in isolation.

2nd Closely related to the above point is the fact that a body cannot exert a force in isolation. Body A cannot exert a force unless there is another body B to exert a force on A. We then say that A and B are mutually interacting.

3rd At all moments of time the force that A exerts on B is of the same magnitude as the force that B exerts on A.

4th An important implication of the above point is that neither force precedes the other one.

5th In the interaction of A and B, the force that A exerts on B is in a direction exactly opposite to the direction of the force that B exerts on A.

The above points can be summed up as: *If body A exerts a force on body B, body B simultaneously exerts on body A force equal in magnitude and opposite in direction*. In our daily life, however, we frequently observe non-symmetric situations; for instance, a collision between a small car and a lorry, or a big ball hitting a small one, a huge man pushing a small man, and so on. We usually tend to think that the bigger, the faster or the stronger object exerts a greater force than the smaller, the slower or the weaker. We can interpret the term 'interaction' with a 'conflict metaphor' (Hestenes et al., 1992).

Daily experiences make it seem counter-intuitive that a massive, rapidly moving body and a small, slowly moving body should exert forces of the same magnitude on each other when they interact. Indeed, it makes more sense *(but is wrong)* to attribute the forces during the interaction to the active bodies and to believe that massive, rapidly moving bodies have large internal forces and consequently exert greater forces on other bodies, while small, slowly moving bodies exert small forces. Newton's Third Law, as it was presented in static situations, is difficult to comprehend. According to Brown (1989), the conception of force, as a property of a single object rather than as arising from an interaction, can be observed in problems involving static situations.

1.1. Aim

The aim of this study was to show the efficiency of the CNF method as a misconception-elicitation technique, using mutual interactions or, traditionally speaking, Newton's Third Law as a research case. When given a sheet of paper with various pictures showing two interacting bodies, the participants were asked to represent, on each picture, the two forces involved between the interacting bodies, using the usual notation of forces that is followed by teachers and textbooks, namely ($F_{A/B} = - F_{B/A}$) according to Newton's Third Law. A space was left after each situation for the student to add an argument or more clarification. It is perhaps worth noting that the programs of the Ministry of National Education in Algeria focus generally on the educational principles, instructional methodology and teaching practice rather than emphasising the need to promote deeper understanding of the subject.

1.2. Analysis of Students' Production

In order for our results to be more expressive and credible, we opted for two options of analysis, one is qualitative which depends essentially on expressions and terms used by subjects in their answers, the other one is quantitative, which concerns (consists of looking at) correct and wrong forces' representations on diagrams in each situation.

1.3. Qualitative Analysis

The first step to identify the categories of displays - expressions, terms and words used by students- an inductive analysis was performed (Patton 1990) in which patterns, themes, and categories of analysis were extracted from the data. In order to formulate a tentative understanding (Roth 1995), the author, one teacher in physics for a long time, and two cognitive psychology teachers with a physics background, separately studied the displays, and then read and reread the participants' arguments and justifications for their forces' representations on diagrams to read and reread the participants' work (three times in total, sometime even more). In subsequent readings, an attempt to confirm the tentative understanding was reached. As part of the verification methodology (Strauss 1987) the three repeatedly reread the data; initial categories were revised as a result of several rounds of discussion. The following categories were identified:

1st There is consistent confusion between a contact situation and a situation at a distance; this leads to confusion not only about forces at a distance and contact situations, but also difficulties in determining the points of forces' actions.

2nd In students' explanations, the word 'reaction' is used in a colloquial way, i.e. as a response to an event, rather than in the scientific usage as a simultaneous equal and opposite exerted force.

3rd There are difficulties in identifying precisely the points of forces' action–the students either do not pay much attention to this issue or they simply cannot do it properly.

4th The majority of students repeatedly use the expression 'the force of...' in their explanations, which supports the persistence of the conception of 'force as a property of objects'.

5th Action and reaction are considered as a temporal process, occurring through time – the action comes first and then the reaction after, which is, of course, wrong. This is perhaps in part because some textbooks continue to use the traditional "obsolete" words 'action' and 'reaction' in presenting the Third Law, instead of 'mutual interaction'. Warren [21] suggests that the terms 'action' and 'reaction' imply a time-consequence.

6th The students have a tendency to introduce irrelevant entities in their explanations, presenting irrelevant force-exerting entities beside those involved in the interaction.

7th There is a tendency to restrict Third Law application to static situations only.

8th There is a tendency to confuse the Third Law with the Second Law.

9th Students use informal explanations in which the word *'force'* is absent, with the words *'push'* and *'pull'* used instead.

10th *The context of situations very much influences students' thinking– they may give answers that are consistent with the scientific view in one context while, in another context, their answers may be opposite or different from the scientifically accepted. ones (Montanero, Suero, Perez and Pardo, 2002;* [12], *Tao and Gunstone, 1999)* [17].

The difficulties given above are not mutually exclusive: more than one of these might apply to a particular answer. From methodological point of view, it is very important to note that difficulties 7 (tendency to restrict the application of Newton's third law to static situations) and 9 (informal explanation in which the word 'force' is absent) clearly, reflect conceptual difficulties that cannot be inferred directly when considering a single diagram but become evident when considering the totality of the sample. The difficulties are clarified further and explanatory examples are provided in the results section below.

Regarding the quantitative part of the analysis, we examined in details the representations of the interactions forces, provided by the subjects, in each situation, and decide whether they are in agreement with the Newtonian point of view or not. Eventually it was concluded that there were three categories of answers:

A- Correct representations (i.e. in total agreement with Newtonian point of view, i.e. two equal and opposite forces, acting on two different objects, on the same line and that suffix indicating the interacting objects);

B- Incomplete and /or imprecise representations (e.g. notations are not clear enough, one of the two forces is missing, some elements are lacking – either forgotten or given less attention, misuse of suffix indicating objects, forces are of different nature etc. Strictly speaking we consider it as incorrect response);

C- No representations displayed at all, it concerns those who refrain to answer the questions.

2. Presentation of Questionnaire

As it was mentioned above, this study aimed to examine, conceptual difficulties faced by Algerian pupils in their final year of secondary school (preparing the baccalaureate exams). The students were asked to represent, in terms of Newton's third law, the interaction forces on each picture, a variety of situations in which two objects interact with each other, was provided for this task. Most situations are familiar to students; some even were inspired from textbooks. The first three problems were designed to obtain an overall view of students' understanding of the third law. The first situation was concerned with the static situation (Figure 1). The sketch showed a table resting on the ground, and the subjects were asked to represent precisely the two interacting forces - table's leg/ground- (Figure 1). Only 8 pupils out of the sample of 102 were able to represent correctly these forces, using the conventional notation $\vec{F}_{A/B} = -\vec{F}_{B/A}$ as used in the text books and followed by teachers, whereas half of the investigated population (50%) supplied imprecise and / or incomplete (this category of answers was clarified in point B above) answers and more than (40%) refrain from responses at all. Note the relatively high percentage of non-response, more than 40% for this situation and more than 55% for other issues. This suggests that either this category of students is undecided and has not been able to decide or that the wording of the question is not clear enough (unclear). Therefore, this point deserves further investigation.

In the second situation students were shown a suspended ball by a wire (Figure 2). Once again they were told to represent the interaction forces between (ball/rope). Only (7%) pupils responded correctly to this question. More than half of the sample (58%) produced imprecise and / or incomplete representations, over 1/3 of the pupils (37%) did not bother to answer the question. Perhaps it is worth to note that, although the question was clear enough, the overwhelming majority of those who responded incorrectly represented interaction (ball/earth) instead. We suggest that, there seems to be clear confusion among students between contact and a distant action. Third question asked pupils to draw on the sketch in (Figure 3) the vectors force which represent the interaction –magnet/compass needle-. About (10%) or (11pupils) who managed to represent correctly this interaction, using the usual notation $\vec{F}_{A/B} = -\vec{F}_{B/A}$ as used in text books and followed by teachers, nearly (40%) produced imprecise and / or Incomplete answers, the category of those who content themselves to refrain from answering the question exceeds slightly (50%). The next two situations (S4 & S5) were prepared to raise the important role played by Newton's third law paired forces as friction forces that make walk and motion possible. In fact, the effects of friction forces are frequently manifested at every moment in our daily life: It is due to friction forces that one can walk, ride a motorcycle, a car, skiing or work at the office without slipping, just like the pens and the papers are on the desk. The prevailing idea among students is that the third law is less important than the other laws. (David E Brown 1989) noticed that "*many text books treat the third law in passing, either mentioning it briefly as an unsupported statement of fact or as an addendum to the section covering conservation of momentum" and then,* he concluded that *"the result of this type of treatment is insufficient to counter the misconceptions students hold about the third law». In* the remaining problems (S6 & S7) the students were asked to predict the outcome of situations where two objects interact with other. In the first problem, the diagram, showed a fixed motor being used in attempt to pull a cart, through a rope (Figure 6). Question S7 was somehow similar to question S6. It showed two objects (a lorry & a small car) about to collide, and the pupils were asked to represent the two interacting forces exerted on each object, it was designed to examine pupils' understanding of the interaction forces between two objects of unequal mass, (S6 & S7) were elaborated to examine one of the most tenacious misconceptions of force, held by students, which converge on a general naïve view of force as a property of objects (objects 'having' more or less force and thus being more or less 'force-full '. This is totally opposed to the Newtonian view point of force arising from interaction between objects rather than. Such a conception of force, as property of objects rather than as arising from an interaction can be observed in various asymmetric problems, as an example, In S7 most of those who produced imprecise and / or incomplete response (strictly speaking concerned as incorrect response) (see table 1 below) confirmed in their justifications with high confidence that the lorry exerts greater force than the small car does when they collide, the justification given for this conclusion was that the lorry (had) more force, and then exerts a greater force in the collision. Situation S5 also showed overwhelming results for a predictable framework. If one object is moving forward and the other one resting, then it is clearly very difficult for learners to accept that the forces on the rope joining the motor and the cart are equal.

3. Results and Discussion

The analysis yielded a considerable number of students' difficulties and categories of responses. The results obtained in this research are summarized in Table 1 below, in which all the information and the relative percentages are included. A first reading of this table shows a very low rate of correct answers which does not reach the (10%), contrary to this score, the rate of imprecise and / or incomplete responses (strictly speaking, they are incorrect) is slightly below (50%). If we combine the two responses (Impre / incom + No Response) then the rate exceeds 90%. This simply shows how wide is the gulf of understanding Newton's third law and the concept of force!

Table 1. *Shows the results of different categories of responses: Correct, imprecise / incomplete and the non-responses corresponding to each situation.*

N° of situation	Identification of interaction	Correct responses	Imprecise and / or incomplete responses	No responses
S1	Table leg/ground interaction	08	51	43
S2	Suspended ball/rope interaction	07	58	37
S3	Magnet/compass needle interaction	11	39	52
S4	Man's left foot/ground interaction	07	54	41
S5	Motorcycle back drive and front wheels /ground interaction	10	43	49
S6	Fixed motor/cart interaction	09	53	40
S7	Lorry/car interaction "collision"	06	41	55
Responses average %	Total 7 Situations	8%	48%	45%

The percentages of responses related to each situation are shown in the table 1 above. However, it should be noted that, with a sample of 102 students, the numbers of responses (also give approximate percentages for each category). Before detailing the tendencies and misconception difficulties, it is important to state that the percentages presented for each situation reflect the data collected from students' responses, and are not representative of the participants' actual degree of knowledge. It is very likely possible that more of the participants hold one or another of the misconceptions, but they do not happen to manifest in the proposed situations. In fact, most of the situations are simple and familiar to students. In the situations illustrated in this research, there is an object which is more or less unambiguously smaller, more massive (S7) or stronger, and generally more obviously acting as an agent of causation (S6) than the other object. Students accustomed to the concept of force as an acquired property of an object would be expected to respond that the more massive, heavier, stronger object would exert a greater force than the less massive, lighter, weaker or the slowest one would not exert a force at all (Maloney, 1984). [9].

Overall, almost 50% (average of percentages) of students found that the set of situations proposed in the questionnaire constituted real obstacles & difficulties in the understanding of the reciprocal interactions (3rd law) and their representations using the conventional notation $\vec{F}_{A/B} = -\vec{F}_{B/A}$ on the diagrams, unfortunately the percentages of correct answers do not exceed (10%), Note the relatively high percentage of non-response, which is more than 45% (average of percentages), this suggests that either this category of students is undecided and has not been able to decide or that the wordings of the questions are not clear enough. Therefore, this point deserves further investigation. In situations S1, S2 and S3 the students were given instructions to represent- according to Newton's third law- the interacting forces between objects using the conventional notation $\vec{F}_{A/B} = -\vec{F}_{B/A}$ as used in text books and followed by teachers. Consequently, these three situations required that the students correctly represent the paired forces in each situation. The results displayed in table 1, showed that students seem unclear of the forces involved in simple situations of static equilibrium. There appears to be a very common mistake that the two forces of third law pair act on the same object to keep it in rest. This result is quite similar to an earlier study of static equilibrium (Terry *et al.* 1985) in which younger children thought that the only one force acted on a box at rest on table-that is the gravity force. But older pupils who had been taught Newton's third law cited this as the reason for the object equilibrium. This type of misconception is confirmed by the second problem which showed a ball suspended by a rope. Out of 102 pupils in the sample, (58%) were unable to suggest a correct and precise representation. Further, (37%) pupils refrain from responding the question. Situation S3 required pupils, to draw the two paired forces that the magnet bar and the compass needle exert on each other. The results displayed in table 1, showed that students seem unclear of the forces involved in simple situations of static equilibrium.

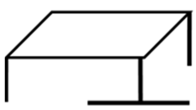

Figure 1. *S1 interaction table's leg-floor.*

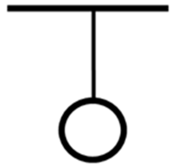

Figure 2. *S2 interaction bull-rope.*

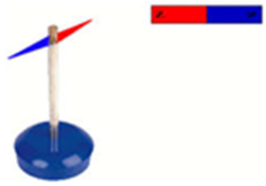

Figure 3. *S3 interaction magnet-compass needle.*

Figure 4. *S4 interaction left foot-ground.*

Figure 5. *S5 interaction ground-back wheel drive and ground-frontwheel drive.*

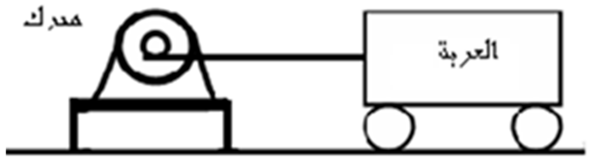

Figure 6. *S6 interation Motor-Cart.*

Figure 7. *S7 interation Lorry-Cart "collision".*

This type of misconception is confirmed by the second problem which showed a ball suspended by a rope. Out of 102 pupils in the sample, (58%) were unable to suggest a correct and precise representation. Further, (37%) pupils refrain from responding the question. Situation S3 required pupils, to draw the two paired forces that the magnet bar and the compass needle exert on each other. In their course of physics, pupils have experience of magnetic forces that arise from pushes and / or pulls. So in this situation the identification and representation of forces involved should not have presented any problem. Unfortunately, in this situation most of students represented a single force exerted by the magnet bar on the compass needle in the direction of its rotation (they justify that by its movement). This suggests that having represented the force exerted by magnet on the compass needle, they do not see the need to analyze the situation further-perhaps because the magnet did not move. Once again, in problem S3 there was no evidence that indicating that students represented the interaction in terms of a pair of forces. Taking S1 and S2 together, these two problems demonstrate that the pupils incorrectly interpreted Newton's third law. Where pupils attempt to identify a third law pair of force, they do not see the need for the forces to act on different objects. This suggests that they do not have an understanding of the concept of force and interaction. They do not understand that forces arise from an interaction between two bodies or that forces involved in an interaction can be described by the third law. There was no indication that the pupils generally think of an interaction in terms of equal and opposite pair of forces.

Situations in situations 4 and 5, In positions 4 and 5, we deliberately chose to have the interaction forces pair in the form of friction forces in order to test the students' ability to analyze each of the two situations separately and to determine the nature of the interaction forces pair in each situation as well as the characteristics of each of them (action point, support, intensity and direction) in fact, friction forces are omnipresent in our daily life. However, it would be a good thing to know how to represent and interpret the involvement of these forces in the mechanism of walking and /or motion. This is the reason for which these two situations have been proposed. Trough (S4 and S5) we want to explore whether students know how to construct and argue, the diagrams modeling the interactions between a walker (in general a mobile car, motorcycle, bicycle etc.) and ground. In a simplified case the walker uses the ground action on his foot to accelerate or to brake, the other foot is in the air (however, the effect of foot action on the ground is not sufficient to accelerate back the ground). All the pupils had previously met situations involving friction forces. But the responses to situations S4 and S5 displayed in the table 1 indicate the serious difficulty many of the pupils have when they asked to analyse situations only slightly different from the one with which they are familiar. The fact that (10%) of the of sample responded correctly to S5 can probably be attributed to the use of this situation as an example to introduce reciprocal interactions text book, only (7%) interpreted correctly the mechanism of walking in terms of Newton's third law. According to studies by Caldas and Saltiel (1995) [3], students often confuse the application of friction forces, with the majority of them believing that the friction forces are always in the opposite direction to the movement of the object in question, and therefore very few of them accept the idea that a frictional force can be also a motor or a propulsion force, rather than a resistant force opposing the motion. For instance, the walker exerts a force on the ground in a direction behind him and the ground exerts a force in a forward direction to enable him moving. Understanding the mechanism of walking allows students to deal with other much more complex situations, such as the interactions between the ground and the drive wheel of a motorcycle in an accelerating or braking situation.

Questions S6 and S7 showed that most pupils used a naïve, intuitive approach to the problems, rather than interpreting the situations in terms of interactions that could be described by the third law.

Situation S6: This question again showed overwhelming results for a predictable misconception. If one object is moving (the cart) and the other one is at rest (fixed motor), then it seems clearly very difficult for students to imagine that the forces on the rope joining the motor and the cart are equal. Over half of the sample (53%) represented the force exerted by the motor greater than that exerted by cart. Typical reason and /or justification were: "motor is giving more force because it does not move», «motor must be putting greater force because it is pulling the cart forward". None of them mentioned the forces between the ground and (motor & cart). The unexpected framework in the question in which the arrows depicting the forces were drawn. An arrow pointing away from the object (motor) along the rope is conventionally intended to represent the force exerted on the motor by the rope. A considerable number of students saw it as being the force exerted by the object on the rope. In fact, 4 times as many pupils interpreted the forces in diagrams in way opposite to the convention followed by teachers and textbooks.

Situation 7: Newton's third law presents certainly few difficulties in symmetrical situations (the interacting bodies are of the same mass), but in very asymmetrical situations, students usually claim that the forces of interaction are not equal (the more massive object exerts a stronger force). It is not that students don't know or don't understand Newton's third law- they simply do not trust it. One student wrote: I know that forces should be equal, but that does not make any sense! Discussions with some of the pupils who responded incorrectly (41%) showed that they were reluctant to compromise in their analysis of the unequal mass situation. Responses to situation S7 showed that clear evidence that most pupils hold a naïve, intuitive approach to the problem.

Although research has mainly focused on contact situations, such as a book on a table Terry, Jones and Hurford [18] (1985; Hestenes et al., 1992; Trumper. R and Gorsky, 1996; Palmer, 2001 [14], and situations with objects at a distance are comparatively rare, such as interaction between the Earth and a golf ball travelling through the air (Kruger, Summers and Palacio, 1990; Hestenes et al., 1992) [8] or between the Earth and a ball that is dropped from a height Suzuki, 2005 [16] Students, however, seem to have serious troubles and confusions in localising points of forces' actions particularly when dealing with contact situations. In order to overcome this problem Viennot,. L 1996, [19] proposed to use the exploded diagrams namely, the different elements of an interaction are deliberately disconnected even if they are in contact (in real situation). At each interaction must necessarily correspond to forces of the same length, opposite direction and acing on two different bodies.

4. Conclusion

As it has been mentioned above, the principal goal of this study was to introduce and evaluate the efficiency of the CNF method for probing students' misconceptions in the physics of forces. The method relies on the basic terminology and conventional notations used at school to represent forces. In this research, the CNF method was taken in the context of a special physics subject, that to say reciprocal actions, traditionally known as 'Newton's Third Law'. It is our view that comprehending physical laws includes the knowledge of how to apply them to real situations. This method has demonstrated the ability to determine whether or not students are indeed able to apply abstract physical laws to real phenomena. In fact, all the situations proposed were relevant to the Third Law. However, only a few students succeeded in correctly representing the interacting forces in each situation. This may be due to the difficulty in bridging the world of physics taught in class and the world outside the classroom. In this context, Cajas (1999) [2] argues that connecting school science with students' everyday life – and this includes students' abilities to use scientific knowledge in real, everyday-life situations rather than merely solving contrived text problems – is a complex task. Mayoh and Knutton's (1997) [11] systematic work on school science and students' out-of-school experience used photographs to question students and teachers about static and dynamic situations they could observe. However, although pictures of situations are at the Centre of the CNF method, the fact that students look at the situation displayed. Using force notation to detect students' misconceptions: mutual interactions case the picture through 'science vision' and represent it according to conventional notation (using vectors) or verbally (using expressions) forces them to reveal their view of how the real and the abstract come together. The importance of this method is that it revealed some undocumented misconceptions and tendencies: l the misconception that the Third Law describes a sequence of events; l the tendency to introduce irrelevant entities in representations; l the use of the word 'reaction' in its colloquial sense. It also reaffirmed some known misconceptions, such as those connected with the tendency to restrict the application of the Third Law to static situations. The fact that new misconceptions were revealed through the use of the CNF method might suggest that it has some unique potential compared with other misconception-elicitation methods. It should be noted that the CNF method did not elicit all of the misconceptions documented in the literature. Perhaps we should have proposed more situations to reveal other misconceptions. So, we may conclude that the CNF method does have unique benefits: l it is very simple and practical; l it can be used easily by teachers as an integral part of their instruction; l it can provide the students with an interesting and authentic way to bridge their out-of-class daily experiences with their physics learning. As has already been mentioned, the purpose of this study was to test the efficiency of the CNF method. The results showed that the CNF method has the ability to bring to the fore students' lack of solid understanding of Newton's Third Law. According to Hellingman (1992:112), [7] 'not only students but also professional physicists to quite a large extent do not have a full understanding of the concept of force'. Furthermore, the CNF method also revealed two further categories of students with regard to the language used in their diagrams: the first category was characterised by an almost complete lack of use of the abstract physics term 'force' and instead everyday language such as 'push' and 'pull' was used; the other category did use the term 'force'. Differences in terms and expressions such as these should be taken seriously. Vygotsky, for example, considered language as the principal of all higher mental functions (Vygotsky, 1934/1986) [20]. Indeed, using scientific terms indicates that, for students who had reached a higher standard of thinking and understanding, it was more natural to describe the real world using physical terminology. Being aware that language plays a crucial role in the process of conceptual growth, it is important that teachers themselves use formal terms and encourage students to use formal terms when explaining real situations involving the Third Law. This makes the explanation more accurate and therefore leads to a better understanding of the Law and its applicability in real situations. In this context, it is worth noting that textbooks, sadly, often still use an old-fashioned formulation of the Third Law in terms of action/reaction instead of force. Mayer and Gallini (1990:715) [10], in their famous article 'When is an illustration worth ten thousand words?', said that: tools and techniques for enhancing students' visual learning of scientificinformation present a relatively untapped potential for improving instructions. We hope that this modest work will be another brick added to the field of science education, and will provide an effective way within the reach of teachers and researchers to upgrade and improve education in general and physics education in particular.

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