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Abstract We looked at how far students aged 10–17 years differentiate between the *force* and *energy* concepts for animates and inanimates. Within a structured interview format, participants described situations in which inanimate objects and animate agents interacted. Results showed that the younger students made no distinction between the two concepts for the *inanimate objects*. They regarded force and energy as the objects' intrinsic properties, related to their height and weight, and tended to attribute both concepts to animates rather than to inanimates. With age, force came to be seen in terms of interactions, while energy continued to be considered in relation to the physical dimensions that affected it (i.e., height or weight). Even so, force continued to impinge on energy, the reverse being less frequent. Conceptions remained unchanged for the *animate agents*, insofar as younger and older students alike expressed undifferentiated force/energy conceptions, relating both force and energy to the agents' effort or the results of their action.

Keywords Force · Energy · Conceptual development · Differentiation · Inanimate · Animate

Development of the Concepts of *Force* and *Energy*

A great many investigations of students' conceptions of force and energy have reported comprehension difficulties (e.g., Brook and Driver 1984; Domenech et al. 2007; Gyberg and Lee 2010; Ioannides and Vosniadou 2002; Koliopoulos and Argyropoulou 2011; Lee and Liu 2010; Megalakaki and Tiberghien 2011; Neumann et al. 2013; Pauen 1996; Solomon 1992; Trumper 1998; Watts 1983). In previous studies, force and energy were studied separately. Our goal was thus to use the same experimental situations for both force and energy, in order to highlight common underlying conceptions or misconceptions (if any) and any conceptual differences between the two concepts.

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Research on the acquisition of the energy and force concepts has revealed more developmental difficulties for the former than for the latter. For the energy concept, it has been shown that *younger pupils* have anthropocentric and vitalistic misconceptions, that is, they frequently associate energy with living things, movement, and the ability to perform actions. Young children acknowledge that nonliving things have energy, but only when their function is to store energy (e.g., batteries). High school and college students have a "tendency to consider energy as something producing actions and effects and thus consuming itself, rather than to use energy conservation and degradation to explain phenomena" (Besson and De Ambrosis 2014, p. 1310). In middle-school students, Lee and Liu (2010) described a learning progression, from energy sources to energy transformation and, last, to energy conservation. For their part, Neumann et al. (2013) developed the Energy Concept Assessment (ECA) to assess the understanding of sixth, eighth, and tenth graders. This indicated that sixth graders understand different forms of energy and energy sources, and eighth graders understand energy transfer and transformation, while only a minority of tenth graders displayed a deeper understanding of energy conservation.

For the force concept, results show a gradual shift towards the scientific conception. Pauen (1996) asked 6- to 11-year olds to predict the direction of an object being pulled by two forces. Results revealed a developmental progression from referring to only one relevant aspect (amount or direction) to integrating both aspects. In a study with 4- to 15-year-old children, Ioannides and Vosniadou (2002) found that for the younger children, force was an internal property of objects, while for the older children, force was an acquired property of objects that move. By the age of 12, children were able to understand the push/pull force and gravity.

In order to explain comprehension difficulties, it has been suggested that knowledge acquisition does not simply amount to the accumulation of novel information in conceptual domains. Rather, acquisition involves the conceptual restructuring of individuals' cognitive structures, subtended by a system of beliefs, observations, and ontological (Chi et al. 1994) and epistemological presuppositions (Vosniadou 1994). The resulting cognitive structures are "counter-intuitive and violate basic principles of naive physics based on everyday experience and lay culture" (Vosniadou and Skopeliti 2014, p. 1428). Depending on the viewpoint, students' misconceptions have been described as "complex dynamic systems" "dynamically emergent from the interactions of conceptual resources" (Brown 2014, p. 1473), and involving a number of interacting factors that contribute to the overall relational complexity of the system (Halford 1999; Halford et al. 1998).

More specifically, in order to explain the difficulties students have understanding the energy and force concepts, some researchers refer to a developmental sequence of hierarchical complexity. For example, Dawson (2006) talks about a set of stages of abstractness and a sequence of complexity levels: representational systems, single abstractions, and abstract mappings. At the representational systems level, children provide elaborate observations of movements, but use motion and energy in an undifferentiated way. At the single abstraction level, they understand "potential energy as the potential for energy to happen" but understanding energy transfer requires them to reach the abstract mapping level (understanding kinetic and potential energy as different energy states). Likewise, Lee and Liu (2009) have proposed a *knowledge integration* perspective, whereby the energy conservation concept requires a higher level of knowledge integration, allowing connecting ideas to explain a phenomenon. Difficulties understanding force have been attributed to "general age-related limits of information-processing capabilities" (Pauen 1996, p. 2741), the difficulty of considering several relevant dimensions of information simultaneously (Piaget 1929), and the fact that "people can make effective use of only one salient dimension of information present in the event" (Proffitt and Gilden 1989, p. 384). Thus, as Pauen (1996) points out, "it may well be that such limits make it hard for people of all ages to evaluate complex dynamic situations in terms of all relevant components" (p. 2741). Because of these persisting difficulties in achieving a more integrated understanding of physics concepts, Opitz et al. (2014) have called for a more explicit approach to teaching.

Differentiation of Force and Energy as a Process of Conceptual Change

For Carey (1991), the conceptual change that occurs in the course of development is mediated by three processes: *replacement* (when one paradigm is replaced by a radically different one), *coalescence* (when many concepts coalesce into a single conceptual unit), and *differentiation* (when one overall concept is later broken down into more specific ones). In the case of the energy and force concepts, we will see that the key issue is differentiation. Famous examples of differentiation include Galileo's distinction between average velocity and instantaneous velocity (Kuhn 1977), and Black's differentiation of heat from temperature (Wiser and Carey 1983). For instance, science education researchers have found that students use the terms *heat* and *temperature* interchangeably (Halliday et al. 2003; Wiser 1986; Wiser and Amin 2001; Wiser and Carey 1983).

According to Piaget and Inhelder (1974)'s view of conceptual differentiation, children initially have just a diffuse, undifferentiated concept of global quantity, and only later construct differentiated concepts of, for example, size and weight, or weight and density. While undifferentiated concepts are said to be "diffuse, syncretic, and holistic relative to their descendants," differentiated ones are "discrete and analyzable in terms of components" (Smith et al. 1985, p. 179). These authors explored conceptual shift in the context of theory change. They concluded that:

> The components of an undifferentiated concept function as a single, integrated unit within the theory. This means that there should be no distinguishable contexts in which the components are separately and systematically applied. Further, there should be some contexts in which both components are concurrently and unsystematically applied to understanding the same phenomena, leading to what looks like confusion relative to later conceptual states. (Smith et al. 1985, p. 184)

Concerning the force and energy concepts, even though they have to date been studied separately, we can nonetheless assume that they are undifferentiated, given that researchers have found them to suffer from similar misconceptions. The first of these more frequent misconceptions, according to which *energy is synonymous with force* and vice versa (Brook and Driver 1984; Duit 1987; Ioannides and Vosniadou 2002; Kruger et al. 1992; Viennot 2001; Watts and Gilbert 1983) underscores the lack of differentiation. As a consequence, the two concepts are used interchangeably: "force is the energy that's inside objects," "force… is what energy does," "humans use force to do things," and "energy is a force produced by our muscles." The term *force* often corresponds to what scientists would call *kinetic energy* (Lijnse 1990; Megalakaki 2008, 2009).

Two further frequent misconceptions are that *force and energy are associated with movement—or with living things*. Concerning the misconception that relates force and energy to movement, research has shown that the currently accepted Newtonian theory of force is difficult for children to understand, and there is a persistent misconception that force is related to the motion of inanimate objects. Thus, children, and even adults, believe that motion implies force (Clement 1982) and that the amount of motion is proportional to the amount of force applied (e.g., Bayraktar 2009; Clement 1982; Minstrell 1982; Osborne and Freyberg 1985). In a typical experimental design, an object is set in motion by an agent (e.g., a coin is thrown vertically upward; Clement 1982; or a golf ball is hit by a golfer; Osborne and Freyberg 1985), and questions are then asked about that object. For example, Osborne and Freyberg asked children and adolescents aged 7-19 years what forces were being exerted on a golf ball moving through the air some considerable distance away from the golfer who had hit it. One common response from the 13-year olds was that "the force from when the golfer hit the ball is still inside it." This response indicated that the participants thought the moving object contained a force, explaining its motion. The source of this force was usually identified as the original mover.

By the same token, children believe that if an object is not moving, then no force is being exerted on it (Clement 1982; Minstrell 1982; Osborne and Freyberg 1985). For example, Minstrell (1982) showed high school students a drawing of a book lying ("at rest") on a table, and asked them to draw vectors representing the forces being exerted on it. Half the students answered that the only force being exerted on the book was the force of gravity, forgetting to mention the force being exerted by the table. In the case of energy, a similar misconception associates energy with motion (Brook and Driver 1984; Kruger et al. 1992; Solomon 1992; Stead 1980; Watts 1983), rather than with height. One consequence of this misconception is that when an object is at rest, participants may well conclude that "there is no energy exerted on the object" or that "no force is exerted" (Clement 1982; Finegold and Gorsky 1991; Gustone and Watts 1985; Kruger et al. 1992; McCloskey 1983; Minstrell 1982; Osborne and Freyberg 1985; Viennot 1979; Watts and Zylberstajn 1981).

According to the third shared misconception, force and energy are often associated solely with living things, owing to what we could call a vitalistic—or anthropocentric —misconception (Gustone and Watts 1985). In the case of force, for example, Duit (1984) looked at the influence of everyday language on the ways in which schoolchildren form conceptions. He identified two meanings of the word force: the first related to "physical, muscular strength," while the second referred to "a general power to bring something about." Similarly, energy is associated with human beings or with other living objects to which human characteristics are attributed (Black and Solomon 1983; Inagaki and Hatano 2004; Kruger et al. 1992; Küçük et al. 2005; Mann and Treagust 2010; Solomon 1992; Watts 1983). In this conception, energy is given a biological slant. Children think that living things need energy to live and be active, and they relate energy to fitness, exercise, food and strength, such that a lack of energy is associated with being tired or unfit (Stead 1980). Black and Solomon found that the proportion of students who associate energy solely with living things decreases with age. As they grow older, students begin to express more general conceptualizations encompassing *nonliving* notions such as electricity, power stations, moving objects, lightning, sun, or fire. Energy thus becomes a measurable attribute of all things.

Contribution of the Present Study

As indicated earlier, the concepts of force and energy have always been investigated separately to date. However, the existence of shared misconceptions, described above, underscores the importance of analyzing changes in these two concepts in the same study in order to see how the conceptual relationship between them is modified in the course of development. Thus, unlike previous studies, we asked the same questions, pertaining to the same situations, about both force and energy, in order to find out whether the students differentiated between these two concepts or whether they used them interchangeably. If they did not differentiate between them, this would raise the question of which concept dominates the other. Furthermore, unlike in previous studies, where the questions only concerned inanimate objects, we explored these two concepts in terms of interactions between animate agents and inanimate objects, asking questions about force and energy in relation to both the animates and the inanimates. Our aim was to gather information regarding common misconceptions and commonalities and differences in the conceptual structures underlying these misconceptions.

Aim and Hypotheses of the Present Study

The aim of the present study was to investigate how students differentiate between the concepts of force and energy, if indeed they do, with regard to animate agents and inanimate objects. To this end, we used the same set of physics problems to probe both concepts, investigating the nature of the students' conceptions of force and energy between the ages of 10 and 17 years.

We reasoned that if the students used the same conceptions for both force and energy to interpret the given problems, emphasizing the box's properties (its weight and/or position) in the case of the inanimate object, and the result of the agent action and physical characteristics (man/boy's) in the case of the animate, this would indicate a lack of differentiation between the two concepts.

Concept differentiation, in the case of the *inanimate* objects, would involve students consistently viewing the concept of force in terms of interaction, paying no attention to the object's height or motion. For *energy*, participants should consistently take the object's position into account, explaining the concept in terms of the relationship between weight and height. In the case of the *animate* agents, there would be no difference between the three situations as the net force exerted by the agent would be the same throughout. Energy would be explained in terms of the relationship between height and weight, and the notion of transfer.

For *inanimates*, we predicted that the students would attribute more force or energy to a moving object than to a motionless one (first situation) and more force or energy to a high object than to a low one (second situation). For example, if, for the first situation, the students considered both force and energy to be proportional to motion, arguing that an object raised off the ground has more force/energy, and if, for the second situation, they considered both concepts in relation to the height of the object, this would indicate a lack of differentiation between the two.

Following the same logic, we predicted that students would regard both force and energy as the properties of animate objects. For example, we would take these two concepts to be undifferentiated if, for the first situation, the students considered both force and energy to be proportional to the result of the agent's action, that is, whether or not he actually managed to raise the object. We would draw the same conclusion if, for the second situation, they considered there to be more force or more energy when the agent lifted the object higher, and if, for the third situation, they considered both force and energy to be proportional to the agent's characteristics (i.e., more force/energy ascribed to the adult than to the child).

With age, and under the influence of instruction, we predicted that the two concepts would gradually become differentiated for inanimates. Initially, the youngest students would make no distinction between force and energy. They would use materialistic conceptions common to both concepts and based on the objects' intrinsic properties, such as weight and position. With age, however, our participants would come to distinguish between the two concepts, regarding force in terms of interactions, and energy in relation to the physical properties that determine it (i.e., height+weight). For *animates*, we predicted that the two concepts would be harder to differentiate. Both concepts would be defined according to the agent's efforts and results.

Method

Participants

Our sample consisted of 90 middle-class students (aged 10-17 years), all from the same suburb of Amiens in northern France. They were randomly divided into two equal groups. The first group answered the questions on force, the second the questions on energy. Each group (force vs. energy) included 15 students from the fifth grade, aged 10 years and 1 month to 11 years and 3 months (mean age 10 years and 3 months), 15 students from ninth grade, aged 14 to 15 years and 10 months (mean age 14 years and 4 months) and 15 from the 11th grade, aged 16 to 17 years and 8 months (mean age 16 years and 7 months). The students selected to take part in our experiment had neither repeated nor skipped a grade.

In French elementary schools, force and energy are generally taught with simple examples concerning the position of objects, energy sources, energy needs, consumption, and saving energy. In the ninth grade, both concepts are part of the curriculum: force is introduced through notions regarding movements and forces that are exerted, while energy is introduced through ideas of energy forms, energy transformations, and transfer. In the 11th grade, force is introduced through notions of movement trajectories, velocity and acceleration, while energy is introduced via energy chains and energy conservation.

Design of the Situations and Their Rationale

We designed three experimental situations, each involving an interaction between an animate agent and an inanimate object (see Table 1). These situations were based on previous findings that revealed common misconceptions for force and energy concepts (used as *synonymous*, associated with *moving objects*, and attributed to *animate objects* rather than inanimate ones*)*.

In order to systematically study whether the *movement misconception* is shared by both concepts, we manipulated this variable by comparing situations in which objects were either on the ground or in mid-air (first situation, see Table 1). In this situation, which was illustrated by two successive pictures, a man tried to raise a box off the ground using a rope and pulley. This enabled us to study participants' explanation for an object *on the ground* moving to *suspended in mid-air* as a result of an agent's action, in terms of force and energy.

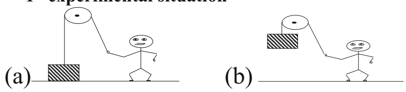
As one widespread misconception is that gravitational potential energy depends solely on the height of an object, we also manipulated the object height variable (second situation, an extension of the first one, see Table 1) in order to find out whether this is another misconception shared by both concepts. In this situation, illustrated by two pictures side by side, two identical men were shown raising objects to different heights. We looked at how children explained differences in the object's height in terms of force or energy. The third situation, also illustrated by two pictures side by side (Table 1), was designed to investigate whether participants thought that force and energy were proportional to the agent's physical characteristics. We manipulated the latter by showing two identical boxes being raised to the same height, one by a man, the other by a child. Likewise, in order to study how the presence of an animate agent might influence the students' interpretations, we manipulated the agent's actions. In the first situation, there were actions with or without results. In the second situation, actions might have had different results or the objects might have been raised to different heights. In the third situation, we manipulated the physical characteristics of the agent (i.e., a man or a child).

Procedure

In our study, we conducted a structured interview. Participants were interviewed individually for approximately 30 min. The order in which the three experimental situations were presented was counterbalanced, but the questions were always posed in the same order for each situation (see Table 1). The students in the force group had to say whether or not any forces were

Table 1 Force/energy questionnaire for the animate and inanimate objects in the three experimental situations, and scientific responses

1st experimental situation



A man tries to lift the box using a rope and pulley, but the box does not move. Finally, the man manages to lift the box.

FORCE	**ENERGY**
Questions for the inanimate object	
1.1 Are any forces exerted on the box when it is on the ground (Fig. 1a)? If so, which ones? ***Scientific response:*** *Yes, the man's force, the object's weight and the ground's reaction.* (ΣF=Fman+Freaction-Weight=0)	**1.1** Is there any energy in the box when it is on the ground (Fig. 1a)? What kind of energy? ***Scientific Response:*** *No energy, as the object is on the ground.*
1.2 Are any forces exerted on the box when it is lifted up (Fig. 1b)? If so, which ones? ***Response:*** *Yes, the man's force and the object's weight.*	**1.2** Is there any energy in the box when it is lifted up (Fig. 1b)? Why? What kind of energy? ***Response:*** *Yes, potential energy.*
1.3 Are the forces exerted in Figures 1a and 1b equal or different? Why? ***Response:*** *The forces exerted are different, but the net force is equal to zero in both cases.*	**1.3** Is the energy equal or different in Figures 1a and 1b? Why? ***Response:*** *Potential energy only when the object is in the air.* (PE=mgh) PE: potential energy (in joules); m: mass (in kilograms); g: Earth's gravitational acceleration (9.8 m/s^2); h: height above Earth's surface (in m)
Questions for the animate agent	
1.4 Is the man exerting any forces on the box in Figure 1a? Why? ***Response:*** *Yes, a force smaller or equal to the weight of the box.*	**1.4** Is the man consuming any energy in Figure 1a? Why? If so, what kind of energy? ***Response:*** *Yes, chemical energy, less than what is needed to lift the box (converted into kinetic and potential energy), so it is transformed into heat between the hands and the rope.*
1.5 Is the man exerting any forces on the box in Figure 1b? Why? ***Response:*** *Yes, a force greater than the weight of the object in order to raise it and then equal to it in order to keep it up in the air.*	**1.5** Is the man consuming energy in Figure 1b? Why? If so, what kind of energy? ***Response:*** *Yes, chemical energy, to maintain the object's potential energy* (PE=mgh).
1.6 Is the man exerting equal or different forces in Figures 1a and 1b? Why? ***Response:*** *More in (b) because the man's force must be greater than the weight of the object in order to lift it.*	**1.6** Is the man consuming equal or different amounts of energy in Figures 1a and 1b? Why? ***Response:*** *Less energy is consumed per unit of time in (a) than in (b), by analogy with force.*

exerted on the objects, and if so, what types of forces. They were also asked whether these forces were the same or different for each of the two pictures illustrating the situation and whether or not the agent was exerting force on the object. In each case, they were asked to justify their answers. Similarly, the students in the energy group had to say whether the object had energy, why, what type of energy, and whether the amount of energy was the same in both

Table 1 (continued)

2nd experimental situation	
 (a) (b) A man lifts a box with a rope and pulley. In both cases, the man and the object are the same. Only the height of the object is different.	
Questions for the inanimate object	
FORCE	**ENERGY**
2.1 Are any forces exerted on the boxes in Figures 2a and 2b? If so, which ones? ***Response:*** *Yes, the man's force and the object's weight.*	**2.1** Does the object have any energy in Figures 2a and 2b? If so, what type of energy? ***Response:*** *Yes, potential energy.*
2.2 Are the forces exerted in Figures 2a and 2b the same or different? Why? ***Response:*** *The forces exerted are the same and the net force is equal to 0 in both cases.*	**2.2** Is the energy of the two boxes equal or different? If yes, why? If no, in which case is there more energy? Why? ***Response:*** *In Figure 2b, the object has more energy because it is higher* (PE=mgh).
Questions for the animate agent	
2.3 Is the man exerting force to lift the object in both cases? (If yes, 2.4) ***Response:*** *Yes, a force greater than the object's weight.*	**2.3** Did the man consume any energy to raise the object in both cases? (If, yes, 2.4). ***Response:*** *Yes.*
2.4 Is the man exerting the same amount of force in Figures 2a and 2b? Why? ***Response:*** *He is exerting the same force, as the object is the same in both cases.*	**2.4** Did the man consume the same amount of energy to raise the object to its final position? If not, in which case did he need more energy? Why? ***Response:*** *When there is motion, the energy consumed by the agent is transferred to the object in the form of potential energy. The man therefore needed more energy in (b).*

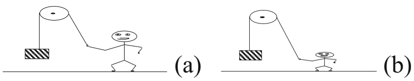
pictures illustrating the situation in question. They were also asked whether the agent consumed energy, and if so, what type of energy, why, and whether the same amount of energy was consumed in both pictures. Each time participants gave short answers such as "yes" or "no," they were prompted to elaborate further and to justify their response.

The interviews were audiotaped, and the data analysis was based on transcriptions. It should be noted that one limitation of the interview research method is that it only activates part of participants' knowledge. In future research, it would be interesting to add scientific inquiry tasks tapping more specific areas of students' knowledge, in order to test more specific hypotheses regarding their knowledge.

Coding Criteria and Statistical Analysis

For the present study, we used coding criteria adapted from Ioannides and Vosniadou (2002) and Vosniadou and Brewer (1992). These coding criteria were therefore constructed by the authors and should be viewed as constructs. We coded students' responses for animates and inanimates separately. In both cases, this resulted in a set of four conceptions (see Appendix 1 for defining criteria and examples for inanimate objects and Appendix 2 for defining criteria and examples for animate agents). It is important to emphasize that in every situation, we used the same coding system for *force* as for *energy*. This allowed us to compare answers for these

Table 1 (continued)

3rd experimental situation	
 A man (a) and a child (b) hold a box up in the air with a rope and pulley. The objects are identical in both figures and are kept at the same height.	
Questions for the inanimate object	
FORCE	**ENERGY**
3.1 Are any forces exerted on the two boxes? If so, which ones? ***Response:*** *Yes, the man's and the child's forces and the object's weight.*	**3.1** Is there any energy in the two boxes? If so, what kind of energy? ***Response:*** Yes, *potential energy.*
3.2 Are the forces exerted on the object equal or different? Why? ***Response:*** *Equal forces (identical boxes)*.	**3.2** Is the object's energy equal or different in Figures 3a and 3b? Why? ***Response:*** *Equal potential energy (identical weight and height in both cases).* (PE=mgh)
Questions for the animate agent	
3.3 Are the man and the child exerting any force to keep the box in the air? ***Response:*** *Yes*	**3.3** Are the man and the child consuming any energy to keep the box in the air? ***Response:*** *Yes*
3.4 Are the man and the child exerting equal or different forces? Why? ***Response:*** *Yes, equal forces (identical boxes).*	**3.4** Are the man and the child consuming equal amounts of energy to keep the box in the air? If not, who is consuming the most energy? Why? ***Response:*** *Equal energy (identical boxes, same height). The man is stronger than the child, but this only means that he finds it easier to raise the box. We must not confuse the consequences of a situation with the energy conservation principle.*

two notions on the basis of the same set of conceptions, which was the central purpose of our study.

According to the first *inanimate* conception (*Internal* and/or *Acquired*), force and energy were both intrinsic, material properties related to the object's weight, height, or both. It should be recalled that there were three questions for each experimental situation. Thus, we assigned each participant to one of the four conceptions on the basis of his/her answers to these questions. In the first experimental situation, we included students in the *Internal* and/or *Acquired* conception if they answered the first question by saying that "the box has force because it's heavy," the second question by saying that "the box has force because it's up in the air," and the third question by saying that "the box has more force because it is up in the air" (see Appendix 1 for defining criteria and examples). It should be noted that participants' answers were consistent across all three questions for a given situation (i.e., all three answers illustrated the same conception).

We included students in the second conception (*Human action*) if they attributed force/energy solely to the animate agents, and thus referred solely to human action, even though the questions explicitly concerned the inanimate object: "The box doesn't have force/energy, it's the man who does, because he's trying to lift the box." Given that the situations we had constructed involved animate-inanimate interactions, if the students attributed force/energy exclusively to the animate agents, we took this as a sign of nondifferentiation.

We placed students in the third conception (*Many forces are exerted*) if they referred to several forces—though not necessarily all the forces—for both concepts (e.g., when the box was on the ground, some participants said that "two forces are being exerted: weight, man," forgetting the ground's reaction). We included students from the energy group in this conception if they used the concept of force instead of energy. Once again, we assumed that the use of this conception for both concepts would be a sign of nondifferentiation.

The fourth conception was the scientific one (only considered if all the answers for a given situation were correct).

For the animates, the first of the four conceptions referred to human action but only took its result into account (*Human action: result*). We placed students in this conception if at least one of their answers solely took the result of the human's action into account. This was the case if, for example, in the first situation, a student answered the first question by saying that "the man exerts force/consumes energy because he's trying to lift the box" and the second question by saying that "the man exerts more force/consumes more energy when the box is on the ground because it's heavy and he can't lift it" (see Appendix 2 for defining criteria and examples).

The second conception also referred to human action, this time taking only effort into account (*Human action: effort*). We included students in this conception when at least one of their answers solely took the agent's effort into account. If, for example, in the third situation, a student answered the first question by saying that "the man and the child exert forces/consume energy" and the second question by saying that "the child needs more force/energy because he's not as strong," it was the lowest score that indicated which category the student should be placed in.

The third conception referred to human action, and took both effort and result into account (*Human action: effort and result*). We included students in this conception if all their answers simultaneously took the man's effort and the result of his action into account, for example, "the man needs more force/energy when he successfully lifts the box."

For the fourth conception, corresponding to the scientific point of view, all the answers had to be correct.

All the answers were coded by two independent judges, and inter-rater agreement, calculated using Cohen's kappa coefficient, was 0.87.

To explore further the differentiation between the two concepts, we used Fisher's exact tests ($p<0.05$) to determine whether the four conceptions defined above were distributed in the same way across the answers participants gave for force and the answers they gave for energy. We carried out separate distribution comparisons for each of the three age groups, for each of the three situations, and for inanimates and animates. This made a total of 18 different analyses, that is 3 (groups)×3 (situations)×2 (inanimate vs. animate) (e.g., for fifth graders, one analysis compared answers for force (data in Table 2) with answers for energy (data in Table 3) for the inanimate object in the first situation).

Results

Differentiation Between Force and Energy in Relation to Inanimates

In the case of the inanimate objects, results failed to reveal any significant difference (Fisher's exact test, $p>0.05$) between force and energy among the younger students (fifth and ninth

Table 2 Force and energy in inanimates: numbers and percentages (in parentheses) of students' conceptions in the three experimental situations

	First situation			Second situation			Third situation		
Conceptions	5th	9th	11th	5th	9th	11th	5th	9th	11th
Force in inanimates									
1. Internal and/or acquired	7 (46.6)	4 (26.6)		11 (73.3)	3 (20)		5 (33.3)	1 (6.6)	
2. Human action	7 (46.6)	6 (40)		4 (26.6)	7 (46.6)		10 (66.6)	6 (40)	1 (6.6)
3. Many forces are exerted	1 (6.6)	5 (33.3)	13 (86.6)		5 (33.3)	15 (100)		6 (40)	10 (66.6)
4. Scientific			2 (13.3)					2 (13.3)	4 (26.6)
Total	15	15	15	15	15	15	15	15	15
Energy in inanimates									
1. Internal and/or acquired	4 (26.6)	6 (40)	5 (33.3)	5 (33.3)	6 (40)	8 (53.3)	8 (53.3)	6 (40)	5 (33.3)
2. Human action	11 (73.3)	6 (40)		10 (66.6)	7 (46.6)	2 (13.3)	6 (40)	5 (33.3)	
3. Many forces are exerted		3 (20)	7 (46.6)		1 (6.6)		1 (6.6)	3 (20)	3 (20)
4. Scientific			3 (20)			5 (33.3)		1 (6.6)	7 (46.6)
Total	15	15	15	15	15	15	15	15	15

Table 3 Force and energy in animates: numbers and percentages (in parentheses) of students' conceptions in the three experimental situations

Conceptions	First situation			Second situation			Third situation		
	5th	9th	11th	5th	9th	11th	5th	9th	11th
Force in animates									
1. Human action: result	4 (26.6)		1 (6.6)	2 (13.3)	2 (13.3)				
2. Human action: effort							8 (53.3)	9 (60)	2 (13.3)
3. Human action: effort and result	11 (73.3)	15 (100)	12 (80)	13 (86.6)	13 (86.6)	13 (86.6)	5 (33.3)	6 (40)	7 (46.6)
4. Scientific			2 (13.3)			2 (13.3)	2 (13.3)		6 (40)
Total	15	15	15	15	15	15	15	15	15
Energy in animates									
1. Human action: result	6 (40)	8 (53.3)	3 (20)	4 (26.6)	2 (13.3)				
2. Human action: effort							12 (80)	15 (100)	8 (53.3)
3. Human action: effort and result	9 (60)	7 (46.6)	10 (66.6)	11 (73.3)	13 (86.6)	15 (100)	2 (13.3)		2 (13.3)
4. Scientific			2 (13.3)				1 (6.6)		5 (33.3)
Total	15	15	15	15	15	15	15	15	15

graders), who used the two concepts indiscriminately in all three experimental situations. For a given situation (e.g., first situation) and a given age (e.g., fifth graders), we compared the distribution of the four conceptions for force and energy in terms of the numbers of pupils who selected them. These data are provided in Table 2. For example, in the first situation, the distribution of fifth graders' responses for force (46.6, 46.6, and 6.6 %; Table 2) did not differ significantly from the distribution of their responses for energy (27 and 73 %; Table 2). The fifth graders attributed both force and energy either to the object's weight or height (*Internal* and/or *Acquired*) (force: first situation 46.6 %, second situation 73.3 %, third situation 33.3 %; energy: first situation 26.6 %, second situation 33.3 %, third situation 53.3 %) or else to the agent who acted upon the object (*Human action*), even though the question was about the inanimate object (force: first situation 46.6 %, second situation 26.6 %, third situation 66.6 %; energy: first situation 73.3 %, second situation 66.6 %, third situation 40 %). The ninth graders also expressed the same conceptions for both concepts (i.e., *Internal* and/or *Acquired*, *Human action* and *Many forces are exerted*). In summary, there was no differentiation between the two concepts.

Among the 11th graders, there was a significant difference between force and energy in all three situations (first situation $p=0.02$, second situation $p=0.0001$, third situation $p=0.007$, Fisher's exact test). For all situations, force was regarded either as an interactionist conception (*Many forces are exerted*) (first situation 86.6 %, second situation 100 %, third situation 66.6 %) or else from the scientific viewpoint (first situation 13.3 %, third situation 26.6 %; see Table 2), whereas energy was viewed either according to the *Internal* and/or *Acquired* conception (first situation 33.3 %, second situation 53.3 %, third situation 33.3 %) or else as being synonymous with force (*Many forces are exerted*) (first situation 46.6 %, third situation 20 %; see Table 2).

In summary, concerning the inanimate objects, we identified an initial conception in which both force and energy were regarded as the object's intrinsic, material properties, related to its weight and height. Students subsequently came to view force as an interaction, but continued to consider energy solely in relation to the object's height or weight.

Differentiation Between Force and Energy in Relation to Animates

Our analysis failed to reveal any significant difference between the conceptions for force and energy within the youngest group (fifth grade) for any of the three situations (Fisher's exact test, $p > 0.05$; see Table 3). For animate agents, pupils used the same conceptions in similar proportions to explain the two concepts. Thus, for the first two situations, they deemed that lifting the inanimate object higher required more force and more energy from the agent (*Human action: effort and result*) (force: first situation 73.3 %, second situation 86.6 %; energy: first situation 60 %, second situation 73.3 %), while for the third situation, they deemed that the child needed more force and more energy than the adult to achieve a comparable result (*Human action: effort*) (third situation: force 53.3 %; energy 80 %).

The only significant differences we found were expressed by the ninth graders for the first ($p=0.002$) and third situations ($p=0.01$), and the 11th graders for the third situation ($p=0.04$). In order to explain how the agent changed the object's height in the first experimental situation (where the object initially rests on the ground), the ninth graders in the force group cited both the agent's effort and the result of his action (*Human action: effort and result* 100 %; see Table 3). By contrast, many of the students in the energy group focused entirely on the result of the agent's action, assuming that when the agent was unsuccessful, no energy was consumed (*Human action: result* 53.3 %; see Table 3). In the third situation, in which the agent's characteristics were salient (man vs. child), all the ninth graders deemed that the child needed more energy than the man, and showed that they only took the agent's effort into account (*Human action: effort* 100 %; Table 3). Regarding force, some of the students shared the same conception as those in the energy group (*Human action: effort* 60 %), the remaining students considering that both the agent's effort and the result of his action needed to be taken into account (*Human action: effort and result* 40 %; Table 3). For the third situation, a higher proportion of the 11th graders in the energy group viewed energy in relation to the agent's physical characteristics, namely his "muscular strength" (*Human action: effort*) (energy 53.3 % vs. force 13.3 %), while their counterparts in the force group related force to both the agent's effort and the result of his action (*Human action: effort and result* 46.6 %). It is also worth noting that some of the 11th graders gave scientific answers (force 40 % vs. energy 33.3 %).

In summary, in the case of the animates, force and energy were both seen in relation to the agent's most salient characteristics, such as the subjective dimension of effort (i.e., an adult compared with a child) and the result of the agent's action on the inanimate object (object successfully raised or not).

Discussion

The aim of the present research was to study the differentiation between the force and energy concepts held by students between the ages of 10 and 17 years for animate agents and inanimate objects. In the case of the inanimates, we predicted that (1) students would attribute force and energy on the basis of either motion (object raised from the ground, first situation) or position (difference in height, second situation), (2) force and energy would be attributed more frequently to animates than to inanimates, and (3) the two concepts would gradually become differentiated for inanimates. In the case of the animates, we predicted that (1) force and energy would both be regarded as proportional to the result of the agent's action (e.g., whether or not the man managed to lift the weight) and characteristics (e.g., a man or a child), and (2) the students would find it harder to differentiate between the two concepts.

In the case of the inanimates, results confirmed our first prediction. The younger students initially expressed an undifferentiated force/energy conception, defining both concepts —albeit incompletely—in terms of the energy concept. Theirs was a materialist conception, whereby both force and energy were linked to the object's weight, motion or height, and corresponded to the concept of energy (*Internal* and/or *Acquired*). When the box was on the ground, for instance, participants said that it had "the energy/force of its weight because it's heavy" or that "it doesn't have as much force/energy as the box up in the air." These interpretations are reminiscent of Piaget's internal motor (1972), Viennot's force of mass (1979) and McCloskey's impetus (1983). Here, the two fundamental presuppositions governing the students' early conceptions were that force or energy are properties of physical objects, the latter's weight, motion and height accounting for their potential to act on other objects.

Results also confirmed our prediction that force/energy would preferentially be ascribed to the agent, in situations featuring an interaction between an agent and a recipient. Each of the three situations featured an animate/inanimate interaction, but the younger students (fifth graders and ninth graders) tended to ascribe force, and even more so energy, to the animate agent, even when the questions actually concerned the inanimate object (e.g., "the man has force/energy but not the object").

With age (ninth graders onwards), some of the participants developed an interactionist conception (*Many forces are exerted*), which they then applied to both concepts. For example, in response to the question about whether the object had energy, they answered from the force point of view, citing the forces being exerted on it. Differentiation between energy and force was only displayed by the oldest students (11th graders). The first concept to detach itself from the common core (where both concepts were viewed from the energy perspective, characterized by weight and/or height) was force, which all the participants came to regard in terms of interactions, even though they did not always mention every single force. In the case of the energy concept, although the students were more likely to view it in relation to the properties associated with energy (height and weight), not all 11th graders took energy transfer and the law of energy conservation into account, continuing instead to regard energy solely as an internal or acquired property, or reasoning in terms of interactions (i.e., force concept).

In line with our hypothesis, another key finding of our study is that students have difficulty conceptualizing force and energy for animates. Participants in all three age groups expressed an undifferentiated conception for force and energy, based on the effort and/or result of the agent's action. They confused force with energy, believing that both were proportional to effort and/or result, and that effort was, in turn, proportional to the agent's size or muscular strength (Megalakaki and Vosniadou 2004).

The youngest students (fifth graders) defined both concepts in terms of the agent's effort and/or result (see Fig. 1). By ninth grade, students were focused on the visible characteristics of each situation. However, while they interpreted energy according to the situation's most salient aspects, namely either the effort made by the agent or the result of that effort, they generally took both effort and result into account in their interpretation of force. Among the 11th graders, there was no improvement in differentiation, with the exception of the third situation, where the students in the energy group generally cited the agent's effort, whereas the force group either took both effort and result into account, or else provided the scientific answer.

Thus, there was *no conceptual differentiation* in the case of *animates*. When pupils took only the result of the man's action into account, the man's failure to perform the desired action (i.e., the object remained on the ground) thus became the main criterion for deciding whether or not he was exerting force or consuming energy (*Human Action: Result*). According to this reasoning, an agent exerts more force and/or consumes more energy when he or she fails to complete the action. The students said, for instance, that "more forces were applied/more

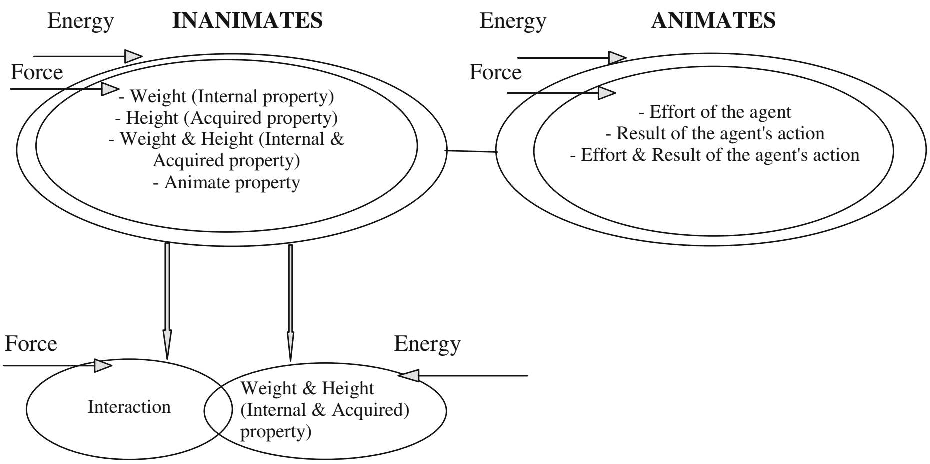


Fig. 1 Differentiation of force and energy in inanimates and animates

energy was consumed when the object remained on the ground, as the man was incapable of lifting it." When the pupils focused solely on the agent's effort, they deemed that his force/energy was proportional to that effort. Thus, to achieve the same outcome, "the child had to exert more force/consume more energy than the adult because he was weaker" (*Human action: effort*). Similarly, the instances where the students simultaneously took effort and the result of the man's action into account (*Human action: effort and result*), stating that "the man has to exert more force to raise the object higher," showed that they confused force with energy, as in this particular situation, the man needed more energy, but not more force.

In summary, our results provide new information about students' differentiation between the concepts of energy and force. Our first key result is that the two concepts develop asymmetrically in the case of inanimates, with the force concept undergoing a more rapid change. This suggests that, in the case of inanimate objects, force and energy are initially embedded in the same cognitive structure, and that the parent concept of both force and energy is the object's weight and height (Smith et al. 1985). The younger students in our study did not initially distinguish between force and energy, defining force in terms of the physical properties that determined energy (i.e., the heavier or higher the object, the more force or energy it possessed), and emphasizing the animate agent's role. In this case (Fig. 1), we can assume that children develop common conceptions for force and energy by considering both concepts either as an internal and/or acquired property or as an animate property. With age, participants gradually developed a conception of the situations based on the animate/inanimate interaction, which they again applied to both concepts. As a result, energy was described in terms of the properties of force. The older students, by contrast, were more likely to make a distinction between force (interaction) and energy (height+weight, internal and acquired property).

In the case of animate agents, importantly, our study shows that there is no differentiation between the two concepts (Fig. 1). None of the students' conceptions distinguished between force and energy, which were both defined in terms of the agent's effort and/or results in our study.

Figure 1 represents the process of differentiation for inanimates and animates observed in our study. For inanimates, children initially made no distinction between force and energy. Force was defined in terms of the properties of energy (weight, height) and the agent's role. Accordingly, students developed common conceptions for force and energy (e.g., internal property, acquired property, internal and acquired property, or animate property). Gradually, participants developed a conception based on the animate/inanimate interaction, which they applied to both concepts. A distinction between force (interaction) and energy (height+weight) then emerged. For animates, there was no distinction between force and energy. Both concepts were defined in terms of the agent's *efforts* and/or *results*—a conception that was dominant in all three age groups.

Factors Accounting for the Students' Difficulties

As we have seen, the participants' conceptions of force and energy were initially embedded in the same cognitive structure (Fig. 1) and supported by very similar systems of beliefs and presuppositions, based chiefly on observable properties (i.e., presuppositions such as "objects have weight, and weight is a form of force/energy," "the higher an object, the more force/energy it has and the greater the damage it can cause if it falls," "a man's force/energy is proportional to his size, his effort and the result of his action"). As a consequence of these presuppositions, the students initially conceptualized both the force and the energy of the inanimate objects as material properties related to the objects' weight or height. Force was the first concept that freed itself from this cognitive structure: students gradually abandoned the materialist conception in favor of an interactionist one, even if they did not systematically mention all the forces that were exerted. The concept of energy remained tethered to the objects' perceived characteristics and the basic presuppositions for longer.

We therefore believe that one of the obstacles to differentiation is the abstract nature of the force and energy concepts, insofar as the students in our study tended to regard them as material, intrinsic properties, relying on the visible parameters and physical characteristics of the objects and agents. This interpretation is in line with Chi's view of misconceptions (Chi et al. 1994; Chi and Roscoe 2002). It is also compatible with Kuhn et al.' (1988) claim that young children start out in life with a commonsense epistemology, in which they see knowledge arising from sensory experiences, which provide true beliefs. According to these authors, pre-adolescents view theory as being entirely compatible with evidence, regarding evidence as "equivalent to *instances* of the theory that serve to illustrate it, while the theory in turn serves to explain the evidence. The two meld into a single representation of the way things are" (Kuhn et al. 1988, p. 221).

A second explanation for students' difficulties concerns the dynamic nature of these concepts (Brown 2014) and the difficulty of simultaneously taking all the relations between the components of the system(s) being studied into account. For example, to explain the first situation, where a man lifts an object off the ground, participants had to consider a whole set of interactions between the man's action, the object and the ground, as well as the net force (zero), extracting information that would explain the state of the system at a given point (object either on the ground or up in the air) without losing sight of the system as an integrated whole. Most of the time, they had only a partial view of that system, seeing it as essentially static and considering only its visible aspects. This difficulty can be ascribed to relational complexity which, according to Halford (1999) and Halford et al. (1998), can be measured in terms of the number of interacting factors, each factor representing a source of variation and contributing to overall relational complexity.

This notion was initially put forward to account for difficulty solving problems or understanding sentences. In the case of problem-solving, "the processing complexity of a task is the number of interacting variables that must be represented in parallel to perform the most complex process involved in the task, using the least demanding strategy available to humans for that task" (Halford et al. 1998, p. 805). According to these authors, two mechanisms that can help people overcome this processing difficulty are segmentation and chunking. Segmentation consists of breaking a complex task down into stages to reduce its relational complexity, while chunking consists of grouping two or more variables into a single unit. We believe that relational complexity provides a convincing explanation for the difficulty of acquiring the concepts of force and energy, insofar as the students in our study initially regarded them as intrinsic properties, and their subsequent progress stemmed from the discovery of the relations between the different elements (Megalakaki et al. 2012). We can assume that they resorted solely to segmentation to process these concepts. The chunking mechanism would have been more difficult for them to apply, as they would first have had to view the situation as an integrated whole, made up of interconnected parts, before extracting elements to explain the system at any given point. One reason why they might have found chunking so difficult is that the laws and principles of energy and force are introduced in a highly fragmentary fashion in the French school curriculum.

This difficulty using multidimensional information for energy and force concepts during development is consistent with studies in other areas of reasoning (e.g., Case 1992; Megalakaki et al. 2012; Pauen 1996; Siegler 1983) and highlights the need to study these concepts in parallel, using a broad set of experimental contexts. This would allow us to develop a meaningful, integrative learning context enabling students to consider all the information, and not just the most visible aspects.

Third, the presence of an animate agent in the systems appeared to present the students with an additional difficulty, as they found it more difficult to consider force and energy from the animate's point of view. They confused the two concepts with the agent's effort and the result of his action, thereby flagging the more general problem of the interaction between animates and inanimates and the confusion between the terms force, strength, effort, and energy. The nature of the conceptions formulated for animates can probably be explained by the fact that children construct a "psychological" conception of these concepts at a very early age, based on a subjective notion of effort and result, with a central role being played by the agent and his/her will and *personal* strength (e.g., "I'm going to lift a big box because I'm strong").

When they are later confronted with these same concepts in physics lessons at school, children are unable to rid themselves of this salient psychological notion of effort and result, and continue to regard force and energy as the properties of animates endowed with a vital force that allows them to act (Black and Solomon 1983; Duit 1984; Inagaki and Hatano 2004; Solomon 1992; Watts 1983). In other words, to explain concepts in physics, pupils reason in psychological and biological (*big*, *strong*) terms. Similar interpretations have been put forward in the field of biology education, where children are particularly sensitive, for instance, to the distinction between motion in animates as agents and inanimates as the recipients of action (Gelman and Spelke 1981). Gelman and Gottfried (1996) also found that children were far more likely to ascribe the cause of motion to a person than to anything inside, in the case of inanimate objects, the opposite being true for animate objects.

Conclusion

In conclusion, the differentiation of the force and energy concepts is a lengthy process during which children and adolescents have to discard beliefs, presuppositions, and an overreliance on observable properties. Our research enabled us to show that parameters such as weight/height for inanimate objects and effort/result for animate ones are genuine obstacles to a full understanding of the concepts of force and energy, as children rely exclusively on the evidence of their own eyes and make no attempt to interpret the underlying theoretical principles. Insofar as one important goal of science education is to help students understand the nature of scientific knowledge by distinguishing theory from evidence, it is important to take account of the distinction between inanimate and animate objects and, more specifically, of the notions of weight/height and effort/result, when teaching the concepts of force and energy. By so doing, we can evoke and challenge students' naive conceptions about these variables and help them discover all the interrelations between the components of different systems, thereby promoting their conceptual development.

At the same time, it is important to improve students' ability to extract the invariants of each situation and thus to consider the concepts of force and energy independently of the situation, as systems made up of interconnecting parts. However, we should point out that one of the limitations of our study is that while it highlights the difficulty that students have understanding and differentiating between the force and energy concepts, it does not propose any remediation. Concerning this point, situations featuring authentic contexts (Barab et al. 2000) such as simulations, scientific inquiry tasks (Linn and Eylon 2011) and modeling activities (Megalakaki and Tiberghien 2011), together with more explicit approaches to teaching (Opitz et al. 2014), would enhance students' understanding of scientific concepts and their conceptualization of all the components that interact in a given system.

Appendix 1

Table 4 Defining criteria for the four conceptions identified for force and energy in the case of the inanimate object

Conceptions	Examples	
	Force	Energy
Internal and/or acquired force/energy. Force/energy is regarded as a property of the object that is related to its size/weight and/or to its height/motion.	(Acquired conception) First situation: Q.1: The object hasn't force because it isn't lifted in the air. Q.2: The object has force, because it is up in the air. Q3: More in (b), because it is up in the air. Second situation: Q.1: The object has force because it is lifted in the air. Q2: More force in the second case because it is lifted in the air. Third situation: Q.1: The object has force because it is lifted in the air. Q2: Same forces because same height.	(Acquired conception) First situation: Q.1: The object hasn't energy because it isn't lifted in the air. Q.2: The object has energy, because it is up in the air. Q3: More energy in (b), because it is up in the air. Second situation: Q.1: The object has energy because it is lifted in the air. Q2: More energy in (b) because it is lifted in the air. Third situation: Q.1: The object has energy because it is lifted in the air. Q2: Same energy because same height.
Human action. Force/energy is attributed to the agent, even though the questions concern the object.	First situation: Q.1: The box doesn't have any force, it's the man who does because he's trying to lift the box. Q.2: Yes, because the man is able to lift the box. Q.3: The man is exerting more force because he has succeeded in raising the box. Second situation:	First situation: Q.1: The box doesn't have any energy, it's the man who does because he's trying to lift the box. Q.2: Yes, because the man is able to lift the box. Q.3: The man consumes more energy because he succeeded in lifting the box. Second situation:

Table 4 (continued)

Conceptions	Examples	
	Force	Energy
	Q.1: The box doesn't have force, it's the man who does because he's managed to lift the box. Q.2: Same forces same height Third situation: Q.1: The box doesn't have force, it's the man who does because he's managed to lift the box. Q.2: The child needs more force.	Q.1: The box doesn't have energy, it's the man who does because he's managed to lift the box. Q.2: Same energy same height Third situation: Q.1: The box doesn't have energy, it's the man who does because he's managed to lift the box. Q.2: The child needs more energy.
Many forces are exerted. Several forces are evoked but not all, or the justification is not correct. In the case of energy students refer to forces exerted and not to energy.	First situation: Q.1: Two forces are exerted (weight, man). Q.2: Two forces (man, weight) Q.3: Different forces Second situation: Q.1: Two forces are exerted (weight and human action). Q.2: The same forces because they are lifted in both cases. Third situation: Q.1: Two forces are exerted (weight and human action) Q.2: Same forces, because same height and same weight.	First situation: Q.1: Two forces are exerted (weight, man). Q.2: Two forces (man, weight) Q.3: Different forces
Scientific. Scientifically correct responses to all the questions.	See Table 1 for scientific responses	See Table 1 for scientific responses

Appendix 2

Table 5 Defining criteria for the four conceptions identified for the force and energy in the case of the animate agent

Conceptions	Examples	
	Force	Energy
Human action: result (this conception was found for the first and the third situation). Students refer to the agent's action but believe that less or no force (or energy) is needed once the result has been achieved. Here, the man's effort is not taken into account.	First situation: Q.1: Yes, he's trying to lift it. Q.2: No, because he's managed to lift it, it was easy. Q.3: The man needs more force when the object is on the ground because the box is heavy and he can't lift it. Second situation: Q.1: Yes, because he's managed to lift the boxes. Q.2: More forces in (a) because he can't lift it very high.	First situation: Q.1: Yes, he's trying to lift it. Q.2: No, because he's managed to lift it. Q.3: The man consumes more energy when the object is on the ground because the box is heavy and he can't lift it. Second situation: Q.1: Yes, because he's managed to lift them. Q.2: More forces in (a) because he can't lift it very high.
Human action: effort (this conception was found only for the third situation). The force (or energy) is proportional to the effort made but not the result achieved (i.e., more effort implies more force (or energy) consumption, whatever the result).	Third situation: Q.1: Yes, in order to be able to lift the box. Q.2: More force in (b) because the child is not as strong.	Third situation: Q.1: Yes, in order to lift the box. Q.2: More energy in (b) because the child is not as strong.
Human action: effort and result. The amount of force (or energy) consumed is related to both the efforts made by the man and the result of his action.	First situation: Q.1: Yes, he's trying to lift it up, he's making an effort. Q.2: Yes, he's managed to lift it. Q.3: More force in (b) because he's managed to lift it. Second situation: Q.1: Yes, he's trying to lift it up. Q.2: The same because he's managed to lift it. Third situation: Q.1: Yes, to lift the box. Q.2: The same because they managed to lift the box.	First situation: Q.1: Yes, he's trying to lift it up. Q.2: Yes, he's managed to lift it. Q.3: More energy in (b) because he's managed to lift it. Second situation: Q.1: Yes, he's trying to lift it up. Q.2: The same because he's managed to lift it. Third situation: Q.1: Yes, to lift the box. Q.2: The same because they managed to lift the box.
Scientific. Scientifically correct responses to all the questions.	See Table 1 for scientific responses	See Table 1 for scientific responses

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