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HOW STUDENT TEACHERS UNDERSTAND DISTANCE FORCE INTERACTIONS IN DIFFERENT CONTEXTS

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ABSTRACT. In this paper, we describe empirical research on the recording of primary school and preschool student teacher conceptions of the concept of distant force interactions in different contexts related to the school curriculum for this subject. For this objective to be achieved, we undertook ten semi-structured interviews with student teachers. Based on the findings from these interviews, we developed a written ten-item questionnaire that was distributed to 264 first-year student teachers at three Greek universities. The main findings of our research are that a significant number of students: (i) experience difficulty in recognizing the interactions in different contexts, and even in different cases within the same context; (ii) place the arrow representing the force on the body that exerts it and not on that which accepts it; and (iii) hold the alternative view that the larger the body interacting, the greater the force it exerts. Based on the above results, as well as in the ways in which they seem to be related, we developed hypotheses, potentially able to lead to the construction of a teaching–learning sequence, which focuses on the comprehension of force as the measure of a unified concept of interaction between two entities.

KEY WORDS: alternative conceptions, distance force interactions, learning in different contexts, physics education, student teachers' content knowledge

Introduction

Force is one of the most significant concepts of physics since it is used to describe or interpret phenomena including bodies at rest or in motion. Scientifically, we consider force as the empirical result of the fundamental concept of *interaction*, the content of which appears in Newton's third law (NTL). In particular we consider that NTL, in combination with gravitational interaction, introduces for the first time the concept of force as a result of an already existing relation between two material entities. A relation is revealed by forces acting on the objects through which it causes changes in their motion or it deforms them. This relation has, in the 18th century, its first autonomous representation: the field. The field representing the interaction in mathematical terms, leaving under discussion its substance, unifies the issue of interactions by distance in all empirical contexts known at the time (gravitational, magnetic, electric, and

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electromagnetic) while at the same time it indicates its nature; e.g., forces cannot act on the field, because forces act on the bodies and not on their relation. Finally, we consider that in the 20th century, interaction obtains its material and clearly autonomous existence through ‘exchange particles’ which describe and interpret phenomena of the microcosm. On the other hand, according to the New Greek Curricula of Early Childhood and Primary School Education (Ministry of Education, 2004), which have adopted a cross-thematic approach to all subjects, *interaction* is considered to be a fundamental ‘conceptual bridge’ between different subjects.

Nevertheless, in the ‘Individual Subject Curricula’ of the new curriculum concerning physics, the concept of interaction is mainly introduced through the concept of force as connected to its empirical results (acceleration and deformation). In fact, as far as we know, this approach is international. Thus, the concept of force remains one of the first concepts children meet as they develop conceptual schemes of interaction that run counter to scientific ones (Jimoyiannis & Komis, 2003).

A number of research studies have focused on student difficulties in interpreting interaction phenomena through forces, mainly in the field of mechanics. Findings show that force is seen as a single-body property rather than the outcome of the interaction of two bodies. Besides, students have problems identifying the forces acting during an interaction. They tend to apply both action and reaction to the same body and, in some cases—for instance when a body is in motion—they find it difficult to accept the equal magnitude of forces: “action always overcomes reaction when two bodies move together” (Grimellini-Tomasini, Pecori-Balandi, Pacca & Villani, 1993). Specifically, a well-established conception is that reaction is not recognized in the case of a stationary car, or a table: or that there is no reason to consider the balance of forces (Terry, Jones & Hurford, 1985; Kruger, Summers & Palacio, 1990a; Summers, 1992; Thijs, 1992). In addition, students seem to have different ideas about the cause of reaction force. For example, they think that the upward force of a table on a book is a form of resistance, or that it comes from air pressure, air molecules, compression, and so on (Bryce & MacMillan, 2005). Furthermore, another group of research studies focuses on students’ thinking about motion and rest and reveals mainly the Aristotelian perspective, that is, that motion implies force. The implicit conceptual scheme to interpret motion is the existence of a combined force in the direction of motion, which incorporates the notion that a constant force induces constant motion (Parker & Heywood, 2000; Galili, 2001; Ioannides & Vosniadou, 2002). We presume that the difficulties students encounter are due to the fact that they do not comprehend force as a differentiated entity, resulting from the interaction between two other entities, as, for example, a 'flow of a conserved vector quantity' with its own spatial–temporal specification (diSessa, 1980; diSessa, Gillespie & Esterly, 2004).

In order to help our students handle this conception, we have designed (and are now implementing) a research program for the introductory teaching of force as an entity representing and measuring the interaction between two bodies, by primary school and preschool student teachers. We assert that a teaching approach with a constructivist orientation should be based on the initial conceptions of the target group. We assume that these initial conceptions exist and they are not random or chaotic even though they are not simply described or strongly systematic (diSessa et al., 2004). Furthermore, our target group has been taught, in the context of Greek secondary education, three ontologically different 'introductions' to the concept of force: force between masses, magnetic quantities and charges. From this perspective, in this paper:

A. We review the extensive literature on the students' ideas of the concept of force
B. We present the recording of the student teachers' conceptions (preschool and primary school student teachers) about the existence, representation and magnitude of distance force interactions in these three different contexts
C. We present the interpretive hypotheses we established based on the combination of our results and the bibliographic data. We consider these hypotheses to be important in the construction of instruction related to our goal.

Literature

In the relevant literature we find various situations that have been studied in order to understand student conceptions of NTL and force interactions, in general. In order to review the literature, we have classified the relevant studies into two groups: (a) the 'rest group', which includes research comprising static bodies in contact, or static ones in a distance relation; and, (b) the 'motion group', which includes research focusing on contact or distant bodies in motion. We argue that some research could belong to both groups. This classification has been made in accordance with our interest in a unified teaching–learning approach to the interactions. In particular, we consider the above categories (rest-motion, contact-distance) to have empirical origins and the research that focuses on them illuminates the basic characteristics of conceptual schemes of students that hinder scientific unification: the interaction 'in contact' is an empirically constructed category of interaction, which in fact is accomplished 'from distance', (what would the contact of two bodies mean since we accept and then teach their particle structure and the electromagnetic interactions?), while 'rest' is an empirical constructed case of 'motion' (according to Newton's first law).

The 'rest group' comprises a number of studies in which we find situations such as: a book on a table, a block suspended from a spring, a small stone resting on a much larger one, an arched bridge, a floating block, a man pulling a rope that is fixed to a spring, a box on a slope or an astronaut standing on the surface of the moon (Terry et al., 1985; Brown, 1989; Kruger, Summers, & Palacio, 1990b; Kruger et al., 1990a; Summers, 1992; Thijs, 1992; Thijis & Bosch, 1995; Trumper, 1996; Heywood & Parker, 2001; Palmer, 2001; Montanero, Suero, Perez & Pardo, 2002; Bryce & MacMillan, 2005). On the other hand, the 'motion group' focuses, as mentioned earlier, on bodies in motion, for example, a collision between a small truck and a car or between two identical marbles or between a missile and a bomb, a student on rollers pushing another one and a small car pushing a large one with constant velocity or acceleration (Watts & Zylberszajn, 1981; Brown, 1989; Gamble, 1989; Kruger, Summers & Palacio 1990a, 1990b; Summers, 1992; Thijs, 1992; Montanero, Perez & Suero, 1995; Trumper, 1996; Heywood & Parker, 2001; Bao, Hogg & Zollman, 2002; Savinainen & Scott, 2002; Savinainen, Scott & Viiri, 2005).

Considering the above studies, we came to the conclusion that the majority include objects either at rest or in motion and always in contact, while most belong to the motion group. In contrast, the studies that refer to resting objects at a distance are considerably fewer. Furthermore, we noted that current studies in both groups are mainly concerned with examining whether different contexts influence student reasoning about the concept of action-reaction or not. Heywood & Parker (2001) question which key ideas students and in-service primary teachers have about floating and sinking as well as how these ideas have extended to different contexts such as static structures (for example, an arched bridge). Similarly, Palmer (2001) studies the concept of action and reaction in nine concrete items. All the items consist of a book resting on another object, for example, a balloon, a table, or floating on water. Individual interviews were carried out with 15 to 16-year-old students who had previously been introduced to the topic of forces and gravity, without NTL yet being covered. In Spain, Montanero et al. (2002) have studied by means of a test, how students (12–25 years old) understand the interaction between two static bodies in contact. The test combines a set of identical situations—e.g., a small stone resting on a much larger one, a small boy resting on a bigger one—where all items are equivalent and the only varying factor being whether the objects are living or inert. Bao et al. (2002) made an analysis of student reasoning (primary student teachers, physics, and engineering majors of different levels) in explaining phenomena associated with NTL. Using qualitative and quantitative methods, they focused on the four contextual features that are frequently used by students: mass, velocity, acceleration, and pushing (the initiator of the action). Savinainen et al. (2005) focused on the specific problems students have when they interpret phenomena of movement according to NTL. They used the notion of 'contextual coherence' in order to measure "the extent to which a student can apply a concept or a physical principle in a variety of familiar and novel situations".

Findings revealed at least two significant issues concerning the idea of force interaction. First, students' reasoning seems to be highly influenced by the context, for example, they may comprehend the balanced forces involved in floating but find it is difficult to transfer such thinking to other more complex situations, such as an arched bridge (Heywood & Parker, 2001). In the same way, Savinainen & Scott (2002), underline—after a pilot application of a new teaching approach where the notion of interaction is central to understanding the force concept—that "many students had difficulties in generalizing from NTL to cover both the accelerated and uniform velocity cases, with many students believing that NTL does not hold to a force situation". Likewise, in previous research (Montanero et al. 1995) where NTL was studied in relation to two colliding bodies, results show that in this case, students follow a different way of thinking, where there is "a perfect identification of the concept of force with the momentum". As a discussion issue, they stressed that the principle of action and reaction is very difficult to comprehend in both cases, namely, when applied to bodies at rest and in contact as well as to colliding bodies. Indeed, a newer piece of research in Spain, showed that most of the students apply NTL using two alternative ways of reasoning—when a body is resting on another one, they consider that: (i) the upper body exerts its weight on the lower, perceiving the weight "as an authentic action of one body on another"; ii) the lower body possesses a passive resistance that "cannot be regarded as a force" (Montanero et al. 2002). Secondly, the researchers pointed out that students seem to have a personal type of reasoning, which is highly structured in their minds, that takes the form of *'if…then'*, for example, if an object is pushed out of shape (e.g., a piece of spongy foam) then a force has been applied (Palmer, 2001). Results, from Bao, Hogg & Zollman (2002), showed that the overriding student reasoning in describing the forces on the objects is ‘the object with dominant features applies a greater force’. For example, when mass or velocity varies in a collision situation they do not see the forces as equal. The identical student thought processes were found in a previous study (Watts & Zylbersztajn, 1981) concerned with action-reaction in a tug-of-war game: the majority of students (14-year-olds) believed that if a man is winning the game, he is exerting a greater force on the rope than his opponent. Researchers commented that this interpretation is an alternative to: “If two bodies interact to generate a state of movement, one of these must be exerting a greater force on the other”. In conclusion, according to the above outcomes, in several contexts students appeared to use different reasoning to that traditionally taught in Newtonian science. Therefore, if we aim to develop an innovative teaching sequence related to force interactions, it is necessary to have a thorough evaluation of student progression in the development of their contextual reasoning.

Another important result of studies is that students were confused about gravity interaction; an interaction by distance that has been generally studied. They are inconsistent when identifying the concepts of gravity and weight: sometimes they use these concepts interchangeably and on other occasions, they seem to perceive gravity as a distinct force of weight (Watts & Zylbersztajin, 1981; Trumper, 1996; Heywood & Parker, 2001). A frequent alternative conception is that the ‘reaction force’ of a table on a resting book is the reaction to the action of gravity on the object (Bryce & MacMillan, 2005) or that the upper body exerts its weight on the lower one (Montanero et al., 2002). Research results showed that a number of students have problems in accepting NTL in the case of a non-contact gravitational force, yet they correctly answer any other case (Authors; Savinainen et al., 2005). The physicist’s view that any pair of bodies attracts each other due to the fact they have mass seems to be too difficult for a relatively large number of students to grasp.

A further important issue related to NTL is the direction of forces. Research shows that students seem to have difficulties in drawing force arrows: they place an arrow on the object that exerts the force and not on the one receiving it. For example, when they (14-year-olds) are asked to insert the arrows on the tug-of-war game, an arrow oriented from the person to the rope is intended to show the force exerted by the person on the rope (Watts & Zylbersztajn, 1981). A frequent alternative pattern is that all arrows are pointed to the direction of movement (Gamble, 1989; Trumper, 1996): they are also ambivalent about the direction of reaction or the direction of gravity (Trumper, 1996). The direction of forces is an important issue that concerns not only the concept of interaction but also the addition of forces.

In conclusion, there is evidence that students' reasoning about interaction is influenced by context. This evidence also contributes to the psychologists' dialogue about the coherence or fragmentation of students' ideas (diSessa et al., 2004): a dialogue that concerns the construction of our teaching hypotheses, as well. Additionally, gravity interactions as well as the direction of forces are two particular issues related to the concept of interaction that need further analysis. Considering the previous studies, we think that there is rather limited research into two interacting bodies at a distance and at rest. However, we consider this specific case, of distant and at rest interacting bodies, to highlight the problem of interaction as a unified concept. Since the students' opinions on interaction and force are vague, we think the variety found in the bibliographic findings is not unexpected: everyday experience justifies the constant intuitive relation of motion and force as well as the multiplicity of alternative approaches introduced by different contexts. Experience leads to the thoughts based on the apparent results of interaction (motion and deformation). Thus, if we insist on giving experience the 'first place' in education, it is difficult to avoid classifications which fragment the unified way of handling problems introduced by Newton. Experience 'teaches' that motion is different from rest. It conceals the fact that motion is a relation (relativity of motion) and not an attribute of the bodies. It conceals the fact that deformation is, in fact, motion. It conceals the fact that the contact of two bodies is performed from a distance.

Based on these facts, we consider it extremely difficult to imagine an empirical way to introduce a unified dimension of the concepts of interaction and force when teaching, without reinforcing the conceptual schemes of the students. We think our literature leads to the direction of attempting an introduction of Newton's mechanics starting with the concept of interaction, closely connected to the forces from a distance it implies, and then attempting to expand whichever concept the students have in the various empirical contexts of application.

The Context of the Research

The final aim of our research program is to develop a teaching–learning sequence with a constructivist orientation (Meheut & Psillos, 2004) that focuses on the concept of force as the measure of the interaction between two bodies (or entities). We aim to do this in a unified way, regardless of the nature/ontological approach of the interaction, the static or dynamic character of the problems and whether the interactions are at a distance or in contact.

Our target population, as well as the sample of the present research consists of primary and preschool student teachers. The selection of the specific groups results from the need for implementing the new Greek Curricula of Early Childhood and Primary School Education (Ministry of Education, 2004), which have adopted a cross-thematic approach to all subjects. According to this approach, the conceptual 'bridge' between different subjects is a set of six concepts; one of them is interaction. (The rest are: space, time, system, individual, and group).

We consider the record of student-teacher conceptions regarding the 'a priori' existence and the ontology of interaction between two objects (or entities), as a prerequisite to the construction of our teaching sequence, based on consideration of its representation by the forces' arrows (the point of application and the direction of the forces). Since we intend to introduce the concept of interaction as a concept unifying three different cases already known to our students (interactions activated from different entities: mass, magnetic quantity, and charge), we decided to investigate student-teacher conceptions in the contexts where the nature of interaction differs and the interactions are explicitly at a distance. For the same reason, from the viewpoint of the specification of conceptual content alternatives (diSessa et al., 2004) we are interested in the *'existential'*, *'coarse quantitative'* and *'ontological'* aspects. We assumed that the *'compositional'* and *'causal'* aspects are very much more related to empirical cases, and we are going to investigate them after the results of the introduction of a unified interaction concept are known. Finally, the rather-limited amount of literature already mentioned makes our record valid. Therefore, the main research question we posed is: How do student teachers understand the force interactions between two physical entities at a distance and at rest?

Method and Sample

The First Phase of the Research

In order to answer the main research question, we conducted a small number of semi-structured interviews with ten first-year female students from the Schools of Education in Florina, Greece, prior to the teaching of the topics in question. The sample was not representative, as it was comprised of volunteers. Our research tool was eight tasks, displayed on cards. These depicted a book on a table, pieces of paper stuck on a just-used comb, a magnet pulling a hanging sphere, the Earth and the Moon, two wooden cubes placed at a distance on a table, an electron orbiting around a proton, and so on.

The sub-questions were: to (a) Identify the objects on the cards, which interact with each other; (b) Draw the forces representing this interaction; and (c) compare the magnitudes of the forces. These questions were posed, together with clarification questions such as: "What do you mean by that?" "Give me an example" "Another student claimed that… comment on it".

After analyzing the interviews, three major alternative conceptions about distance force interactions became evident. The first one is whether the interaction between the objects exists or not. It seems that the students interviewed identified the interaction between the Earth and the Moon more easily than between two wooden cubes. The typical answer was that the cubes do not interact, since they are neither magnets nor are they charged. The second alternative conception is about placing an arrow that indicates the action of one object on the other. Most of the interviewees place it on the object that exerts the force and not on the one receiving it, claiming that "it is the one giving the force". We called this alternative conception the 'giving model', considering it as evidence that students classify force ontologically as a property. The third alternative conception known from literature (Grimellini–Tomasini, Pecori–Balandi, Pacca & Villani, 1993) is that 'the larger the entity the greater the force it exerts'. A typical answer was, "since the Earth is larger than the Moon, it exerts a greater force".

We wanted to confirm the aforementioned findings with a larger sample. Therefore, we set up the second phase of the research, described as follows.

The Second Phase of the Research

In order to confirm the existence of the three alternative conceptions mentioned before, we analyzed the initial research question, in the following three sub–questions:

A) Is the existence of force interaction identified in a similar way in various subject matter contexts?
B) Which of the two objects is the arrow of the force placed on?
C) How are the magnitudes of the two forces interacting related to each other?

In order to answer these questions, we developed a ten-item questionnaire[1]. Three items dealt with gravitational interaction, four with magnetic interaction, and the last three looked into electric interactions. Each question had the same structure, including four sub-questions and drawings. In each question, there was a system of two interacting objects. These were: the Earth and the Moon in the first question; the Earth and an apple in the second; two wooden cubes in the third; and two unequal magnets with the unlike poles opposite each other in the fourth. In the fifth question, there were the same magnets with the like poles opposite each other. In the sixth and seventh questions there was a magnet with a small and a big iron cube, respectively. In the next two questions, there were two unequally charged bars placed the way the unequal magnets were in questions four and five, respectively. Finally, in the tenth question, there was a charged bar with a small piece of paper.

The first sub-question (a) of each question asked whether entity A (a mass, a magnet, a charged bar) exerts a force on entity B (a mass, a magnet or an iron cube, a charged bar or a piece of paper). Additionally, the students were asked to choose between two drawings: the first one representing this force alternatively and the second one scientifically. They may draw their own version, if neither of the ones suggested agree with theirs. The second sub-question was exactly the same as the first and investigated the action of entity B on entity A. The structure of the sub-questions proved to be very helpful. If we had asked the students to depict the interactions in the same drawing, we would not have been able to understand where they placed the force which each object exerts, namely, either on the other object (scientific conception) or on the same one (alternative conception—'giving model'), as occurred in the first phase of the research. The third sub-question was a multiple choice one and included four suggestions about the way that the magnitudes of the forces are related. In the fourth sub-question, the students were asked to justify their conceptions. Obviously, we are not interested in gravitational interaction between entities in questions 4–10. No student recognized this kind of interaction. For the analysis and interpretation of the data, we took into account the fact that part of the sub-questions a and b, as all of the sub-questions c had meaning only in the cases where the students first accepted the existence of some force. Thus, for example, the cross tabulations testing relations as 'the larger the entity, the greater the force it exerts' were realized only in the number of students accepting the existence of some force. The percentage of 'I don't know/answer' answers referred to in 'the placing of the arrow' or in 'relation to the magnitudes of forces' was always interpreted in relation to the percentage of students accepting the existence of some force. While the calculation of the concentration factor was done on the entire answers, our interest in the concentration or the distribution of opinions led us to consider the 'I don't know/answer' answers as a separate class. For the sake of brevity, we have analytically presented the fourth question representatively in the Appendix. We validated the questionnaire by giving it to three independent researchers of science education to check it. In the interviews that followed, it was verified that the questions led to the answers that interested us and small changes in the questionnaire were made in this direction.

We distributed this questionnaire to 264 student teachers: 160 of them studied in the Early Childhood Education Department and the remaining 104 in the Primary Education Department at the Universities of Athens, Thessaloniki, and Florina. The majority of the students were freshmen: approximately 60% of them come from the humanities and the remainder from the sciences. The vast majority of the students, almost 85%, were female, typical of the male/female ratio in Greek Schools of Education. During their study in the upper secondary school (Lyceum), all students had been taught a general physics course which included force interactions between masses, electric charges, and magnets. The students selecting a science specialization had been taught physics in greater depth.

The analysis of 40% of the questionnaires (randomly selected), was carried out by two researchers, in order to control reliability. The agreement of the results was fairly high on the first three sub-questions (a, b, c) of each question (constantly above 85%). Lower percentages (near 70%) were observed in the analysis of the fourth (d) sub-question. However, most disagreements were solved here too after the discussion that followed between the researchers.

RESULTS

We will describe the outcomes of the recording of the student conceptions in three phases, corresponding to the three sub-questions in the questionnaire (a, b and c -ee Appendix I). In the first one (5.1), we investigated whether the students had identified the existence of forces between the two interacting entities. In the second phase (5.2), we sought to identify the object which the students had placed the arrow on, representing the force. In the third (5.3), we looked into the way the students perceived the relationship between the force magnitudes. Finally, in (5.4), we looked for any possible relationship, either between similar tasks in different contexts or between different sub-questions of the same task.

The Existence of Forces

The students' answers in the first sub-question 'a' of the ten items of the questionnaire can be classified in the following four categories: I. 'There are two forces', II. 'There is one force', III. 'There are no forces' and IV. 'I don't answer/know'. In category I 'There are two forces' the percentages were between 94.0 and 29.7%. High percentages were observed in questions four (two magnets–unlike poles opposite), eight (two charged bars–unlike charges opposite) and one (Earth–Moon) (94.0, 93.2, and 88.0% respectively), while low percentages were observed in questions two (Earth–apple), three (two wooden cubes) and ten (charged bar–a piece of paper) (60.5, 45.1, and 29.7%, respectively).

There were high percentages in questions two (Earth–apple), six (magnet–big iron bar), ten (charged bar–a piece of paper) and seven (magnet–small iron bar) (34.6, 32.3, 29.7 and 27.1%, respectively) with respect to the existence of one force (category II). The 'no force' case (category III) presented significant percentages in questions three (two wooden cubes), ten (charged bar–a piece of paper), five (two magnets–like poles opposite), and nine (charged bars–like opposite charges) (39.1, 27.1, 15.8, and 14.3%, respectively). The higher percentages of students who did not answer or declare 'I do not know' (category IV) corresponded to the questions ten (charged bar–a piece of paper) and three (two wooden cubes) (13.5 and 9.0%, respectively).

Examining student answers to questions 1–3, we noted that the existence of interaction is overtly identified in question 1 (Earth–Moon), somewhat less in question two (Earth–apple) and even less in question three (two wooden cubes). Thus, when the two celestial objects (question one) become a celestial and a terrestrial one (question two), the percentage that identified the interaction decreases. It decreased even more when two terrestrial objects are involved (question three). In this case, students claimed that, "the cubes do not interact, since they are neither magnets nor are they charged". These results were in agreement, on the one hand, with the conception that gravity is not a universal relation between bodies (Watts, 1982; Kruger et al., 1990a; Heywood & Parker, 2001) and, on the other, with the conception that in rest situations no forces are present (Thijs, 1992).

The significant drop in the percentage that did not identify the interaction in questions six (magnet–big iron cube) and seven (magnet–small iron cube) could be due to the fact that one of the objects is not a magnet. This conception that interaction may occur only between similar entities has already been noted: “interaction exists mainly between two objects, which are the ‘same’ or ‘similar’ (i.e., size, shape, mass, and velocity) rather than between different objects” (Kolokotronis & Solomonidou, 2003).

Quite an interesting case concerns the number of students (15.8 and 14.3% in questions five (two magnets–like poles opposite) and nine (two charged bars–like charges opposite), who did not identify any interaction, claiming that “no forces are exerted; these (the like poles) simply repel each other”. Thus, it appears that the traditional teaching of ‘like poles repel each other’ predisposes students to identify only the attraction of the magnets as a force, not the repulsion.

Finally, in question ten (a charged bar–a piece of paper) there was quite a considerable distribution of answers in all categories, which is most probably due to the nature of one of the interacting entities (a piece of paper). This is rather striking since the task is a popular and usually successful school experiment. We also considered that this case was similar to the one referred to in a previous paragraph where it had been noted that the interaction is not easily recognized between different objects (Kolokotronis & Solomonidou, 2003).

The Placing of the Arrow

The students’ answers in the second sub-question ‘b’ (placing the arrow) of the ten items of the questionnaire could be classified in the following four categories: I. ‘Placing the arrow on the correct object’, II. ‘Placing the arrow on the other object’, III. ‘Using another symbol’, and IV. ‘I don’t answer/know’. In the category I (‘Placing the arrow on the correct object’) the percentages of answers were between 48.9 and 13.5%, with higher percentages in questions five (two magnets–like poles opposite), nine (two charged bars - like charges opposite), six (magnet–big iron cube) and two (Earth–apple) and corresponding percentages: 48.9, 46.6, 46.2, and 44.0%, respectively. In the category II (‘Placing the arrow on the other object’) the percentages of the answers are 41.4–16.5%, with higher percentages in questions one (Earth - Moon), seven (magnet–small iron cube), four (two magnets–unlike pole opposite), and eight (two charged bars–unlike opposite charges) and corresponding percentages: 41.4, 38.0, 32.3, and 32.0%, respectively. Obviously, there is a significant proportion of the students who, in accordance with the literature (Ioannides & Vosniadou, 2002), perceived force as an internal property of the objects. Thus, they placed the arrow (representing the force) on the object exerting it and not on the one receiving it (Watts & Zylbersztajn, 1981). As we mentioned before, we call this view the 'giving model'. A small number, up to 8.6%, used a different symbol (category III), which is often a double arrow (↔).

Quite a high percentage of students (56.4–16.5%) either did not answer or their answers could not be classified in the cases mentioned above (Category IV). Up to a point, this can be explained by the fact that in some questions [three (two wooden cubes), five (two magnets–unlike poles opposite), nine (two charged bars–like charges opposite), ten (charged bar–piece of paper)] a high percentage of students perceived that there is no force exerted (see previous paragraph) and they, therefore, did not insert a symbol for it. In fact, if we had separated these students who answered 'no force is exerted', from those ones who did not answer questions three and ten (higher percentages), then the percentages of those who did not actually answer were reduced from 56.4% and 48.9% to 17.3% and 21.8%, respectively.

The Relationship Between the Magnitudes of the Forces

The students' answers in the third sub-question 'c' of the ten items of the questionnaire can be classified in the following five categories: I. 'Equal forces are exerted', II. 'Larger entity, greater force exerted', III. 'Larger entity, smaller force exerted', IV. 'There is only one force' (thus there is no reason to compare their magnitudes), and V. 'I don't answer/know'. In category I ('Equal forces are exerted') the percentages of answers were between 51.5 and 13.5%, with higher percentages in questions one (Earth–Moon), eight (two charged bars–unlike charges opposite), nine (two charged bars–like charges opposite), four (two magnets–unlike poles opposite) and corresponding percentages: 51.5, 47.4, 43.6, and 40.2%, respectively. In category II ('Larger entity, greater force exerted') the percentages of answers were between 46.6 and 25.9%, with higher percentages in questions six (magnet–big iron cube), four (two magnets–unlike poles opposite) and two (Earth–Moon), and corresponding percentages: 46.6, 45.5, and 44.4, respectively.

Very few percentages of answers, ranging from 8.6% [question seven (magnet–small iron cube)] to 0.0% [question ten (charged bar–piece of paper)] were identified in the third category ('Larger entity, smaller force exerted'), while in the fourth category ('There is only one force') bigger percentages corresponded to questions two (Earth–Moon, 27.1%), ten (charged bar–piece of paper, 24.1%) and six (magnet–big iron cube, 23.3%).

The high percentage of those who did not answer, for example, questions three (two wooden cubes) and ten (charged bar–piece of paper), 48.5 and 36.5%, respectively, lay in the fact that in the first sub-question 'a' of the respective items they stated that there was either one or no force exerted.

A considerable percentage (51.5–13.5%) of the students of our sample stated that the forces exerted were equal, in accordance with the scientific conception. In contrast, 46.6–25.9% of the students, in agreement with the literature considered that the larger the object, the greater the force exerted. The percentage (2.3–27.1%) who considered that there is only one force exerted was roughly equal to those who stated that there was one force exerted (paragraph 5.1, 0.8–27.1%). However, the latter figure was somewhat lower, probably since some students answered the third sub-question 'c' of each question, regardless of their answers to sub-questions 'a' and 'b'. The high percentage of those who did not answer, for example, questions three and ten, can be explained by the fact that in sub-questions 'b' and 'c' of the respective questions they stated that there was either one or no force exerted.

Looking for Relationships

In this phase, we tried to identify the questions, in which the students' answers were highly concentrated, based on the assumptions of Bao, Hogg & Zollman (2002). Specifically, we calculated the concentration factor C, for each of the ten questions, in all three sub-questions (a, b, c). C "is defined as

$$c = \frac{\sqrt{m}}{\sqrt{m}-1} \times \left(\frac{\sqrt{\sum_{i=1}^{m} n_i^2}}{N} - \frac{1}{\sqrt{m}} \right)$$

where m represents the number of choices for a particular question, N is the number of students, and n_i is the number of students who selected choice i of the question" (Bao, Hogg & Zollman, 2002, p.771).

When the value of concentration factor C is greater than 0.5, this means that the concentration is high. Thus, it is very likely that students apply a common model to comprehend the issue the question poses. When the value is between 0.2 and 0.5, this means that the concentration is moderate. It is quite possible that the students apply two models to cope with the issue in the question. A value lower than 0.2 indicates that the student responses are somewhat evenly distributed, among three or more choices. In this case, students either have no consistent reasoning at all—and respond rather randomly—or they may belong to an evenly distributed population for all the possible models involved in the question (Bao et al., 2002).

Looking at the graphic representation of the concentration factor values regarding the questions (Fig. 1), we can postulate that with respect to sub-question 'a', in questions 1 (Earth–Moon), four (two magnets–unlike

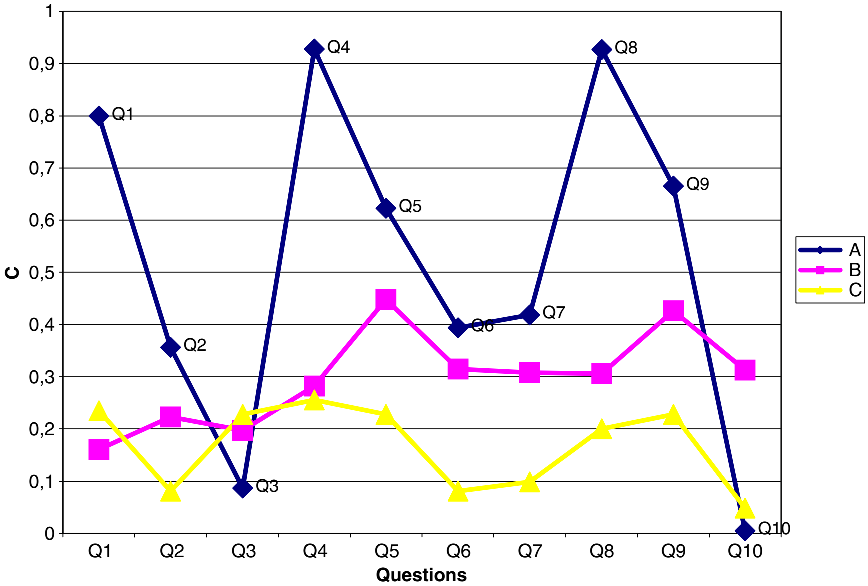


Figure 1. The graphic representation of the concentration factor C value, in all ten questions

poles opposite), five (two magnets - like poles opposite), eight (two charged bars–unlike charges opposite) and nine (two charged bars–like charges opposite), there is some high concentration, which indicates the dominance of one conception. This is the scientific conception and can be attributed to the fact that in these questions there are two ‘active’ interacting entities (planets, magnets, charged bars). The small decrease in questions five and nine (a second important conception appears) might lie in the fact that a significant number of students dealt with the interaction between the two active entities in a different way when the two entities attract or repel each other.

In the same sub-question ‘a’, questions two (Earth–apple), six (magnet–big iron bar) and seven (magnet–small iron bar) show a moderate concentration of answers. The problem seems to be confronted from two different perspectives: the scientific one (the interaction with two forces) and the approach of the action of the ‘active’ entity (Earth, magnets) on the proper entity (the receiver of the action). Finally, questions three (two wooden cubes) and ten (charged bar–a piece of paper) should be dealt with separately. In both, the concentration factor values indicate that either students answered randomly or that their answers are influenced by many factors. In question three (two wooden cubes), we can assume that the first thing happens: the students did not recognize a gravitational interaction between two terrestrial bodies and responded randomly.

However, in question ten (charged bar–piece of paper), where they almost definitely have had some sort of personal experience of the problem, we should assume that their answers were influenced by many factors. A possible explanation is that the experience of electrostatic attraction (between the bar and paper) does not lead them to interact from a distance. It is rather indicative of a static problem like “the piece of paper is stuck to the bar”. If this is actually happening, then it is possible that some students thought of this as a static problem of two entities in contact and they were influenced by many factors (Driver, Squires, Rushworth, & Wood–Robinson, 1998).

Regarding the second sub-questions ‘b’, the concentration factor values indicate the existence of two major conceptions, which have been pointed out, namely, the scientific and the ‘giving model’ one. The concentration factor, in the third sub-questions ‘c’, indicates a rather complex context of student reasoning. The two conceptions (the scientific one and ‘the larger the entity the greater the force it exerts’) seem to dominate marginally when two ‘active entities’ interact, planets (question one), magnets (questions four and five) or charged bars (questions eight and nine), as well as in question three (two wooden cubes), which half the students did not answer. On the contrary, when ‘active entities’ (Earth, magnet or charged bar) interact with passive entities (questions two, six, seven, and ten), there is another strong conception, which supports the existence of one force and complicates the issue.

Based on the first verification of the existence of strong concepts, we moved on to check if there were any relations between student answers, verifying that students kept their views as the contexts (the nature of interactions) change. The check (using cross tabulation and the Chi-square test at the 0.05 level) showed that students tended to answer consistently. For example:

1. Students tended to keep their view about the existence or not of repulsion both in the case of the magnets and of the charged bars (questions five and nine); 184 out of the 223 students who answered, acknowledged the existence of repulsion and 20 out of 223 rejected it in both contexts. Only 19 out of 223 changed their views when the context changed, too.
2. They tended to support the ‘giving model’ or the scientific one in every context. For example, 60/157 students applied the ‘giving model’ and 71/157 applied the scientific one in both contexts—between magnets and charged bars (questions four and eight). Only 26/157 students changed the model they applied when the context changed, as well.

3. They tended to support 'the larger the entity the greater the force it exerts' model or the scientific one when two 'active entities' interacted in every context (gravitational, magnetic, electrostatic). For example, 130/204 students applied consistently either the one or the other model in the Earth–Moon interaction (question one), as well as in the two magnets—unlike for poles interaction (question four). Only 74/204 students changed the model they applied, when the context changed, too.
4. They tended to support 'the larger the entity the greater the force it exerts', the one force model or the scientific one when an 'active entity' interacts with a 'passive entity' in every context (gravitational, magnetic, electrostatic). For example, 97/159 students applied consistently one of the three models in the Earth–apple interaction (question three) and the charged bar–paper interaction (question ten). The rest of the 62/159 students changed the model they applied when the context changed, as well.

Discussion and Teaching Implications

The above results led us to formulate an interpretative hypotheses that provided general guidelines in order to develop our teaching–learning sequence. According to the literature (Duit & Treagust, 1998), we considered that the alternative ideas of the students are constructed from: (a) experiences from teaching–learning in their elementary and secondary education; and (b) the everyday practical experience which co-existed with the local cultural-linguistic characteristics of the students.

Specifically, we hypothesized that:

1) The almost unanimous acceptance of the existence of interaction between celestial bodies, as well as between charged bodies was the outcome of teaching–learning experience. This came about since we considered that the students could not have practical experience of the interaction of celestial bodies and because electrostatic interactions are rarely evident in everyday situations (for example, away from a laboratory-based activity).
2) The existence of the magnet interaction apart from the teaching–learning environment, we hypothesized, is also constructed from within everyday experiences. Moreover, the practical everyday experiences tended to characterize the magnetic interaction mainly as attraction opposed to repulsion. Even in the case of two magnets being found in our hands with

their like poles opposite each other, the final result is usually an attraction. One of the two magnets turns and 'sticks' to the other, borrowing from the outcome of repulsion a momentary characteristic. It thus appears that the representations that resulted from these experiences may justify the reason why repulsion is not confronted by a significant number of students as an interaction of the same 'class' as that of attraction. This was a circumstance, which also appears with analogous regularity in the electrical interactions.

3) It also appeared that the significant percentage of students who rejected the idea that the interaction between two terrestrial bodies, could be attributed to everyday practical experiences. We considered the spread of ideas that appeared concerning the interaction of a charged body with a piece of paper, is due both to the practical everyday experiences of the students and the influence of teaching–learning experiences. As an example, a very common experience is the attraction of a piece of paper to a charged pen, but not vice versa.
4) The representation of force in the form of an arrow is undoubtedly of teaching–learning origin and as introduced through the questionnaire, it referred to this framework. The fact that a significant number of students systematically and consistently utilized the 'giving model', in other words, ontologically handled force as a transferable property could possibly be due to the language used in everyday life.
5) Finally, the systematic appearance of the view: 'the larger the entity, the greater the force it exerts' by a significant number of students may be attributable to a combination of experiences and linguistic characteristics. Very frequently, in the intuitive thought of children we meet the linear connection of two quantities which are interdependent as 'more A, more B' (Stavy, Tamir & Tirosh, 2002).

The above hypotheses brought up the following problem. Teaching can lead to the construction of permanent and consistent non-intuitive concepts, such as with the interaction between celestial or charged bodies. At the same time, an experiential approach to the concept of force interaction, supported by everyday language, reinforces equally permanent and consistent alternative approaches by the students even in contexts in which they have no experience at all. This is even likely to occur in experiential approaches, which are used within the school context. As a consequence, a viable alternative teaching–learning approach would be the design of appropriate educational software including the Newtonian theoretical entities (Hennessy, Wilshart, Whitelock, Deaney, Brawn, Velle, McFarlane, et al. 2007). In this context, and in the first phase, we think that the displacements of bodies reinforcing the connection of force with motion should be left out. When they are introduced (in a second phase), we should make sure they always refer to two interacting objects, so that there is a possibility of connecting interaction and change of motion (motion is also perceived as a relation of the interacting bodies). The artificial environment also facilitates these latter approaches. For example, it accommodates the presence of Earth and a table in the same context, when the table stands on the floor. It allows the placing of a book on the table without eliminating the Earth. We believe that this teaching environment, if combined with an ontological discussion about the autonomous existence of interaction may perhaps contribute to the modification of the alternative ideas of the students regarding the existential, ontological and coarse quantitative aspect, towards the scientific ones. Specifically, we should reinforce the existential aspect of the interactions so as to also include those between an 'active' and 'non-active' entity as well as that between 'non-active' entities. As for the ontological aspect of the interactions, we consider that the determination of the force as a differentiated entity can reinforce the incorporation of attraction and repulsion as the result of the relation of interaction. Moreover, this determination can help in understanding the scientific ontological aspect instead of the 'giving model' (diSessa, Gillespie & Esterly, 2004). Finally, with reference to the coarse quantitative aspect of the two actions of each interaction, we consider that the negotiation of the corresponding mathematical formula ($m_1Xm_{2/}r^2$ or $q_1Xq_{2/}r^2$) may reinforce the conception of the equality between forces' magnitudes and their mutual nature in the interaction, for it reinforces the hypothesis that forces are the result of a distant relation between two physical entities and not the result of the action of one entity on the other. As the formula shows, in the relation, both entities contribute with their masses, charges, magnetic quantities, as well as the distance between them. On the contrary, in an action, we can but assume that the characteristics of an acting entity are those that mostly determine its size.

We estimate that the results of our study are fairly convincing. However, they are more 'negative' than 'positive'. They show with more certainty that we probably cannot achieve the introduction of the concepts of interaction and force in an empirical way in a real/material context, compared with introducing the concept of interaction as a relationship implying force. The latter remains to be verified or falsified through the next steps of our research program.

APPENDIX

Question 4

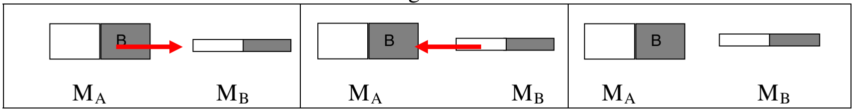
Suppose that we have two magnets fixed on a table. The north pole of one of the magnets is near the south pole of the other.

a) Do you think that magnet M_A exerts a force on magnet M_B?

Yes…… No…... I do not know……

Which of the pictures, (1) or (2), represents this force? If you disagree with the way the force is shown in pictures (1), (2), draw your own on picture (3).

Two magnets on a table



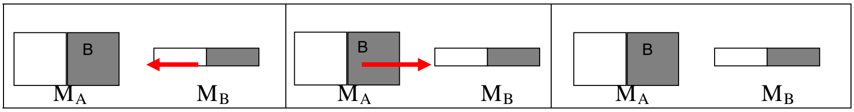
Picture 1 …… Picture 2…… Picture 3……

b) Do you think that magnet M_B exerts a force on magnet M_A?

Yes…… No…... I do not know……

Which of the pictures, (1) or (2), represents this force? If you disagree with the way the force is shown in pictures (1), (2), draw your own on picture (3).

Two magnets on a table



Picture 1 …… Picture 2…… Picture 3……

c) Regarding the above problem, which of the following statements do you think is correct?

Only one force is exerted……………

Magnet M_A exerts a greater force on magnet M_B ……………

Magnet M_B exerts a greater force on magnet M_A ……………

The two forces have equal magnitude……………

d) Justify briefly your above answers. ………………………………………………

NOTE

[1] The ten-item questionnaire is available from the first author

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