Quebec children and elementary pre-service teacher’s conceptions of force and motion

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Abstract. The analysis of the data of the paper questionnaire that we distributed to fifty-eight (58) children and 85 pre-service teachers of elementary education from Quebec in Canada demonstrates that most of their conceptions of force and motion are incompatible with established scientific theory. They look like those developed in the setting of the pre-Newtonian Physics such as the Aristotelian view and the 14th-century Impetus theory by Buridan. Most of the misconceptions identified are: the movement requires the continuous application of force; in the absence of a force, the objects are to be at rest; if an object is not moving, there is no force acting on it. The results were analyzed in the light of previous research on students’ conceptions of motion and force.

1. Introduction
The works of numerous researchers demonstrate that children’s conceptions of force and motion are erroneous regarding accepted scientific views [1–4]. The most common misconceptions identified in the literature are: objects under a constant force move at the constant speed; continuous force must be required to maintain movement. These erroneous conceptions resemble some theories developed during history and that have been refuted since the development of the Newtonian Physics [5–7]. These false conceptions should change following formal education, but several research findings show that they persist to changes in traditional teaching [8–10]. Also, some studies have shown that not only students, but also pre-service and in-service teachers have erroneous conceptions about force and motion [11–13]. Note that few published types of researchers compared the children and pre-service teachers’ conceptions about force and movement. The present research aims to uncover the conceptions of children’s and preservice teachers of elementary level on motion and force.

2. Methodology and population
To identify the conceptions of fifty-eight (58) children (aged between 10 and 12 years) and eighty-five (85) pre-service teachers (aged between 19 and 23 years) in teacher training for elementary school, we have given them, on a voluntary basis paper and pencil questionnaire of sixty minutes duration. To fill out, they had to refer to their spontaneous conceptions. Note that in the case of the children they have received no education on the topic related to the concepts of motion and force comparatively to the pre-service teachers. Indeed, they have taken a course on these themes in secondary school.

To verify that the children understood the questions, we asked three teachers from different schools if they thought that their formulation is appropriate to their language skills. They replied that they were understood in pointing out that they will have difficulty answering correctly.
To analyse the result of the questionnaire, we regroup the answers in distinct categories, the number of which, being variable from one question to the other. Let’s note that this categorisation serves us to make the distinction between their correct, incorrect, partially and indecipherable answers. To qualify in such a way, we compared them to the right responses to our questionnaire presented below. After a while, we interpreted the set of categories identified to put in evidence the constructed conceptions.

3. Paper and pencil questionnaire: Construction and analyses

The questionnaire we have constructed is about Newton’s laws (inertia, action, and reaction). The notions prescribed in the Quebec Education Program [14] associated with this subject are summarized below (Table 1).

Table 1. Notions prescribed in the Quebec Education Program: Force, movement, and gravitation.

| 1. Characteristics of motion: |
|-------------------------------|
| 1.1 Describes the characteristics of motion (e.g. direction, speed). |
| 2. Effects of a force on the direction of an object: |
| 2.1 Identify situations involving the force of friction (pushing on an object, sliding an object, rolling an object) |
| 2.2 Identifies examples of a force (e.g. pulling, pushing, squeezing, stretching) |
| 2.3 Describes the effects of a force on an object (e.g. Sets it in motion, changes its motion, stops it) |
| 2.4 Describes the effects of a force on a material or structure |
| 3. Combined effects of several forces on an object: |
| 3.1 Predict the combined effect of several forces on an object at rest or an object moving in a straight line (e.g. reinforcement, opposition). |

About these notions, we have constructed five questions (see Appendix). Below we will present the objectives of each one followed by its analysis.

3.1 Construction of the first question and the categorization of the data

A person tries to move his car that, unfortunately, doesn't run. Is there a force applies to the car? This question is intended to determine whether, for the children and pre-service teachers, several forces are acting on the vehicle (combined effects of several forces on an object). The muscle power that the person uses, the weight (gravitation) of the car, the reaction force opposite to the weight, and the friction due to the tire contact with the ground and probably the action of the wind. Table 2 summarises the five categories of answers identified, followed illustrative of some pupils and pre-service teachers’ responses.

Table 2. Categorization of children and pre-service teacher’s answers to Question 1.

| Category 1: The car does not move because the force of the person is not big enough compared to the weight of the vehicle. |
|---------------------------------------------------------------|
| Children (20/58-34%) | Pre-service teachers (30/85-35%) |
| “Yes, if the car is not moving, because the man is not strong enough.” (C21) | “Yes, there is a pushing force that applies to the car, but it is not enough to move it.” (P31) |
| “Yes, because of the person force, but the car is too heavy.” (C44) | “Human force only.” (P36) |

| Category 2: The car doesn’t move because the force of the person is not significant enough compared to the gravitational force. |
|----------------------------------------------------------------------------------------------------------------------------------|
| Children (4/58-7%) | Pre-service teachers (15/85-17%) |
| “For sure there is a force, all the things that cars include have gravity.” (C29) | “There is undoubtedly the earth attraction that draws the car towards the ground. In my opinion, this is what makes it difficult to push.” (P58) |
“Yes, the force of gravity allows objects to remain in place.” (P84)

Category 3: The car doesn’t move because the force of the person and the one that is opposite to his force.

| Children (4/58-7%) | Pre-service teachers (9/85-11%) |
|---------------------|----------------------------------|
| “Yes, the wind pushes it to the other side, which prevents the moving of the car.” (C39) | “There is a force that applies to the car: it is friction. Also, the person exercises another force by pushing the car.” (P15) |

Category 4: Unreadable or incomplete justification.

| Children (9/37-24%) | Pre-service teachers (16/85-19%) |
|----------------------|----------------------------------|
| “Yes, because the car weighs a lot of gas and the car needs to be stable.” (C38) | “Yes, there is a force but no movement.” (P25) |

Category 5: No force applies to the car because there is no movement.

| Children (21/58 - 36%) | Pre-service teachers (15/85-18%) |
|------------------------|----------------------------------|
| “The brake, maybe it is on” Park”. (C24) | “No, because the car is on the brake, it's impossible to move it. If it was neutral, it could move.” (P4) |
| “No because the battery is at zero.” (C40) | “No, because if there were a force, the car would move. A force is what makes it possible to move an object.” (P79) |

For 64% (children) and 82% (pre-service teachers), there is a force that is applied to the car even if it is stationary. 54% (children) and 43% (preservice teachers) of them, this force is the one applied by the person. For them, the intensity of this force is not enough to overcome the inertia of the car (because the car is heavy). Only 11% (children) and 21% (preservice teachers) mentioned the presence of a second force that is opposed to that applied by the person. However, they did not explain the origin of this frictional force (contact between the tires and the ground). Surprisingly, 11% (children) and 21% (preservice teachers) referred implicitly to the gravitation (the weight of the car) without developing it. After all, 36% (children) and 18% (preservice teachers) has given no response or vague answers.

3.2 Construction of the second question and the categorization of the data

On a sunny day without wind, a person moves on its bicycle along a straight road (without a slope). When he ceases to peddle, and without using his brakes, the bike continues moving slower during a certain amount of time. According to you, is there still a force applies to the bicycle during its more gradual movement? With this question, we wanted to know how the children and pre-service teachers explain the rectilinear motion of a bike after stopping pedaling. When the person ends driving, the bicycle acquires a certain speed. In the absence of an external force, it will continue to move at that velocity and in a straight line according to Newton's first law (law of inertia). However, in our condition, the bicycle will stop because of the presence of friction between the tires and the ground (friction force). Table 3 summarises the five categories of answers identified, followed illustrative of some pupils and pre-service teachers’ responses.

Table 3. Categorization of children and pre-service teacher’s answers to Question 2.

| Category 1 - There is a force applied to the bicycle: The gravitational force. |
|---------------------------------------------------------------|
| Children (9/58 - 15%) | Pre-service teachers (22/85-26%) |
| “The force of gravity.” (C23) | “In my opinion, the only force that exerted on the bicycle is the gravitation.” (P5) |
| “Yes, the earth's gravity.” (C27) | “Yes, there is the gravity exerted on the cyclist and the bicycle.” (P78) |
Category 2 - There is a force applied to the bicycle: The force that the person has used on pedalling.

| Children (12/58: 21%) | Pre-service teachers (26/85: 30%) |
|-----------------------|----------------------------------|
| “Yes, person strength. If there were no force, the bicycle would not move forward.” (C₁) | “Yes, a force that put the bicycle in motion and keeps it moving.” (P₃₁) |
| “Because the strength of his feet is not completely used.” (C₂₅) | “The force exerted on the bicycle is that gained by pedaling before.” (P₇₇) |

Category 3 - There is a force applied to the bicycle: The friction force.

| Children (0/58: 0%) | Pre-service teachers (9/85: 11%) |
|---------------------|----------------------------------|
| “There is the friction of the tires on the asphalt.” (P₃₈) | |
| “Yes, the friction of the wheels on the ground will cause the bicycle to stop.” (P₆₈) | |

Category 4 - There is a force applied to the bicycle: Not applicable data problem/Answer indecipherable/Incomplete.

| Children (12/58: 21%) | Pre-service teachers (16/85: 19%) |
|-----------------------|----------------------------------|
| “Yes, because he has to pedal to the bicycle advance.” (C₂₁) | “Yes, since there is movement.” (P₂₅) |
| “Yes, when it comes down to a bicycle coast, the wind is stronger.” (C₅₈) | “It descends a slope.” (P₅₅) |
| “Yes, because after a while he will fall.” (P₇) | |

Category 5 - There is no force: The child does not pedal, or it does not wind, or there is no slop.

| Children (25/58: 43%) | Pre-service teachers (12/85: 14%) |
|-----------------------|----------------------------------|
| “No, I think if there is no wind, it does not force on the bicycle.” (C₁) | “You cannot stand on a bicycle without pedaling, or braking, we would fall, unless we go down a hill.” (P₆₁) |
| “If there is a slope, yes.” (C₁₆) | “No, there is no force on the bicycle because the person does not pedal and does not brake.” (P₆₃) |
| “No. Because there is no wind, the bicycle can not advance.” (C₃₉) | |

Note that only a few pre-service teachers (11%) referred to the friction force between the tires and the ground. Also, for a few of them (3%) there is no force applied since the car is not moving forward comparatively to children (24%). Similarly, 30% of the pre-service teachers and 21% of the children explain the bicycle continues movement after the person has stopped pedaling by referring to the force that he applied on pedaling. This false conception is like that one developed within the impetus Buridan’s theory (“intrinsic force” that keeps things moving). On this subject note that some student in Physics (high school and university) have this false conception even after taking several courses on the Newtonian Physics [14]. After all, for many children (43%), no force applies on the bicycle since it does not wind, and the person does not use the pedal. So, for them, the movement requires the application of force. In the case of pre-service teachers, only 14% have this misconception.

3.3 Construction of the third question and the categorization of the data

Let’s suppose that an object moves under the action of several forces. If one removes them all, it will slow down and will stop. True or wrong? This question associated with the law of inertia in which the rectilinear movement at constant speed requires no force. Thus, the object will continue to move with the speed he had at the moment we have removed all forces. The analysis of the data has permitted us to identify five categories of answers. Table 4 summarises each one, followed by illustrative of some children and pre-service teachers’ responses.
Table 4. Categorization of children and preservice teacher’s answers to Question 3.

| Category | Description | Children (Percentage) | Pre-service teachers (Percentage) |
|----------|-------------|-----------------------|-----------------------------------|
| Category 1: If we remove all the forces, the movement of the object will slow down and stops. | “True because the weight that forces gave decreases gradually and slow the movement of the object and stop.” (C20) | "Yes, if there is no more force to advance the object, the object will slowly lose what it has stored and then stop.” (P58) |
| | “True because it cannot stop instantly.” (C23) | “True, for if there is no more force, the object in question will slow down and finally come to rest.” (P73) |
| | “True, when the force decreased, the object slows.” (C53) | |
| Category 2: At the moment when removing all forces, the movement of the object will stop. | “Yes, because these are the forces that move the object. If there is no force to move the object, then it will stop, right?” (C1) | “True, I believe that if an object does not undergo any force, it cannot move. So, it stays there.” (P55) |
| | “It will stop because it needs force to move forward and then we remove it, then it could not move forward.” (C2) | “In my opinion, it will stop abruptly.” (P72) |
| | “True, when we move an object, we give force, so if we do not give any, it will stop.” (C20) | “True, for the object without force to push it will remain in place.” (P61) |
| Category 3: By removing all forces, the gravitational force will stop the object. | “True, the weight of the object would stop it.” (P7) | |
| | “I suppose so. At any given moment, it will be under the effect of no force, except that of its weight which holds it to the ground.” (P60) | |
| Category 4: By removing all forces, the object will continue its movement. | “It will keep its speed constant until a new force arrives. Since it is the application of a force that produces acceleration and deceleration.” (P37) | |
| | “False, if no force and friction are present, the object will continue its trajectory.” (P35) | |
| Category 5: By removing all forces the object will stop. No explanation/No justification/Undecipherable. | “For the children (53%) and pre-service teachers (20%) when we removed all forces, the object continues to move for a brief instant and stops (category 1). This conception is false because according to the inertial law it continues its movement with constant velocity and rectilinear trajectory. For them, the object retains its action until the force applied is "used" entirely. The second category regrouped the children (38%) and pre-service teachers (28%) for whom the object will stop at the time we remove all forces (Aristotelian view). On the other hand, for 13% preservice teachers (category 3), the object will stop because of gravity. Thus, they did not consider the data of the problem since one removes all the forces applied. No pupil has given this false conception. Conclusively, 13% of pre-service teachers regrouped in the fourth category; the car continues its movement at a constant speed when we remove all forces. This answer is correct according to the law of inertia." (P28) |
| | Children (5/58-9%) | Pre-service teachers (22/85-26%) |
3.4 Construction of the fourth question and the categorization of the data
When one applies a constant force on an object, will it move at a constant speed? This question is constructed to see what relationship children and pre-service teachers develop the concepts of force and speed. According to Aristotle's conception of the motion, the force is related to the speed. Since Newton's work on the movement, we know that the force is associated with the acceleration (the rate of change in velocity). Thus, in Newtonian's view when the resultant force applied to a given body is null, the object moves in a straight line at a constant speed or is not in movement (First law of Newton: Inertia). Table 5 summarises the three categories identified responses, followed illustrative of some pupils and pre-service teachers’ responses. Note that we characterized two subcategories in the Category 5 and Category 2.

Table 5. Categorization of children and pre-service teacher’s answers to Question 4.

| Category 1: When one applies a constant force on an object, it will move at a constant speed. |
|---------------------------------------------------------------|
| Children (30/58-52%) | Pre-service teachers (46/85-54%) |
| **Subcategory 1.1: A constant force is applied - We always apply the same speed - The more you force, the more speed you have - Because it is the force that moves the object.** |
| Children (25/30-27%) | Pre-service teachers (27/46-59%) |
| “Yes, because we applied a constant force on the object.” (C17) | “Yes, since there is no acceleration.” (P1) |
| “Yes, because if I push the object, for sure it will go at the same speed as I pushed.” (C21) | “Yes, the force constant controls the speed of the object.” (P29) |
| Subcategory 1.2: No justification - Incomplete – Indecipherable. |
| Children (5/30-17%) | Pre-service teachers (19/46-41%) |
| Category 2: When applying a constant force on an object, it will not move at a constant speed. |
| Children (20/58-34%) | Pre-service teachers (24/85-28%) |
| **Subcategory 2.1: Because it will depend on its weight.** |
| Children (25/20-27%) | Pre-service teachers: (27/24-59%) |
| “It depends on the object. If it’s an eraser yes, but if it is a bus, no.” (C14) | “The more you apply force, the longer the object will move. It also depends on the volume of the object.” (P3) |
| “No, because if the object is heavy and you will put all your strength, it will not advance more quickly.” (C15) | “No, by his weight, he will gain speed.” (P24) |
| Subcategory 2.2: Indecipherable – No justification – Incomplete. |
| Children (13/20 - 65%) | Pre-service teachers (10/24 - 42%) |
| Category 3: No response or indecipherable reply. |
| Children (8/58 - 14%) | Pre-service teachers (15/85 - 18%) |

3.5 Construction of the fifth question and the categorization of the data
When a golf player throws his ball, is there a force that applies to it once it is launched? This question relates to whether for children and pre-service teachers, the force applied by the player maintains the movement of the ball for a while after launch. This view is erroneous, and it looks like the idea developed by Buridan in his theory of impetus: when a player throws his golf ball, after the launch, the force applied is transferred to the ball. Table 6 summarises the seven categories identified responses, followed illustrative of some children’s and pre-service teachers’ responses.
### Table 6. Categorization of children and pre-service teacher’s answers to Question 5.

| Category 1: The force given to the ball during the throw is transferred to the ball. |  |
|----------------------------------|----------------------------------|
| Children (18/45 - 45%) | Pre-service teachers (17/85 - 20%) |
| “Yes, the force that the player put above to strike it.” (C₃) | “Yes, the initial force applied by the golfer's shot.” (P₈) |
| “Yes, the force he has given for the launch.” (C₁₅) | “Yes. The golfer's striking force sent the ball to such a distance but when it reached its "maximum", it dropped.” (P₂₇) |
| “Yes, because the force applied by the player makes the ball continue to fly in the air.” (C₁₆) | “Yes, there is a force transmitted on the ball from the player.” (P₄₅) |
| “This is the force of the player because he wants the ball to go further.” (C₂₄) |  |
| “Yes. When the ball is launched, it will travel with the force of the golfer, and there will be pressure on the ball.” (C₃₃) |  |

| Category 2: When a golf player throws the ball, the wind exerts a force on ball. |  |
|----------------------------------|----------------------------------|
| Children (12/45 - 27%) | Pre-service teachers (9/85 - 11%) |
| “Yes, the wind pushes since it is light.” (C₈) | “The air comes to exert a force, even if it is not visible. If there was no air the ball would never stop because there would be nothing to stop it as in space.” (P₇₀) |
| “The air since it is not very aerodynamic, air produces a pressure on the ball.” (C₄₈) | “Yes, there is a force. In my opinion, it is the force of the air.” (P₇₄) |
| “Yes, because the ball flies through the air.” (C₅₈) |  |

| Category 3: When a golf player throws the ball, two forces applied on the ball: the gravitational force and the force given to the ball by the player during the throw. |  |
|----------------------------------|----------------------------------|
| Children (0/45 - 0%) | Pre-service teachers (23/85 - 27%) |
| “The gravitational force and the force exerted initially influence the ball.” (P₅) | “Yes, the force applied by the player and gravity.” (P₉₀) |

| Category 4: When a golf player throws the ball, two forces applied on the ball: the gravitational force and the wind force (or friction) exerts on the ball. |  |
|----------------------------------|----------------------------------|
| Children (0/45 - 0%) | Pre-service teachers (15/85 - 17%) |
| “Yes, the friction of the air which makes it decelerate and the force of gravitation which makes it fall. If these two forces were not present, the ball would continue its projection constantly.” (P₅₄) |  |

| Category 5: When a golf player throws the ball, the gravity exerts a force on the ball. |  |
|----------------------------------|----------------------------------|
| Children (6/45 - 13%) | Pre-service teachers (12/85 - 14%) |
| “Yes, the force of gravity because the ball will descend.” (C₂₁) | “Yes, it is the force of attraction towards the earth.” (P₉₉) |
| “Yes, the force of gravity otherwise the ball fly and could go around the world several times.” (C₃) | “Yes, the force of attraction. Projected upwards, it always ends up falling to the ground.” (P₉₆) |

| Category 6: When a golf player throws his ball, there is not a force that applies to it once it is launched. |  |
|----------------------------------|----------------------------------|
| Children (7/45 - 14%) | Pre-service teachers (5/85 - 6%) |
| “No, because it is at the beginning that the force is applied.” (C₂) | “No, there was a force when it was launched only. It will go far if there has been a great strength.” (P₂₂) |
| “No! The force was when the player launched the ball.” (C₉) | “There is not any force that applies to it: it will slow down and eventually fall. If there was a  |
“The force is applied to it in contact with the stick, but I think when it is in the air, it is only the power of his stick.” (E22) force it would continue its ascent, until there was no force.” (P79)

Category 7: No answer or do not know.

| Children (15/58 - 26%) | Pre-service teachers (4/85 - 5%) |

4. Summary of the results and conclusion

A tiny percentage of children and pre-service teachers answered correctly, based on scientific reasoning. The majority have provided incorrect answers. Their conceptions appear irreconcilable with those developed in classical mechanics by Newton. Table 7 lists the most critical misconceptions which encountered implicitly or explicitly during this study.

Table 7. Children and pre-service elementary teacher's misconceptions and scientifically acceptable conceptions.

| Misconceptions                                             | Scientifically acceptable conceptions                                      |
|------------------------------------------------------------|--------------------------------------------------------------------------|
| The motion requires the continuous application of force.   | The rectilinear motion at constant speed requires no force.             |
| A force produces motion.                                   | A force produces acceleration.                                           |
| In the absence of force, the object is at rest.            | The resultant of the forces applied to an object that moves in a straight line and at a constant speed is null. |
| The force acting on an objet is proportional to the speed (F = m.v) | The net force F is proportional to the acceleration of an object (F = m.a). |
| Zero acceleration means zero velocity.                     | Zero acceleration means that the object will maintain the velocity it happens to have, neither slowing down nor speeding up nor changing direction. |
| Most things that are in our environment must be pushed or pulled to overcome gravitation. | Most things that are in our environment must be pushed or pulled to overcome friction. |
| Force is a quantity.                                       | Force is a vector quantity (both magnitude and direction).               |
| When a car is at rest on a ground (not moving), other than the force of gravity, there are no other forces acting on it. | The gravitational interaction between the car and the Earth consists of a pair of equal and opposite forces; one is the Earth pulling down on the car, the other is the car pulling up on the Earth. |

The poor performance of the children in tests is not surprising: it is well established that the everyday language often leads children to have views, about force and motion that are not explicit as the scientist language. Also, their conceptual difficulties result from their experiment with friction. However, we were surprised to see that the pre-service teachers’ conceptions did not evolve towards scientific views despite education over several years. In this context, it is impossible for these future teachers to create appropriate instruction about force and motion as prescribed in the curriculum of the elementary school. It is therefore essential that the prospective teachers be aware of their misconceptions to address them.
5. Appendix : Paper and pencil questionnaire

Question #1
Someone is trying to push his car, but unfortunately, doesn’t succeed. According to you, is there a force that applies itself to the car? Explain the answer.

Question #2
On a sunny day without wind, a person moves on its bicycle along a straight road (without a slope). When he ceases to peddle, and without using his brakes, the bike continues to move going slower during a certain amount of time. According to you, is there still a force that applied to the bicycle during its slower movement?

Question #3
Let’s suppose that an object moves under the action of several forces. If one removes them all, it will slow down and will stop. True or false? Explain your answer.

Question #4
When one applies a constant force on an object, will it move at a constant speed? Explain your answer.

Question #5
When a golf player throws his ball, as illustrated, is there a force that applies to it once it is launched? Explain your answer.
6. References

[1] Hast M and Hestenes D 2012 Understanding the beliefs informing children’s commonsense theories of motion: the role of everyday object variables in dynamic event predictions Research in Science & Technological Education 30 3-15

[2] Halloun I A and Hestenes D 1985 Common sense concepts about motion American Journal of Physics 53 1056-1065

[3] Gunstone R F and Watts D.M 1985 Force and Motion. In R. Driver, E. Guesne, and A. Tiberghien (dir.), Children’s Ideas in Science, (85-104). Buckingham, England: Open University Press.

[4] Watts D M and Zylbersztajn A 1981 A survey of some children’s ideas about force Physics Education, 16 360-365

[5] Kozhevnikov M and Hegaty M 2001 Impetus beliefs as default heuristics: Dissociation between explicit and implicit knowledge about motion Psychonomic Bulletin & Review 8 439-453

[6] Sequeira M and Leite L 1991 Alternative conceptions and history of science in physics teacher education Science Education 75 45-56

[7] McCloskey M and Kohl D 1983 Naive physics: The curvilinear impetus principles and its role in interactions with moving objects Journal of Experimental Psychology: Learning, Memory, & Cognition 9 146-156

[8] Clement J 1982 Students’ preconceptions in introductory mechanics American Journal of Physics 50 66-71

[9] Zeilik M Schau C and Mattern N 1998 Misconceptions and their change in university-level astronomy courses The Physics Teacher 36 104-107

[10] Halloun I. A. and Hestenes D 1985 The initial knowledge state of college physics students American Journal of Physics 53 1043

[11] Bayraktar S 2009 Misconceptions of Turkish pre-service teachers about force and motion International Journal of Science and Mathematics Education 7 273-291

[12] Kruger C Palacio D and Summers M 1992 Surveys of English primary teachers' conceptions of force, energy, and materials Science Education 76 339-351

[13] Narjaikaew P 2013 Alternative Conceptions of Primary School Teachers of Science about Force and Motion. Procedia - Social and Behavioral Sciences 88 250-257

[14] Quebec Education Program (2009) Progression of Learning in Elementary School: http://www.education.gouv.qc.ca/fileadmin/site_web/documents/education/jeunes/pfeq/PFEQ_science-technologie-primaire_2009_EN.pdf