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The intertwined effect of collaborative argumentation and whole-class talk on the process of scientific concept learning: A case study☆

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ABSTRACT

There is compelling evidence to show that peer argumentation prompts student scientific concept development at different ages. However, there is also evidence that when students discuss their ideas with their peers, the gains are delayed rather than being immediately evident. Moreover, group outcomes do not seem to be related to individual gains. It is hypothesized that peer discussions trigger a metacognitive process that, in turn, prompts the post-collaborative settlement of students' differences. In classroom settings, it is likely that whole-class interaction plays a relevant role, but this has not yet been properly explored. We conducted a case study with the aim of describing how whole-class interaction may contribute to students' knowledge transformation initiated during peer discussions. We followed one group of four students during a whole unit (Forces) and described how progressive small-group and whole-class interactions prompt the transformation of some notions (gravity and magnetic force) from pre- to post-tests, while leaving others almost unchanged. The results suggest that, while rich peer argumentation around contradictory ideas (discussion) followed by repetitive whole-class arguments may contribute to the progressive transformation of scientific ideas, the mere expression of contradictory ideas, involving tangential argumentation and followed by authoritative whole-class corrections but no arguments, only partially leads to changes. The internalization of the whole-class argument facilitated by peer discussions may enable students to reason in new situations.

1. Introduction

There is compelling evidence to show that peers' discussion of different perspectives (Asterhan & Schwarz, 2007; Aydeniz & Dogan, 2016; Chen & She, 2012; Howe, 2009; Kuhn, 2015; Reznitskaya et al., 2009; Tolmie, Howe, Mackenzie, & Greer, 1993), prompts student concept development at different ages. Following the literature on instructionally induced conceptual change, and the ideas of Piaget, this can be accounted for by the effect of cognitive conflict on scientific knowledge restructuration (see Vosniadou, 2013): contradictory views, when explicitly juxtaposed, prompt students' awareness of their own alternative conceptions, prompting their revision with the consequent knowledge restructuration (Chi, 2008) and/or the replacement of incoherent ideas with accepted ones (Posner, Strike, Hewson, & Gertzog, 1982).

However, there is evidence showing that the simple presence of conflicting views, in which one is the canonical idea, is not

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sufficient to account for student progress (see Limón, 2001). Chan, Burtis, and Bereiter (1997) found that the effect of conflict, especially among peers, on knowledge quality (evolution), is mediated by the deeper knowledge-building activity (and sophistication of the discourse processes) that conflict prompts. Kendenou and colleagues found that, although refutational texts were more effective than traditional texts in reducing the impact of alternative conceptions on knowledge, the presence of scientific conception explanations (Kendeou, Walsh, Smith, & O'Brien, 2014), and their level of interconnectedness or complexity (Kendeou, Smith, & O'Brien, 2013), were the key factors accounting for students' performance.

Argumentation is typically involved when there are different views (particularly controversial ones) and there is a desire to understand, or settle, differences; it emerges in social life when speakers, in order to deal with controversial issues and to reach an understanding, come up with additional pieces of discourse to support a given position and eventually challenge one another's ideas (see Leitão, 2000; van Eemeren & Grootendorst, 1992). Therefore, argumentation is a specific type of dialogue in which opinions are not only formulated but also justified in a rhetorical context of criticism, in which alternative positions, oppositions and counter-arguments are anticipated or explicitly formulated. In terms of classroom talk, argumentation – as a type of discourse in which teachers and students are involved in giving and asking for reasons and challenging one another's ideas, both implicitly or explicitly – is conceived of as a mode of talk in which students not only contribute to the construction of classroom meaning (Reznitskaya & Gregory, 2013), but also formulate arguments to support a given position in the face of an alternative viewpoint.

As a socially discursive practice, argumentation is seen as prompting knowledge construction, at both an inter-personal and an intra-personal level (see Leitão, 2000). According to Leitão (2000), argumentation offers semiotic mechanisms that facilitate knowledge construction: justification, counter-argument and response. Overall, these mechanisms force speakers to be progressively aware of their thinking weaknesses, opening them to alternative views, which in turn prompts knowledge revision.

Scholars such as Nussbaum and Sinatra (2003) state that argumentation “has the potential of deeply engaging students, making their thinking visible, and refuting misconceptions” (p. 385). Through argumentation students evaluate alternative ideas and their merits, being able to metacognitively arrive at accepted ideas. According to Asterhan and Schwarz (2007), “the unique structure of argumentation, which links premises, conclusions, conditions, rebuttals, and so forth, is thought to considerably improve the organization of knowledge” (p. 626), prompting better recall and understanding of scientific ideas.

However, empirical evidence does not fully support this view. First, peer discussions do not necessarily lead to better recalling of ideas, compared to other types of dialogue (see Tolmie et al., 1993). Second, according to previous accounts, the effect of peer argumentation on students' content knowledge depends on scientific ideas being discussed or at least mentioned and, eventually, being acknowledged as accepted solutions, in order to undermine alternative conceptions. However, evidence shows that group solutions or outcomes are not related to gains (Howe, 2009; Howe & Zachariou, 2017), meaning that either scientific ideas are mentioned and acknowledged – but this does not necessarily predict gains (Mugny & Doise, 1978), especially in middle-school students – or there is individual progress despite alternative ideas being agreed at group level (Howe & Zachariou, 2017; Kapur, 2008).

Moreover, empirical evidence also shows that: 1) the effect of peer argumentation on science content knowledge learning is rather stable over time (Asterhan & Schwarz, 2007; Howe & Zachariou, 2017; Rivard & Straw, 2000), which is different from the effect of direct instruction, for example (see Kapur, 2016); and 2) students who discuss their views during peer interaction gain even after the collaborative phase (Howe, McWilliam, & Cross, 2005; Howe & Zachariou, 2017; Tolmie et al., 1993).

Two alternatives have been raised. Howe et al. (2005) suggest that the discussion of contradictory ideas during group work may have the effect of priming and activating discussed ideas, with difference settled later following new physical evidence or consultation with authorities (Howe, 2009). Leitão (2000) and Howe and Zachariou (2017) argue that the practice of argumentation prompts a metacognitive process of knowledge revision that only starts in peer interaction but which continues at an individual level after collaboration, being relatively independent of which ideas were discussed during the collaborative phase. According to Limón (2001):

> On the other hand, presenting conflicting information helped students to reflect more about their ideas to give an explanation of the phenomena studied, and possibly this reflection could activate their curiosity about the phenomena taught. Even if no weak or radical change is produced as it was predicted, presenting anomalous data may promote the first steps of the process of conceptual change.
>
> (p. 364)

Collaborative argumentation, that is, argumentation occurring among peers in collaborative activities, can trigger a process of content knowledge learning that continues at an individual level through a process of individual reasoning (see Larrain, 2017a), influenced by subsequent consultations or learning experiences. More than the complete abandonment of alternative conceptions (see Mortimer, 1995), such a process of learning would consist of the progressive organization of scientific knowledge around arguments and counter-arguments: knowledge that would be characterized not by the mere presence of a given scientific idea, but by the use of the argumentative sequences through which alternative conceptions are discarded. More than static ideas, knowledge would be seen as a process of inner argumentative speech where claims (statements about a state of affairs) are supported by an additional piece of discourse (justification) composed of arguments, which in turn are contrasted by counter-arguments. In fact, recent evidence suggests that, when faced with juxtaposed ideas (alternative conceptions and scientific explanations), students inhibit and neutralize alternative conceptions (Diakidoy, Mouskounti, Fella, & Ioannides, 2016; Mason, Zaccoletti, Carretti, Scrimin, & Diakidoy, 2018).

Yet again, how does individual reasoning triggered by peer argumentation lead to canonical scientific ideas? How is difference settled productively? Feedback from the authorities might be relevant (teachers, parents, older siblings, the Internet, etc.). In fact, in real classrooms small-group argumentation rarely occurs in isolation, but is rather embedded in curricular units in which knowledge is designed to be learned progressively and accumulatively throughout several lessons (see Davis & Krajcik, 2005); in which many small-group interactions may occur, feeding one another (see Reznitskaya & Gregory, 2013); and in which whole-class interaction plays a crucial role: plenary discussions and teachers' explanations give valuable feedback to students. There is recent evidence to suggest that instructional design boosts the effect of classroom argumentation on delayed content knowledge learning (Larrain, Howe, & Freire, 2018). It is likely that a designed epistemic progression combined with repetitive experiences of small-group discussions – that is, argumentation in which contradictory ideas are argued for, and whole-class plenaries in which group outcomes are discussed – may lead to content knowledge gains. So far, however, little attention has been paid to the intertwined and progressive effect of small-group and whole-class discussions on scientific understanding (see Mason & Santi, 1998, for an exception). On the one hand, there is considerably more empirical evidence relating small-group interactions than whole-class talk to learning (see Howe & Abedin, 2013; Muhonen, Rasku-Puttonen, Pakarinen, Poikkeus, & Lerkkanen, 2017). On the other hand, although there has been a clear focus on classroom talk in the past two decades arguing for the benefits of dialogic modes of talking for learning (see Alexander, 2001; Mercer & Littleton, 2007; Wells, 1999; Nystrand, Gamoran, Kachur, & Prendergast, 1997), the differential role of small-group and whole-class talk has received less attention.

In order to contribute to filling this gap, we conducted an exploratory in-depth case study, the aim of which was to describe and understand how primary-school students' scientific ideas discussed during group work are transformed along several group-work instances followed by whole-teaching interactions. The research question we wanted to address was: *Does – and, if so, in what way – whole-class talk contribute to productively settling differences that emerged during group-work discussions*?

2. Method

2.1. Design

We conducted a case study because, given the exploratory nature of our questions, we wanted not to generalize but rather to describe and understand the further process of the transformation of ideas discussed during group work, being able to grasp all of its complexity relying on different sources and data (Stake, 2000). We followed one group of fourth-grade students (10–11 years old) during the teaching unit on Forces (six lessons), with curriculum materials especially developed to foster argumentation. The group was part of a larger study that had the aim of evaluating the effect of curriculum-material-supported argumentation on content knowledge learning (Larrain et al., in press) and exploring how curriculum materials especially designed to foster argumentation might support teacher use and orchestration of argumentation (Larrain et al., 2017).

2.2. Participants

From the 30 fourth-grade students (18 females) participating in a larger quasi-experimental study working with curriculum materials that fostered argumentation (Larrain et al., in press), we selected one group of students that showed a higher frequency of group-work argumentative utterances during the six lessons of the unit (129 versus 71 formulated by the group that follows). The students attended one privately administered, but publicly funded, school from Región Metropolitana, Santiago, Chile. All of the children came from families of medium to low socio-economic status. We invited this particular school to participate in the study because: (1) it was a publicly funded school; (2) it was located in a vulnerable area of south Santiago; and (3) we were acquainted with the school principal. Students were aged between 10 and 11, and all were native speakers of Spanish and ethnically homogeneous. The teacher was a male primary-school teacher aged 43, who at the time of the study was teaching Physical Education, Science and History in the fourth grade. From the five students (all female) that participated in the group, only four gave their own, and their parents', written permission. So, although the fifth girl was part of group interactions (identified as S/C in the transcripts), she didn't participate in individual pre- to post-test measures.

2.3. Procedure and materials

2.3.1. Procedure

The teacher agreed to teach the unit on Forces using lesson plans especially designed to foster dialogic and argumentative interactions, in both whole-class teaching and peer-group interactions. The teacher took the knowledge written tests both before and after teaching the unit. Post-tests were taken on two occasions: one immediately after finishing the unit and the other four weeks later, on average. In addition, we conducted individual interviews after each written test. Below we describe the measures and materials used.

The first phase of the study began with the collection of permission from the teacher, parents and students; the participant teacher then met the research team at each school. We then attended Science lessons in both classes (90 min each) weekly for six weeks. All the lessons were videotaped using seven sets of video cameras and microphones: one captured whole-class interactions and the other six recorded the small-group interactions. Lessons, including whole-class and small-group interactions, were transcribed. Finally, as a follow-up measure we returned to schools one and two years after the intervention had finished and individually interviewed each student following the script of the pre-interview described below.

2.3.2. Classroom materials

To foster argumentative and dialogic interactions, we used an adapted version of Forces through materials originally developed within the epiSTEMe® project (Ruthven et al., 2011) and adapted in a replication study (Larrain et al., 2018) that had the aim of promoting whole-class and peer-group dialogic interactions. EpiSTEMe Forces lessons are based on carefully structured problem situations designed to activate students' wider experiences and to promote a scientific enquiring attitude in order to develop scientific concepts (see Howe et al., 2015). These lessons are particularly coherent with the aim of fostering argumentation, insofar as they are designed to promote discussion and exploratory talk in both whole-class and small-group interactions. Each lesson began with a whole-class warm-up activity, in which previous ideas were activated and discussed; this was followed by problem-solving activities, which had to be developed in small groups, and ending again with whole-class plenaries. A large proportion of the small-group, problem-solving activities had hypothesis-testing designs, in which students first had to discuss and agree on predictions, then test their predictions through hands-on activities, and finally discuss the outcomes and agree on a conclusion. Finally, the groups shared their outcomes in whole-class interactions guided by the teacher. The adaptation, conducted in the context of a replication study (Larrain et al., 2018), involved the re-design of five lessons insofar as the British and Chilean curricula differ.

2.4. Measures

2.4.1. Forces learning

We used three equivalent versions (in terms of difficulty and reliability) of disciplinary content knowledge tests originally developed by Howe et al. (2015) and adapted by Larrain et al. (2018). The Cronbach alpha coefficients for each version were: pre-test, $\alpha = 0.89$; post-immediate, $\alpha = 0.92$; and post-delayed, $\alpha = 0.89$. Each version included 19 items on the topics covered by the module. Each test began with seven items, where correct answers had to be selected from options. For example, "When is a car stopped?" Options: although there are forces acting on it, they can't move it because it is too heavy; there are no forces acting on it; only gravity force is acting on it; there are balanced forces acting on it. "We call trajectory…" Options: the movement of an object; the distance that an object runs when moving; the path of a moving object through space. The maximum score for the section = 7. These were followed by 12 items relating to conceptual application to real-life examples. For example, "Pablo pulls a tree with a 1200 newton force but the tree doesn't move. What is the amount of force that the tree exerted over the string?" Options: fewer than 1200 N; 1200 N; >1200 N. The maximum section score = 17. Most items in the knowledge tests were straightforwardly correct or incorrect. Two items were open, with a maximum score of two each. In total, therefore, the maximum score for each test was 21. As a result, every student was assigned scores out of 21 for each test, with 2 indices of learning gain computed by subtraction: 1) pre- to immediate gain, that is, immediate post-test score less pre-test score; and 2) pre- to delayed gain, that is, delayed post-test score less pre-test score.

2.4.2. Individual interviews

We conducted individual oral interviews to explore the students' understanding of the notion of forces from a qualitative point of view. Interviews were conducted based on standardized scripts especially developed for the study by the researcher team based on the work of Howe, Tolmie, Anderson, and MacKenzie (1992). Different scripts were developed for the pre-, post-immediate and post-delayed versions of the interview. In the pre-version of the interview we showed two identical paper sheets to students and asked them to fold one into two parts, forming a rectangle. Then we asked them to predict and explain which sheet would hit the ground first if they were dropped from the same height. In the post-immediate version of the interview we showed a stone and a metallic clip to students and then asked them to wrap them into identical sheets, forming two small balls of the same shape and size. Then we asked them to predict and explain which ball would hit the ground first if they were dropped from the same height. In the post-delayed version of the interview we showed a balloon filled with helium and metallic clips and we asked them to use the metallic clips to make the balloon stay still without reaching either the ceiling or the ground. Then we asked them to explain the effect of the metallic clips on the balloon. The interviews were piloted with fourth-grade students. We posed concrete situations involving objects falling, and asked students: 1) to predict what would happen; 2) to conduct the experience; 3) to explain what actually happened; and 4) to answer some additional questions. The interviews lasted around 20–30 min each, and were conducted in the school library by educational psychologists especially trained by one of the authors based on the pilot videotaped interviews and including field supervision. All interviews were videotaped and then qualitatively analysed.

2.4.3. Group-work dialogue

We analysed students' dialogue during collaborative work for the whole sample of the larger study. From the total small-group talk we selected on-task talk. We used a coding scheme developed by Larrain et al. (2018) to analyse small-group-work argumentation based on the work of Leitão (2000); that is, identifying the critical sequence of argumentative dialogues. Our unit of analyses was utterances. The codes that were developed are defined and exemplified in Table 1. Two trained judges (one educational psychologist and one co-author) coded 30% of the transcripts in seven rounds using The Observer XT (Noldus ©). In the last round, agreement in all the codes was above 96%, which was considered excellent, with the exception of students' counter-arguments (65%), which was considered only acceptable. The differences were discussed and resolved. Once the coders had reached agreement, one of them coded the remaining material. We calculated the total score for each group for each observation corresponding to the total frequency of argumentative utterances observed in the group.

2.5. Analysis

We analysed two types of data: students' measures and classroom interactions (small group and whole class). Regarding measures,

Table 1
Definitions of small-group argumentative utterances.

	Definition	Example
Justificative questions	Students' questions that ask for reasons and justifications in a context of controversy.	S1: I say C. S2: I say A. **But why do you say C?**
Argumentative questions	Students' questions that invite people to agree or disagree with a given claim.	S1: Then shall we put human force? S2: Okay, human force. S3: **Who agrees with human force?**
Arguments	Students' formulations of reasons and justifications to support a claim.	S1: Which of these objects would a magnet attract? Why? S2: Clip, metallic ball and nail. S2: **Because they are made of iron and the magnet sticks to the iron.**
Counter-arguments	Students' formulations of reasons and justifications to discuss an argument or counter-argument.	S1: Who executed the force? S2: The string, because it is cutting the plasticine up. **S3: No, the string cannot execute any force; we made the force, not the string, because it has no force.**

Bold emphases indicate the identification of the code.

we analysed them by student, identifying students' performance in the written test by concept measured, and concept understanding in the interviews. The unit of analysis here was each student, following a longitudinal look; then we identified transversal commonalities and organized the answers in a comparative way. We then identified the main progress made from pre- to post-test measures. Regarding classroom interactions, we organized the transcripts in one long sequence, intercalating whole-class and the selected small-group transcripts as they occurred in the classroom. First, based on the previous coding we identified the moments during small groups in which there were contradictory ideas and discussions (formulation of arguments and counter-arguments). We identified the concepts and ideas involved in those contradictions, and traced them backwards and forwards to identify when, where and how they appeared, and whether they were transformed during the unit. Then we came back to students' measures to describe the relationship between how they were treated and discussed during classroom interactions, and the students' progress. Finally, we conducted a narrative analysis in which we described, with a historical focus, lesson by lesson, the relevant interactions in both whole class and small group, considering the transformation of students' ideas.

3. Results

3.1. Students' progress

The group made up of Jaci, Ada, Fiona and Jo formulated more argumentative utterances during group work than the other groups (see Table 2). So, as can be expected given the available empirical evidence, the students, except for one who missed the post-tests (Jo), gained from pre- to post-tests considerably more than the class average. Fiona and Jaci, the two students from the group who took the post-delayed test, improved even from post-immediate to post-delayed test. Two students (Ada and Jaci) were above the class average on pre-test performance, and the other two were below it (Fiona and Jo).

Table 3 shows students' responses to the Forces knowledge test (correct = ✓; incorrect = x) according to the concepts involved in the different items. Although at the beginning of the unit they showed some knowledge of balanced forces, especially in the application questions, they showed considerably less previous knowledge regarding gravity and weight, speed and force of friction. The pre-interviews (selected answer in Table 4) revealed that, although students could correctly predict which sheet would hit the ground first, their explanations shared alternative conceptions: namely, that heaviness explains objects falling and that weight increases when an object is compressed. Although air is mentioned in the students' explanations, and it is supposed when Jo and Jaci say that the stretched sheet "flies", it is only explicitly mentioned by Jo to support the idea that heavy things fall faster: the wind would push the heavier sheet to the ground.

The post-tests show clear progress in the case of Fiona and Jaci regarding balanced force. They also progress in the notion of trajectory, gravity and speed, particularly in the application items, but no progress was observed regarding the notion of friction. This is not surprising given that during the unit little attention was paid to exploring this notion. Post-interviews revealed (see Tables 5

Table 2
Descriptive statistics.

Variable	N	Mean	S.D.	Fiona	Jo	Ada	Jaci
Forces knowledge (FK) test pre-	26	10.15	3.01	9	7	14	11
FK post-immediate	30	10.29	3.36	12	–	16	13
FK post-delayed	22	12.45	2.77	14	–	–	15
FK pre- to post- immediate gains	23	0.91	5.51	3	–	2	2
FK pre- to post- delayed gains	22	2.40	2.53	5	–	–	4
Proportion of argumentative utterances/min of group work	26	0.11	0.12	0.53	0.09	0.32	0.09
Total frequency of group argumentative utterances (excluding claims)	39.6	39.57	39.57	129	129	129	129

Table 3
Written forces knowledge test pre- to post-gains by concepts involved in items.

Type of question	Concept involved	N°	Fiona			Ada		Jaci		
			Pre-	Post-immediate (PI)	Post-delayed (PD)	Pre-	PI	Pre-	PI	PD
Conceptual questions	Balanced forces	2	x	✓✓	✓✓	✓x	✓x	xx	xx	x✓
	Forces	1	✓	✓	✓	x	✓	✓	✓	✓
	Trajectory	1	x	✓	✓	✓	✓	x	✓	✓
	Weight	1	x	✓	x	x	x	x	x	x
	Speed	1	✓	✓	x	x	x	x	x	x
	Movement	1	x	✓	✓	✓	✓	✓	✓	✓
Application questions	Balanced forces	4	✓✓✓x✓	xx✓✓	✓✓✓x	xxxx	xx✓✓	xx✓✓	xx✓✓	✓✓✓✓
	Gravity and weight	4	xxxx	✓xxx	✓xxx	xxxx	✓✓✓	xx✓✓	xx✓✓	x✓✓✓
	Speed	3	✓xx	✓✓x	✓xx	xxx	✓✓✓	xxx	✓✓x	✓✓x
	Force of friction	1	x	x	x	x	✓	x	✓	x

and 6) an interesting dimension of this progress. Regarding the notion of weight, students were persuaded that heavier objects fall first, which was consistent with the post-delayed experience but not with the post-immediate. When asked to explain why the two balls fall at the same time, despite the fact they have different weights (post-immediate interview), the three of them identified gravity as being involved. Surprisingly, however, Ada, who at the beginning of the unit thought that gravity attracted objects to the ground, suggested that it made one ball slow down (thus pushing upwards). In the last question of the post-immediate interview Jaci said that magnetic force might be involved in the balls falling, but immediately retracted this, saying that this was not possible because there was no magnet. Finally, it is worth noting how in the post-delayed interview the three students (Fiona, Jaci and Ada) identified gravity as pushing both upwards and downwards; moreover, they mentioned magnetic force as being involved in the balance of the balloon. Ada and Jaci not only identified, but also discarded, it because there was no magnet. As we will see, in order to discard the participation of magnetic force they used an argument insistently repeated during the unit, in both whole-class interaction and then group work.

3.2. Students' progress tracked through group work and whole-class interactions

From the narrative analysis three types of transformation of students' ideas through interaction emerged. Overall, they focus on three key concepts that emerged in classroom interactions from lessons 1 to 6: weight, gravity and magnetic force.

1. *Contradictory ideas and evidence with little argumentation.* This section addresses the notion of weight as a relevant factor in objects falling. Evidence regarding weight and speed was gathered during lessons 1, 2, 3, 4 and 6 (the former two regarding horizontal movement; the latter three regarding horizontal fall). In all these cases, contradictory ideas emerged, mostly in the form of different predictions, but the evidence they gathered during small-group work supported the idea that weight is a relevant factor for the speed of objects' movement (both horizontal and vertical). Argumentation and discussions during small-group work regarding these notions were limited, with students tending to reach agreement quickly. Whole-class talk involved the emergence and justification of contradictory ideas, but there was no exploration of the possible explanations: the action of friction, mass, gravity and acceleration were never clearly accounted for. In the following, there is a detailed description of the process.

In lesson 1, in one of the first whole-class interactions when the class was discussing whether or not a car was moving (see Table 7 for the activities on each lesson), weight emerged for the first time as a relevant factor for objects' speed: a student associated lightness with speed, saying that lighter cars run faster. This idea reappeared during lesson 2. During group work, when Fiona, Jo, Ada and Jaci had to predict which ball would reach the finish line first, they rapidly, and with no exploration of alternative arguments (in 8 turns), agreed on the smaller one because it was lighter (argument given by Jaci). Then, in the whole-class plenary the students publicly disagreed: some argued for the smaller and others for the larger one, both giving the balls' weight as justification. After evidence had been gathered, the class accepted that the smaller ball ran faster because it was lighter. There was no further explanation concerning the relationship of weight, gravity, friction and acceleration.

In lesson 3 whole-class plenary students initially disagreed on their predictions regarding which washer would move a plastic car and hit the ground first (see Fig. 1 to track the description). Then the class agreed that the larger washer would hit the ground first because it has more force – and the smaller one less – than the car. In the following group work, before the experience, Ada reformulated this explanation, saying that the smaller one wouldn't reach the ground because it had insufficient weight (argument). Although they didn't elaborate much on the prediction and became absorbed in the hands-on activity, Fiona disagreed, stating that the smaller washer would reach the ground faster (with no justification). Whereas in Ada's contribution, an implicit and coherent view of unbalanced forces was operating, in Fiona's case previous contributions (lessons 1 and 2 whole class, and lesson 2 group talk), regarding the relationship between lightness and speed in horizontal movement, seemed to predominate. After doing the hands-on activity they briefly shared their conclusions in a whole-class interaction, devoting only three turns to explain what they had observed. The teacher asked: *Which washer took more time to reach the floor*? And a student answered: *The car with the bigger washer.* T: *Why*? S: *Because it has more weight.* T: *Okay*! Again, weight was accepted as the main factor in objects' speed, without exploring its

Table 4
Pre-interview students' responses.

Question no.	Answers			
	Fiona	Jo	Ada	Jacinta
1. Which sheet of paper will fall first? What makes you think so?	This one (the folded one) will fall first. Because when they fold it the weight comes here and pushes down with more force.	That they won't fall to the ground at the same time because this one (the unfolded one) flies more. Because as it falls this opens up; it sort of flies (makes the paper flutter). The wind makes it, the sheet of paper, fall like this; it moves the sheets.	That the folded one will fall first. Because it'll be folded and… it'll weigh more.	I think this one (folded) will fall first. Because it gains weight when you fold it. And the sheet is lighter than everything else. Like when you drop a ball and it falls quickly, but if you drop a sheet of paper, it moves like this (floating motion) and it'll take much longer.

Table 5
Post-immediate interview students' responses.

Question	Answers		
	Fiona	Ada	Jaci
1. What do you think will happen if you drop both balls from the same height? Will they fall at the same time? Will one fall first? Which one? What makes you think so?	The stone will fall first because it's heavier, and because of gravity it'll fall faster.	That this one with the stone will fall faster, because it's heavier.	One will fall faster than the other. The one with a stone inside.
2. Was it what you expected? Could you try to explain what you saw?	Because they are wrapped.	Because… um… I don't know.	Because we may have applied the same force.
4. Why do you think the two balls, despite not "weighing" the same, reach the floor at the same time?	I don't know. Because there's gravity.	Because of gravity, that makes them [*makes a downwards motion*], from the same distance, it makes them touch the ground at the same time.	Because they have the same force and the same height.
8. Imagine that a classmate tells you that he thinks that the heavier an object, the faster it falls. What would you say to him?	That it's correct. I mean, no, because we just did that and it didn't work. It may depend on what's outside.	Because the heavier something is, the more it's pulled downwards.	That it's true. Because if you throw it down hard, it can fall faster than the other.
[*Only in Jaci's interview.*] 9. But look, let's remember this exercise (the one with the balls with a clip and a stone inside). What was different about them? And did one stone fall faster than the other? What may have happened? Gravity. But, then, what influences this? Apart from gravity?			That the stone is a heavier object. No. Because of gravity. Magnetic force. I think it can't be magnetic force because there must be a magnet. Because when you make a ball with that inside, the weight of the sheet increases; it becomes heavier.

Table 6
Post-delayed interview students' responses.

Question	Answers		
	Fiona	Ada	Jaci
1. If we filled the balloon with water or flour, for instance, what do you think would happen if you released it? What makes you think so?	They would go up because they have helium, and helium is an air that makes them float. If we fill a balloon with flour it goes down because it's heavy, but this one (the balloon filled with helium) is lighter.	They fly. I don't know. It goes down because the weight of the flour pushes it downwards. The balloons that fly up may have a magnet inside, because, I don't know, they stick to the magnet. But only on iron; that's not iron.	It goes up because they put helium in it. Because it has something inside it, something much heavier than helium.
8. In which direction does "weight" or "gravity" push the object? What forces acting on the balloon can make it go up, go down, or stay suspended in the air?	Up? Down. Gravity makes it go up suddenly. Not only down. [*Referring to the other forces that affect the balloon.*] Force… I only know a few forces. Centrifugal, gravity, human, um, I can't remember the others. Magnetic? With the regular balloon, when you rub it on your head it sticks, and we could do the same with this one.	Gravity? Down. It pushes the regular balloon down and this one up. I don't know. Could be magnetic because it has some magnets. But this one has no magnets. It could be gravity.	Magnetic force? No, I don't think it's that one because that one pushes things down. But magnetic force needs a magnet. The force of gravity pushes things up. Because if we were on the planet and there were no gravity, we'd be floating.
[*Question for Jaci only.*] If there were no gravity, we'd be floating. And where does gravity push things?			Down. Because gravity… helium and gravity, because helium makes it go up and gravity makes it go down.

relation to gravity, friction or acceleration.

In lesson 4 weight emerged in whole-class interaction around the discussion of which object (metallic clip or metallic washer) would reach a magnet first. One student said that the washer would reach the magnet first, justifying it through a relation between the washer's form and its weight (see Table 8, turns 432 and 437), followed by a disagreement stating that the lighter object would be attracted faster (turns 433, 436 and 437). The teacher settled the prediction in turn 440 and obtained the feedback from the activity.

Table 7
Summary of activities and contents worked by lesson.

Lesson/theme	Whole-class activities	Group-work activities
Lesson 1	1. Initial discussions regarding what movement is. 2. Plenary regarding woodlouse group-work activity. 3. Discuss from a set of objects whether they are moving.	1. Following the path of a woodlouse, discuss notions of trajectory and displacement.
Lesson 2	1. Plenary to discuss group-work activity.	1. To predict which ball (among three balls of different sizes) would reach a finish line first. To measure the time every ball takes to reach the finish line, and to discuss why that happens.
Lesson 3	1. Initial discussion regarding objects falling. 2. Plenary discussion of group-activity outcomes.	1. To predict what would happen if they left a plastic vehicle on the table with washers of different sizes attached to it by a string, and left the washers to fall to the floor. To implement the activity and discuss the outcomes.
Lesson 4	1. Initial discussion of images. 2. Plenary discussion of group-activity outcomes. 3. Plenary discussion of group-activity outcomes. 4. To discuss which type of forces are involved in different situations.	1. Discussion of forces acting on situations (images). 2. To describe the changes in the different materials and to discuss why objects change. 3. To predict which objects would move with the effect of a magnet. To implement and discuss outcomes.
Lesson 5	1. Initial discussion of images. 2. Plenary discussion of group-activity outcomes.	1. To discuss if forces are balanced or unbalanced in daily situations presented in three images. 2. To discuss the situation of an *accelerated car*.
Lesson 6	1. Plenary discussion of group-activity outcomes. 2. Synthesis of ideas worked on during the unit.	1. To predict on which surface a car would run faster. To implement the activity and discuss the outcomes.

Yet again, they did not elaborate on the explanation of why the clip was attracted faster and why the weight would have been a relevant factor.

Finally, in lesson 6 they resumed the activity of the car with the washer attached to it. Students were asked to discuss why a car attached to a metallic washer would move compared to a car with no attachment. In the whole-class plenary Jaci said: *The car is going to fall because of the weight of the washer. Without the washer it does not fall because the string does not weigh more than the car but the washer does*. Then the teacher asked what would happen if there were two washers of different sizes, and Jaci said: *It falls but if the washer has less weight it falls slower.* The teacher then asked about the relationship between gravity and the washer's fall. One student answered (and another then repeated): *The two fall down*. When the teacher tried to explore the conception of mass and gravity as objects fall down, the students agreed that the common aspect of weight and gravity is weight and that heavy objects fall more quickly than light objects. Jaci said: *If the washer has more weight, then the car falls faster, and if it has less weight, then it falls slower.* With this conclusion the unit ended.

In summary, the notion of weight was present in almost all lessons except lesson 5. It emerged to account for objects' speed during horizontal and vertical movement, but this distinction was never explicitly discussed. Two contradictory ideas were constantly and repetitively involved (*heavier objects move faster; lighter objects move faster*), and there was some argumentation around them, but the disagreements were never explored in-depth (counter-arguments seldom appeared) and they almost did not occur during small-group interaction. The evidence gathered during the hands-on activities showed both ideas to be true, and as the notions of friction, acceleration and gravity were not systematically incorporated, we observed an almost irreflexive acceptance of the relationship between weight and speed. Although in Jaci's last intervention some progress is evident (probably due to related notion transformations, for example, gravity and balanced forces), overall, ideas related to weight and speed remained unchanged. Even one and two years later, in the post-delayed interview, Jaci, Ada and Fiona still thought that a folded piece paper would fall faster because its weight increased when compressed.

2. *Tangential peer argumentation with whole-class correction but no argument*. This section addresses the notion of gravity. The group expressed different and contradictory ideas regarding where gravity pulls to, but these ideas were not argued and counter-argued directly. Then, although in whole-class interaction the “right” notion of gravity was insistently expressed, the “wrong” notion of gravity was never explored and no argument was given to completely discard it: it remains juxtaposed, even for students that initially didn't hold this notion (Ada and Jaci). In the following, there is a detailed description of the process.

The notion of gravity emerged in classroom talk from the beginning (see Fig. 2 to track the description). In lesson 1, in the initial whole-class interaction, gravity emerged in students' interventions as something that is involved in the movement of objects and as a force that attracts us to the ground. Then, in the whole-class discussion of whether different objects (boiling water, runner, car, and plant development) move, gravity was identified as a relevant factor. It emerged as being related to magnetic force: when discussing the image of the runner, while one student said that beyond human force, gravity is involved, another student stated that it is

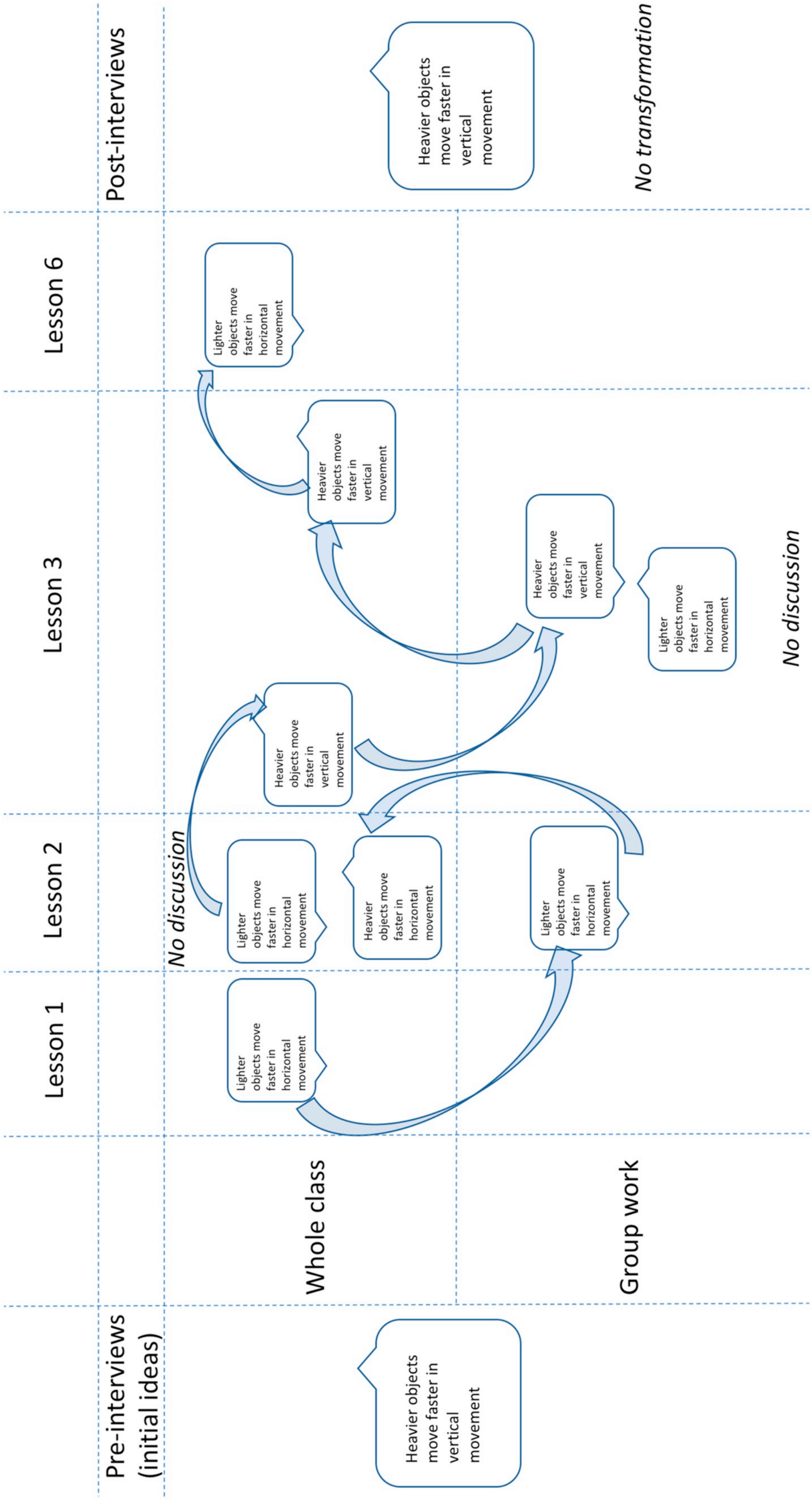

Fig. 1. Description of the evolution of the notion of weight.

Table 8
Whole-class interaction, lesson 4, activity 1.

Turn	Participant	
430	Student 8	Teacher, I think it's the washer.
431	Teacher	Why?
432	Student 20	Because the round body allows it to move more… and attracts it more strongly because it's bigger.
433	Student 4	Because one is lighter than the other.
435	Student 1	Because one is heavier.
436	Teacher	The size is important, also the shape… but we'll see that in a minute.
437	Student 15	Teacher, it's not clear… because the paper clip is lighter but the washer can roll.
438	Teacher	Well, okay… okay, let's think about this a little, look… if this is smaller, is it lighter? Or is this smaller and heavier?… Which one will need more distance or less distance to attract it?
439	Student 4	The washer.
440	Teacher	The washer because it's heavier. Okay, you're predicting now… let's put this into practice. Let's try the paper clip, watch out. What forces are acting here?
441		[*They perform the activity together.*]
442	Student	The force of gravity.
443	Student	Magnetic force.
444	Teacher	Great, you remembered the magnet. Now you can't tell me it's magnetic force when a body is attracted towards Earth. What attracts bodies to Earth?
445	Student	Magnets.
446	Student	The… what attracts things to Earth?
447	Student	Gravity…
448	Teacher	What attracts metals?
449	Students	Magnets.
450	Teacher	And what force is that?
451	Students	Magnetic.

magnetic force that is involved. There was no further clarification from the teacher.

In lesson 2, in the whole-class plenary where students shared their predictions on which ball would hit the finish line first, gravity was mentioned by the teacher as a force that attracts objects to the ground. It is surprising, however, that gravity was not involved in the discussion of lesson 3 regarding the different-sized washers and the movement of the car attached to them. It only reappeared again in the initial whole-class interaction of lesson 4, in which the class had to discuss forces acting on everyday situations (an apple falling from a tree, an astronaut, two human feet from below, and a paratrooper falling to the ground). Gravity was identified as acting on the astronaut, and even when different conceptions were expressed, they were not explored and argued for (see Table 9). For instance, in turn 28 a student stated that gravity attracts more on the moon; then in turn 34 another student said that in space gravity is minus zero, which was reinforced in turns 36 and 38 when a student insisted that there is no gravity because there is no air (both notions are reported in the literature as common alternative conceptions). In turns 40 and 42 gravity is conceived of as something that attracts objects to the ground involved in the falling of the apple from the tree. Regarding the image of the paratrooper, there was disagreement about whether there are forces acting on it. Whereas in turns 69, 72, 74 and 83 students stated that there is no force, in turns 70, 80 and 85 the force of air was identified as acting on the parachute. Interestingly, in turn 70 one student stated that air pushes the parachutes, but it was not clear whether it pushes it upwards or downwards.

When students had to discuss the image in small groups, we observed the first group-work interaction in which there was an extended discussion, that is, an engaging interaction in which arguments and counter-arguments were discussed to reach an agreement on a solution. Table 10 shows the discussion of Fiona, Ada, Jo and Jaci. The first force mentioned by Fiona was human force, following the point where the whole-class discussion of this image ended (turn 65, Table 9). However, Ada disagreed, formulating an argument: gravity is acting on the feet because it is an attracting power (turn 104). Interestingly, Fiona disagreed, formulating a counter-argument that expresses an alternative conception: it is not gravity because gravity makes things float (see turn 105). After agreeing that the feet are not floating, Ada discarded gravity (turn 109) and Fiona formulated a new argument proposing magnetic force as something that can attract them to the floor (turn 110). However, Ada returned to the notion of gravity as something that attracts, and then changed her mind, insisting on gravity as acting on the feet (turn 111) and formulating a counter-argument directed to Fiona's (turn 105) counter-argument. Fiona and Jaci agreed with no further discussion, leaving the two contradictory notions of gravity (something that pulls down and something that makes thing float) both juxtaposed and accepted (in turn 118 Fiona insisted that gravity is acting on the apple because it is floating). Turn 141 is rather confusing: Ada, speaking to herself, discarded gravity as acting on the paratrooper because it does not attract him (formulating a counter-argument directed to the argument that gravity might be involved because it attracts the parachutist), and considered magnetic force as possibly acting on him instead. After Fiona's counter-argument, Ada again considered gravity as possibly acting on him (145). It is worth noting that human force (weight) and gravity are seen as different forces (147), and also that the parachutist is seen as not having weight. Ada again insisted on gravity as acting on the paratrooper (154), but Jaci insisted on magnetic force acting on him, and gravity was not mentioned again.

In the plenary discussion that followed the previous interaction, when discussing the image of the feet, Fiona disagreed with another group about gravity attracting the feet to the ground, saying: *It is human force because the human causes its attraction to the floor*. No one disagreed, implicitly accepting that gravity is not involved in what they call human force. Then the teacher drew

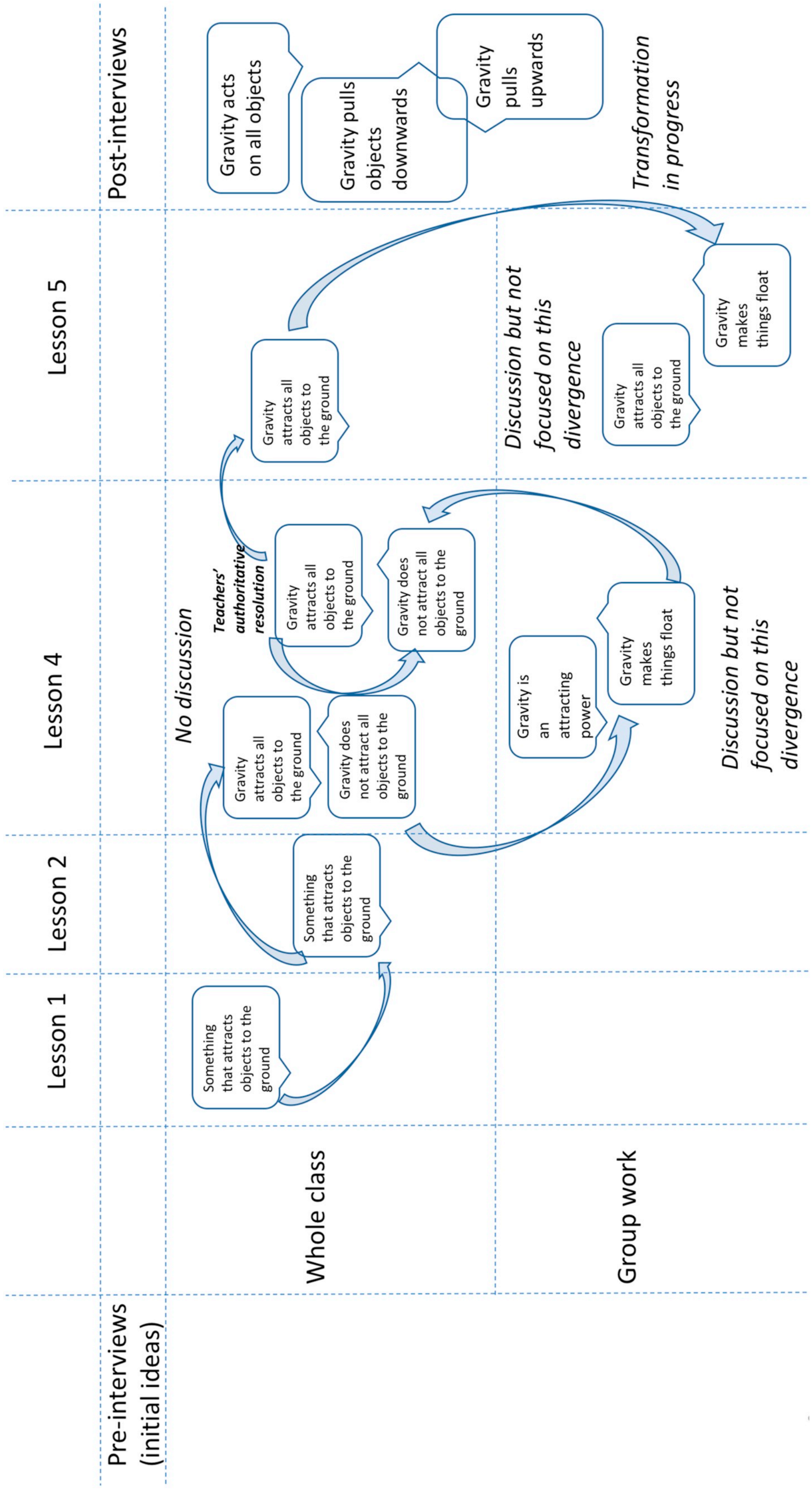

Fig. 2. Description of the evolution of the notion of gravity.

Table 9
Whole-class interaction, lesson 4, activity 3.

Turn	Participant	
21	Teacher	What force is acting?
22	Student 4	Gravity.
23	Teacher	Where?
24	Students	On the astronaut.
[…]		
28	Student 4	Yes, because on the Moon the attraction is stronger than on Earth.
29	Teacher	Does anyone have a different answer? E., What about you?
30	Student 5	Gravity is what keeps us here.
31	Teacher	C.? What do you think it is? Is it floating in…?
[…]		
34	Student 7	In space gravity is below zero.
35	Teacher	B. says that in space gravity drops to zero. Does that mean there's no gravity?
36	Students	Nooo.
37	Teacher	Tell me, Hey, A.,
38	Student 8	Teacher, there's no air there and we don't breathe… and it's, there's a vacuum there.
39	Teacher	Okay, let's analyse one by one… What force is acting here? [*Points to the picture of the falling apple.*]
40	Student 8	Teacher, some time ago you told us… some time ago you showed us this, there was an apple in the tree and it fell to the ground.
41	Teacher	So this is? Force of…?
42	Student 9	Force of gravity because the apple was attracted to the ground.
43	Teacher	Is there force here?
44	Students	Yes!
45	Teacher	What force?
46	Students	Magnetic?
47	Teacher	And who exercises magnetic force?
48	Student 4	Teacher, it can't be magnetic force because it's not being attracted.
49	Fiona	It's like there was no force.
50	Teacher	Nothing here… but there's something here… What about this one here? [*Points to the picture of human feet.*]
51	Student 5	There's force here too!
52	Teacher	What force?
53	Student 9	The force of the feet that must…
54	Teacher	Force of the feet, okay… I said we had to imagine what was below.
55	Student 10	Magnetic force.
56	Teacher	Yes?… And who exercises magnetic force?
57	Student 10	It's like a magnet that…
58	Teacher	Where's the magnet?
59	Student 3	In the atmosphere?
60	Teacher	Okay, is there a force here?
61	Students	Magnetic!
62	Student 8	There's no force here, teacher.
63	Teacher	And when we step on the ground, what force does he use?
64	Student 5	Human force.
65	Teacher	Okay, but there's a force… we'll talk about that later… in number four… What's happening in picture four? In case it's unclear, there's a man hanging here. [*Points to the picture of the parachute.*]
66	Students	Yes!
[…]		
69	Student 3	There's no force.
70		It's the wind that's moving the parachute. The guy has to try to steady himself but the wind is pushing the parachute so that…
71	Teacher	I'd like to hear what M. has to say, Is a force acting?
72	Student 11	No.
73	Teacher	No? Well. Hey, A., This is the force of gravity. Is there a force here?
74	Students	No!
75	Teacher	Okay, you say no… What about you… What attracts us to Earth?
76	Students	Gravity.
[…]		
80	Students	Yes, teacher, there is one!
81	Teacher	Yes, why?
82	Student 5	The force of air.
83	Student 12	Teacher, there's no force, it's only [*inaudible*].
84	Teacher	A. says there's no force because… the same thing that Miss M. says because it's falling…
85	Student 12	The wind carries him.
86	Teacher	Okay, the wind carries him.

attention to an image of a child slipping down a slide, and asked: *Which force makes objects fall*? Students: *Gravity*! Teacher: *In this image is gravity acting on the child*? Students: *No.* Teacher: *No*, *he is in the air*? Students: *No. Gravity is acting*! Teacher: *Okay.* Although no other student mentioned that gravity pushes objects upwards, the previous hesitation shows that many students shared a selective notion of gravity (gravity acting on some objects). Finally, in whole-class interaction gravity was mentioned again as following the activity of the magnet and the metallic clip and washer. The teacher perceived the students' confusion about magnetic force and

Table 10
Group-work interaction, lesson 4, activity 1.

Turn	Participant	
100	Fiona	What about the third one? [*Refers to the picture of shoes seen from below.*] The teacher said it's human force.
101	Jaci	What does it say here?
102	Ada	The third one…
103	Fiona	I say it's human force.
104	Ada	I say that's not human force. I think it's gravity because gravity is a power that attracts.
105	Fiona	No, because if it were gravity he would be floating. He'd be like this, "Wowowowow".
106	Ada	So he's not floating. Is he floating?
107	Fiona	No.
108	Jaci	He's not floating.
109	Ada	Okay now… so why say it's gravity?
110	Fiona	Oh, that's right. It's sort of magnetic too, because it can have something that attracts him.
111	Ada	So the third one here is gravity, it's because he's not flying.
112	Jaci	I told you that and you told me off.
113	Fiona	The third one here is gravity because he's not flying. So is the apple flying?
114	Fiona	Yes.
115	Jaci	It's not flying.
116	Ada	Yes, yes it is.
117	Jaci	It's not flying, it has no wings.
118	Fiona	Yes, when it falls. When it falls it's like this, it's like gravity.
119	Ada	So down here it's magnetic. [*Goes back to the picture of the feet.*]
120	Fiona	I also say it can be magnetic, but also human force, because he is applying a force…
121	Jo	It's like he applies upwards force and then [*gestures with her hands*].
122	Fiona	He applies a force so the foot…
123	Ada	Look, when we all said it was human force, the teacher was not too convinced it was human force.
124	Fiona	Yes, that's right.
125	Fiona	He applies the force for the foot to reach the ground. Downwards.
126	Ada	Okay, human force.
[…]		
135	Fiona	The fourth situation…
136	Jaci	The parachutist. Magnetic, magnetic.
137	Ada	Magnetic?
138	Jaci	Because he's falling and the magnet tells him to "come down".
139	Fiona	Okay, what do we put here, then?
140	Jaci	I'm gonna write magnetic because he's falling down.
141	Ada	So here, in the one below, is it gravity? [*Talking to herself.*] Why is he falling? No, because it's attracting him… No, then it's magnetic because gravity doesn't attract him. Who attracts him? Nothing.
142	Fiona	Because if something were attracting him, he'd fall really fast, like the magnet; when a magnet catches something, it comes really fast. So it's not magnetic. Okay, let's rule out magnetic force… we already know it's going down.
143	Ada	Okay, down.
144	Fiona	But now… okay, it's not magnetic force, it's not human force either.
145	Ada	Gravity.
146	Jo	I think it's human force.
147	Ada	No, because he's not applying the force. It's not like he had a cord that you could pull to make him come down.
148	Fiona	I think it's the air that keeps him up there.
149	Jo	I think it's the air's force.
150	Ada	Centrifugal force.
151	Jaci	The air's force, haha.
152	Fiona	Hey, it could be centrifugal force.
153	Jaci	No, because he'd have to be stuck around something. [*Makes circular motions with her hand.*]
154	Ada	I don't know, I'd say it's gravity.
155	Jaci	No, I'd say it's magnetic force.
156	Fiona	No, because magnetic force…
157	Jaci	But he's falling.
158	Fiona	No, but he'd still fall, because if you place a magnet and some metal here, the metal would fall, fast. Because it's magnetic force and he's being attracted.
159	Jaci	Listen. But if you place the magnets far away. It's hard for them to get together again.
160	Fiona	Oh… That's right.
161	Ada	What?
162	Fiona	That if you put a magnet here and another one here… have you noticed when they are…? And it's hard for them to move because they turn sort of slowly, and then when they're a bit closer [*pushes two erasers together quickly*]. It's like when you're almost on the ground, it's like you come down.
163	Jo	Immediately.
164	Fiona	No, because the balloon is coming down, but it's like the wind is [*makes an upwards motion with her hands*], and when it comes down…
165	Fiona	I still think that Jaci is right.
166	Ada	Me too, but I think [*unclear*].
167	Jaci	Oh, okay, write air force.
168	Fiona	The ground is, like, it attracts humans, because humans are always on land. Have you noticed that? Like a magnet.
169	Ada	No, because there is no force [*unclear*].

(*continued on next page*)

Table 10 (*continued*)

Turn	Participant	
170	Fiona	It's as if our shoes had a magnet like that, that only attracted us towards the Earth.
171	Jaci	Like if my shoes only wanted to go to McDonalds.
172	Ada	But I don't think it's magnetic force because nothing is attracting him.
173	Fiona	Yes, the Earth can attract him.
174	Ada	Who attracts him?
175	Fiona	The Earth. The ground, because the ground…
176	Ada	The ground is a magnet?
177	Jaci	Yes.
178	Jo	We can't walk, because [*unclear*].
179	Fiona	Look, this [*the table*] is the Earth and he [*a pencil coming from above*] is here; he's moving slowly and as he approaches the ground he moves faster, like the magnets.
180	Ada	Okay, magnetic force.

gravity, and through turns 444 and 451 (Table 8) he therefore made sure that everybody differentiated between them: while gravity attracts bodies to Earth, metals are attracted by magnets.

Gravity emerged again in lesson 5, in the initial whole-class interaction, as a force that attracts objects to the Earth. Then, when discussing again the image of the parachutist, Fiona intervened but did not mention gravity as the force pulling the parachutist to the ground, identifying human force instead, even when gravity had been mentioned in lesson 4's whole-class plenary as attracting all objects to the ground. However, in the small-group discussion that followed the previous plenary, Ada and Fiona rapidly agreed that gravity was actually acting on a stopped car, something that Fiona shared in the following whole-class interaction. Then the teacher asked about the direction of gravity, and Fiona doubtfully said: *Downwards.* The teacher asked her why she was doubtful, but Fiona accepted the fact that gravity attracts us to the floor. Then in the next whole-class plenary, when sharing group ideas regarding forces acting on an accelerated car (upon which group 2 agreed quickly, with no discussion), Fiona disagreed with the solution of another group, saying: *There is not only one force, but two, the car engine force and gravity; otherwise, the car would be floating.* It seems that thus far Fiona had accepted the idea that gravity pulls objects downwards. However, this was less clear in the next small-group interaction, where the students had to decide which forces were acting in daily situations, deciding whether or not they were balanced. As can be observed in Table 11, even when in whole-class talk on several occasions it was accepted that gravity pulls objects to the Earth, even by Fiona herself, again she seemed to hold both notions of gravity: what attracts objects to the floor, and what makes objects float. Fiona and Ada admitted in turns 673–6 that in the situation of a man floating on an inflatable mattress there might be zero gravity because the man is floating (gravity is acting upwards), but also because the man is lying on the inflatable mattress (gravity is acting upwards). Fiona seemed troubled and was aware that the accepted notion of gravity is that it pulls downwards (turn 677), something that Ada also seemed to know (see turn 683). They again discussed whether gravity is involved in the case of a person who stops at a traffic light. It is clear in turns 697 and 704 how even when they were not persuaded about the action of gravity, they understood that it was the right way to think (see also turns 715–20). In fact, Ada and Fiona repeated the argument that gravity makes things float (in turns 737–40); at the same time, they identified gravity as a force that pulls things down (see turns 747 and 767), but apparently only acting selectively on some objects (see turn 769).

The last time gravity was mentioned was in the final whole-class interaction of lesson 6, in which the teacher asked about the relationship between gravity and weight, without providing clarification.

The post-interviews (see Tables 4 and 5), as already mentioned, show how Ada, Jaci and Fiona held a dual notion of gravity: it pulls upwards and downwards. So, although Fiona was progressively accepting the idea that gravity pulls downwards, she didn't abandon the idea that it pulls upwards. Moreover, Ada and Jaci adopted this idea, although initially they showed a more conventional (but uncritical) understanding of gravity. So, although gravity was part of two small-group extended and rich discussions (lesson 4, Table 10, and lesson 5, Table 11), the second of which showed more consideration of the conventional idea of gravity accepted by the class in the whole-class interactions (lessons 1, 2, 4 and 5), the juxtaposition of ideas did not lead to a coherent understanding. There were repetitive peer discussions, but the focus was not on solving this contradiction. Moreover, whole-class interventions on gravity were more like authoritative teachers' clarifications without elaborating on the alternative conceptions (some of which were out of the sight of the teacher in small-group interactions) or giving any additional support to the idea (argument). It was clear that whole-class clarifications pushed students to include the accepted and scientific notion of gravity in their further peer discussions, without discarding the non-accepted ones. A selective notion of gravity may have contributed to allowing the two notions to be held together. The idea that gravity in space was not zero was neither discussed nor clarified in the whole unit and was present in the Forces post-test knowledge of the students.

3. *Focused peer argumentation with whole-class argument.* This section covers magnetic force, which was seriously considered, argued and counter-argued during the small-group discussion of lesson 4 (Table 10). It was also the problem solution that the group reached. However, in whole-class discussions the teacher and other students insistently formulated an argument, that is, a claim supported by a justification (*If there is no magnet, then it is not magnetic force acting on the situation*), offering the useful resource of reasoning to discard its participation in the objects falling. It is likely that the focused and elaborated discussion (composed of arguments and counter-arguments), in addition to the authoritative argument, helped students to discard, after a quick and situated process of reasoning, the participation of magnetic force in accounting for objects falling, as the post-interviews show (see

Table 11
Group-work interaction, lesson 5, activity 2.

Turn	Participant	
662	Ada	"A person is floating on an inflatable mattress. What forces are acting?"
663	Fiona	Let's see, let's see, "A person is floating" … Air!
664	S/C	Floating? Force of gravity, because we don't know where the person's going.
670	Ada	Gravity?
671	Teacher	Okay?
672	Ada	She's floating.
673	Fiona	True, no gravity. Should we write no gravity? Because if she's floating it's because there's gravity; there's gravity but I don't know if she's [*makes a downwards motion with her hand*].
674	Ada	If there were no gravity, she'd be on the ground.
675	Fiona	No. Oh, that's true… gravity then?
676	Ada	It could still be zero gravity because there is a mattress and she falls on it.
677	Fiona	No, but gravity is more conscious.
678	S/C	Yes, because in zero gravity, even if she had the mattress she'd still be floating.
679	Fiona	Okay, read it out, it's your turn to read.
680	S/C	"A rocket… [*unclear*]". [*The case of a rocket being launched.*]
681	Fiona	The rocket would be the [*unclear*].
682	S/C	Gravity?
683	Ada	No, because gravity doesn't go up.
[…]		
696	Fiona	"A person stops when he sees a red light."
697	S/C	Gravity.
698	Ada	She's obsessed with gravity.
699	S/C	But if there were no gravity he'd be floating.
700	Fiona	Okay, it must be gravity and something else.
701	S/C	I mean, gravity is used to move backwards.
702	Ada	I think gravity has nothing to do with this.
703	Fiona	Yes, because the topic we studied says it should be gravity, but what else?
704	Ada	Just gravity, that's what we wrote here…
705	Fiona	He stops, he stops.
706	S/C	It could be the person's force.
	Ada	When a person steps on the ground.
[…]		
714	Fiona	Gravity and human force. And human; gravity and human.
715	Ada	"Some flowers in a vase."
716	Fiona	Gravity.
717	Ada	Why?
718	Fiona	Because they'd be floating otherwise.
719	Ada	Let's just write gravity in all of them.
720	Fiona	But it's true.
[…]		
729	Fiona	"A ship is sinking because of a leak."
[…]		
732	Ada	It's not magnetic force.
733	Fiona	Nope.
734	S/C	It could be gravity, because gravity is pulling the ship down.
735	Fiona	No, because there's a hole. The force of the water.
736	Ada	With no gravity, it would be flying.
737	Fiona	No, because it'd be flying.
738	Ada	It's floating.
739	Fiona	It'd be flying.
740	Ada	And it's sinking here.
[…]		
747	Fiona	Gravity?
748	Teacher	What else?
749	Ada	It can't be magnetic force.
750	Teacher	No, because the ship is not sinking. If it starts filling with water, what happens with the ship?
751	Fiona	It sinks. It starts filling with water.
752	Teacher	If I have a ship, it weighs something, right?
753	S/C	Yes.
754	Teacher	And it always weighs the same, but I start filling it with water.
755	S/C	It breaks and sinks.
756	Teacher	What happens with its weight?
757	Fiona	It increases.
758	Teacher	Okay.
759	Ada	Gravity and it increases.
760	Fiona	Gravity and increase.
761	Ada	"A car is hanging from a magnetic crane."
762	Fiona	Magnetic.

(*continued on next page*)

Table 11 (*continued*)

Turn	Participant	
763	Ada	Nothing, because nothing's attracting it.
764	Fiona	The crane has a magnet.
765	Ada	Yes, it has a magnet that's hanging…
766	Fiona	Yes, it has a magnet and it's hanging.
767	Ada	Gravity?
768	S/C	Magnetic force!
769	Fiona	No, it's magnetic force. It must be magnetic because it has a magnet.

answers to post-delayed interview question 8, and post-immediate question 9).

Magnetic force emerged for the first time in lesson 1's whole-class interaction regarding forces acting on the image of the runner (see Fig. 3 to track the description). Then, it reappeared in the whole-class interaction of lesson 4 regarding the forces acting on the image of the feet (see Table 9). One student suggested that magnetic force was involved, something that was not shared by other students (see turns 48 and 49) but which was not explored by the teacher. Fiona agreed with the idea that it could not be magnetic force, saying that there was no force acting on the feet. Magnetic force is mentioned again in turns 55 and 61, even though the teacher questioned the idea by asking where the magnet was the first time this argument appeared. With these ideas, and their own preconceptions, Fiona, Ada, Jaci and Jo considered magnetic force in the small-group discussion of the same lesson (Table 10) after discarding gravity (turn 109) as accounting for the attraction of the feet to the Earth (turn 111). As gravity was not straightforwardly seen as a force attracting every object to the ground, magnetic force was seriously considered as being involved in the Earth's attraction over objects (argument). In turns 136 and 138, in relation to the paratrooper image, Jaci formulated the argument – probably following the ideas explored in the whole-class discussion – that magnetic force is involved because a magnet would attract the paratrooper to the ground. Contrary to gravity, in this case the possible participation of magnetic force was argued (136, 138, 141), counter-argued (142) and again counter-argued (158), with sound arguments involving observational evidence of the functioning of magnets, which led the group to seriously consider and then reconsider it. Jaci (159) then formulated a counter-argument directed at turn 158, based on the distance of the magnets, which was accepted and appropriated by Fiona (turn 162), adding that the wind may contra-rest the action of the magnet (164). Again, Ada was not completely persuaded (166, 169, 172), but in turns 168 and 170 Fiona identified magnetic force as the force that attracts us to the ground, saying that the ground is a magnet, and using as evidence the observation that when things fall they accelerate when approaching the ground, just like two magnets. Ada accepted the idea (turn 180) and the interaction finished. The students failed to reach the scientific solution, but the ideas they discussed did not stop developing. In the following whole-class plenary the teacher asked about the forces involved with the astronaut, and one student said it was magnetic force. Another student disagreed, saying that a magnet causes magnetic force (probably resuming the teacher's previous whole-class argument). The teacher asked: *Is there a magnet acting here*? The students answered: *No*! And the teacher asked: *Then can it be magnetic force*? And the students finally answered: *No*! The argument in which magnetic force is related to the presence of magnets was repeated.

Then, in the whole-class interaction in lesson 5, when discussing the forces acting on the parachutist, one student said: *Downwards, because the magnet force attracts him like a magnet.* And the teacher answered: *Okay, emm, but only downwards*? And after another student mentioned the force of air, Fiona said: *No because when the parachute is open it is because of the wind* […] *and it catches air.* […] *And it could also be because of human force; otherwise, he would only go upwards.* Finally, the teacher said: *Very good, the man also exerts force but the air creates friction and pushes upwards, preventing the parachute from falling. Right*? It is interesting to note that Fiona formulated, in a more elaborated way, her argument on lesson 4's small-group interaction (turn 164, Table 10) about the air and the magnetic force. However, this time, and contrary to the other students in her class, she didn't mention magnetic force as acting on the parachutist (probably following the conclusions of lesson 4's whole-class plenary). She identified human force, instead of gravity, as pulling the parachute down, even when gravity was also mentioned in lesson 4's whole-class plenary as attracting all objects to the ground.

Fiona insisted on the participation of magnetic force in the accelerated car in the whole-class plenary that followed the small-group interaction; however, the teacher asked the other students: *Do you agree that magnetic force is also acting here*? [The students said *Nooo.*] *Why not*? *What should exist*? And one student said: *Because there is no magnet. Okay, very good, there is no magnet*, finished the teacher. For the first time, the argument about the magnetic force was mentioned in the whole-class interaction. Afterwards, in the whole-class interaction devoted to analysing more daily situations, Fiona insisted on magnetic force as participating in the forces acting on a man. In the small-group work that followed (Table 11), it is interesting to note that Ada challenged the idea of magnetic force conditioned (763) by the identification of the magnet, which Fiona successfully did (764). This shows how their previous discussion, fed by the whole-class argument, could have contributed to settling the issue of the participation of magnetic force in daily situations.

The post-interviews showed that Ada, Jaci and Fiona did not abandon the idea that magnetic force might be involved in objects' horizontal movement, but they were able to discard it using the same authoritative argument mentioned in whole-class interactions repeatedly, and then in the small-group work of lesson 5 (Table 11). This suggests that the group-work discussion of lesson 4 may have facilitated the appropriation of the whole-class argument, which was used for the first time during lesson 5's group work, and then in the post-interviews.

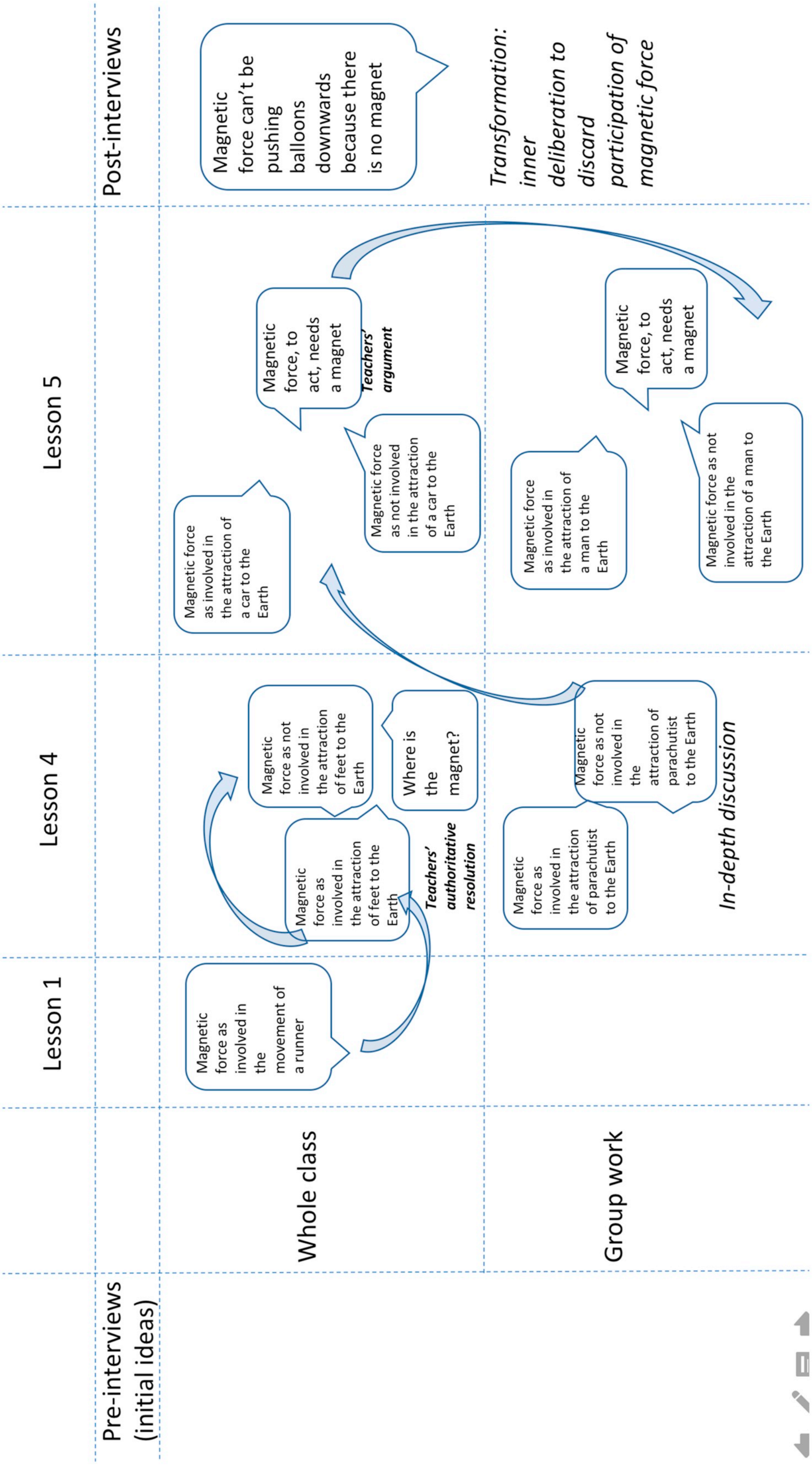

Fig. 3. Description of the evolution of the notion of magnetic force.

4. Discussion

Peer argumentation, especially when discussing contradictory ideas, has been seen as contributing to students' conceptual gains (Asterhan & Schwarz, 2007; Aydeniz & Dogan, 2016; Howe, 2009; Howe & Zachariou, 2017; among others). However, as gains tend to be delayed (Howe et al., 2005; Tolmie et al., 1993) and are not necessarily related to group outcomes (Howe, 2009; Howe & Zachariou, 2017; Kapur, 2008; Mugny & Doise, 1978; Sampson & Clark, 2009), the mechanism through which peer argumentation prompts learning is still unclear. It is likely that discussions prompt post-collaborative metacognitive processes that, in turn, contribute to scientific knowledge revision and restructuration. This would account for the delayed effect, but not necessarily for the fact that differences are somehow settled productively. The aim of our study was to describe the role that whole-class interaction may play in productively settling students' differences, as expressed during group discussions.

In fact, we think we can positively answer our research question (*Does – and, if so, in what way – whole-class talk contribute to productively settling the differences that emerged during group-work discussions*?). Our results suggest that whole-class interactions may contribute (or fail in doing so) valuable resources to scientific knowledge transformation. Two conditions, however, seem to be relevant: the in-depth exploration of contradictory views; and the presence of an argument that settles the difference during whole-class interaction – that is, a piece of reasoning. The students that were the focus of our analyses all used the whole-class argument that was given regarding magnetic force to discard the participation of magnetic force in observed daily situations in the post-interviews. However, even when this argument appeared for the first time in the initial whole-class interaction of lesson 4 (Table 9), that is, before students engaged in the discussion in which they argumentatively explored in-depth the participation of magnetic force (Table 10), it was only used by students in the group after that discussion (in a small-group activity in lesson 5, Table 11), probably as a result of the argument repetition used by the teachers in the plenaries of lessons 4 and 5. This suggests that peer argumentation of contrary views (discussions) and whole-class explanations are intertwined: although peer discussions are not sufficient to productively transform students' thinking, they increase students' sensitivity to the whole-class arguments. This increased sensitivity may be due to a basic cognitive effect of priming, as Howe et al. (2005) suggest, or a result of the role played by the imagination in knowledge construction (Larrain, 2017b). Argumentation may foster students' ability to imagine and differentiate relevant ideas (see De Vries, Lund, & Baker, 2002), prompting their understanding of the meaning of scientific ideas and facilitating meta-cognition and knowledge revision. That they didn't do this once and for all is evident, which may explain the delayed effects (see Howe, 2009): although students were not automatically persuaded by whole-class arguments, after a while they were. Coherent with the findings of Howe (2009) and Howe and Zachariou (2017), among others, the group discussion's outcome does not seem to be relevant, but the cognitive elaboration that unfolded in argumentative language does (see Chan et al., 1997).

According to these findings, and in line with Mortimer (1995), productive knowledge transformation would be characterized not by the absence of alternative conceptions (ruled out by metacognitive processes) but by the students' ability to use knowledge to represent and imagining all possible factors (enriching the field of meaning of a given concept), and to reason, discarding irrelevant factors. This is coherent with the findings of Mason et al. (2018) and Diakidoy et al. (2016), who show that the juxtaposition of incorrect and correct explanations in refutational texts may facilitate the inhibition and neutralization of misconceptions. Our findings suggest that, when faced with new situations, students who have discussed their ideas, and afterwards have access to scientific arguments, consider irrelevant factors, activating alternative conceptions; however, instead of letting them prevail, they use scientific arguments to discard them. This suggests that non-experts' scientific knowledge is not a sum of scientific ideas, but rather a group of reasoning paths (arguments or a group of ideas in which some of them support or challenge others) that are unfolded to think about a given natural phenomenom. The intertwinement of peer discussions and whole-class interactions may facilitate the internalization of scientific arguments: first, peer discussions increase students' sensibility to them (see Howe et al., 2005); then, whole-class interactions (especially dialogic ones) offer students' scientific explanations; and, finally, later whole-class talk and small-group work offer students valuable opportunities to use these arguments, prompting their appropriation (see Anderson et al., 2001) and later internalization (that is, the use of those arguments to regulate their own thinking – see Larrain, 2017a).

Our findings also suggest that when contradictory ideas emerge during group work, but are not the focus of a discussion, and there is an absence of an authoritative argument, knowledge transformation does not follow the same path. Thus, mere contradiction, with no group argumentation and no guidance, or contradiction, with tangential argumentation and authoritative correction but no argument, are not sufficient for knowledge to progress. This was the case with the notion of weight and gravity, which were never really explored either in small-group or whole-class scenarios, pointing out the relevance of the intertwined quality of small-group and whole-class talk. Following Kendeou et al. (2013, 2014) and Chan et al. (1997), it is not the presence of contradictory ideas that is relevant for learning, but rather the presence of articulated pieces of knowledge. In the case of gravity, although the teacher insisted several times that gravity pulls downwards, he never gave an explanation or argument that served to discard the idea that it pulls upwards. Consequently, it is possible to observe how students progressed from a non-problematic (but not necessarily coherent with the available scientific knowledge) notion of gravity to a problematic, partially incoherent, notion of gravity in which the scientific idea was accepted but not yet understood. Students held a selective notion of gravity as being independent of weight, dependent on air and absent in outer space (alternative conceptions reported by Ber and Brouwer, 1991; Galili, 1995; Sharma, Millar, Smith, & Sefton, 2004; and Watts, 1982).

It is worth noting, however, that given the exploratory and focused nature of the study, these results are not meant to be generalized, and have to be taken as tentative hypotheses regarding the intertwined effect of the impact of whole-class talk and small-group argumentation. As such, the results can be helpful to orient future qualitative and quantitative studies in which these hypotheses are further explored.

Teaching and learning are part of a purposeful, accumulative and progressive process (Alexander, 2004). However, it should be seen not as a linear movement but rather as a complex dynamic whose direction is refracted by teachers' and learners' minds and their intertwinement (teacher–student; student–student), whose trajectory involves qualitative forwards and backward leaps, and whose temporality does not necessarily coincide with pedagogical and curricular timing. Pedagogical practice, however, should take into account the need to design carefully both small-group and whole-talk interaction to foster both their quality and their virtuous contribution to the transformation of students' scientific knowledge.

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References

Alexander, R. J. (2001). *Culture and pedagogy: International comparisons in primary education.* Blackwell: Oxford and Boston.
Alexander, R. J. (2004). *Towards dialogic teaching: Rethinking classroom talk.* Cambridge: Dialogos.
Anderson, R. C., Nguyen-Jahiel, K., McNurlen, B., Archodidou, A., Kim, S. Y., Reznitskaya, A., & Gilbert, L. (2001). The snowball phenomenon: Spread of ways of talking and ways of thinking across groups of children. *Cognition and Instruction, 19*(1), 1–46. https://doi.org/10.1207/S1532690XCI1901_1.
Asterhan, C. S. C., & Schwarz, B. B. (2007). The effects of monological and dialogical argumentation on concept learning in evolutionary theory. *Journal of Educational Psychology, 99*, 626–639. https://doi.org/10.1037/0022-0663.99.3.626.
Aydeniz, M. A., & Dogan, A. (2016). Exploring the impact of argumentation on pre-service science teachers' conceptual understanding of chemical equilibrium. *Chemistry Education Research and Practice, 7*, 111–119. https://doi.org/10.1039/c5rp00170f.
Chan, C., Burtis, J., & Bereiter, C. (1997). Knowledge building as a mediator of conflict in conceptual change. *Cognition and Instruction, 15*(1), 1–40. https://doi.org/10.1207/s1532690xci1501_1.
Chen, C. H., & She, H. C. (2012). The impact of recurrent on-line synchronous scientific argumentation on students' argumentation and conceptual change. *Educational Technology & Society, 15*(1), 197–210.
Chi, M. T. H. (2008). Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. In S. Vosniadou (Ed.). *Handbook of research on conceptual change* (pp. 61–82). Hillsdale, NJ: Erlbaum.
Davis, E., & Krajcik, J. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher, 34*(3), 3–14.
De Vries, E., Lund, K., & Baker, M. (2002). Computer-mediated epistemic dialogue: Explanation and argumentation as vehicles for understanding scientific notions. *The Journal of the Learning Sciences, 11*(1), 63–103. https://doi.org/10.1207/S15327809JLS1101_3.
Diakidoy, I. A. N., Mouskounti, T., Fella, A., & Ioannides, C. (2016). Comprehension processes and outcomes with refutation and expository texts and their contribution to learning. *Learning and Instruction, 41*, 60–69. https://doi.org/10.1016/j.learninstruc.2015.10.002.
Galili, I. (1995). Interpretation of students' understanding of the concept of weightlessness. *Research in Science Education, 25*(1), 51–74. https://doi.org/10.1007/BF02356460.
Howe, C. (2009). Collaborative group work in middle childhood: Joint construction, unresolved contradiction and the growth of knowledge. *Human Development, 39*, 71–94. https://doi.org/10.1159/000215072.
Howe, C., & Abedin, M. (2013). Classroom dialogue: A systematic review across four decades of research. *Cambridge Journal of Education, 43*(3), 325–356. https://doi.org/10.1080/0305764X.2013.786024.
Howe, C., Ilie, S., Guardia, P., Hofmann, R., Mercer, N., & Riga, F. (2015). Principled improvement in science: Forces and proportional relations in early secondary-school teaching. *International Journal of Science Education, 37*(1), 162–184. https://doi.org/10.1080/09500693.2014.975168.
Howe, C., McWilliam, D., & Cross, G. (2005). Chance favours only the prepared mind: Incubation and the delayed effects of peer collaboration. *British Journal of Psychology, 96*, 67–93. https://doi.org/10.1348/000712604X15527.
Howe, C., Tolmie, A., Anderson, A., & MacKenzie, M. (1992). Conceptual knowledge in physics: The role of group interaction in computer-supported teaching. *Learning and Instruction, 2*, 161–183. https://doi.org/10.1016/0959-4752(92)90007-9.
Howe, C., & Zachariou, A. (2017). Small-group collaboration and individual knowledge acquisition: The processes of growth during adolescence and early adulthood. *Learning and Instruction*. https://doi.org/10.1016/j.learninstruc.2017.10.007.
Kapur, M. (2008). Productive failure. *Cognition and Instruction, 26*(3), 379–424. https://doi.org/10.1080/07370000802212669.
Kapur, M. (2016). Examining productive failure, productive success, unproductive failure, and unproductive success in learning. *Educational Psychologist, 51*(2), 289–299. https://doi.org/10.1080/00461520.2016.1155457.
Kendeou, P., Smith, E. R., & O'Brien, E. J. (2013). Updating during reading comprehension: Why causality matters. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*, 854–865. https://doi.org/10.1037/a0029468.
Kendeou, P., Walsh, E., Smith, E. R., & O'Brien, E. J. (2014). Knowledge revision processes in refutation texts. *Discourse Processes, 51*, 374–397. https://doi.org/10.1080/0163853X.2014.913961.
Kuhn, D. (2015). Thinking together and alone. *Educational Researcher, 44*(1), 46–53.
Larrain, A. (2017a). Group-work discussions and content knowledge gains: Argumentative inner speech as the missing link? *Learning, Culture and Social Interaction, 14C*, 67–78. https://doi.org/10.1016/j.lcsi.2017.04.002.
Larrain, A. (2017b). Argumentation and concept development: The role of imagination. *European Journal of Psychology of Education, 32*(4), 521–536. https://doi.org/10.1007/s10212-016-0316-7.
Larrain, A., Moreno, C., Grau, V., Freire, P., Salvat, I., López, P., & Silva, M. (2017). Curriculum materials support teachers in the promotion of argumentation in science teaching: A case study. *Teacher and Teaching Education, 67*, 522–537. https://doi.org/10.1016/j.tate.2017.07.018.
Larrain, A., Howe, C., & Freire, P. (2018). 'More is not necessarily better': Curriculum materials support the impact of classroom argumentative dialogue in science teaching on content knowledge. *Research in Science & Technological Education, 36*(3), 282–301. https://doi.org/10.1080/02635143.2017.1408581.
Larrain, A., Freire, P., Grau, V., López, P., Salvat, I., Silva, M., Gastellú, V. (in press). The effect of peer-group argumentative dialogue on delayed gains in scientific content knowledge. *New Directions in Child and Adolescent Development*.
Leitão, S. (2000). The potential of argument in knowledge building. *Human Development, 43*, 332–360. https://doi.org/10.1159/000022697.
Limón, M. (2001). On the cognitive conflict as an instructional strategy for conceptual change: A critical appraisal. *Learning and Instruction, 11*, 357–380. https://doi.org/10.1016/S0959-4752(00)00037-2.
Mason, L., & Santi, M. (1998). Discussing the Greenhouse Effect: Children's collaborative discourse reasoning and conceptual change. *Environmental Education Research, 4*, 67–85. https://doi.org/10.1080/1350462980040105.
Mason, L., Zaccoletti, S., Carretti, B., Scrimin, S., & Diakidoy, I. A. (2018). The role of inhibition in conceptual learning from refutation and standard expository texts. *International Journal of Science and Mathematics Education*. https://doi.org/10.1007/s10763-017-9874-7.
Mercer, N., & Littleton, K. (2007). *Dialogue and the development of children's thinking.* London: Routledge.
Mortimer, E. F. (1995). Conceptual change or conceptual profile change? *Science & Education, 4*, 267–285. https://doi.org/10.1007/BF00486624.
Mugny, G., & Doise, W. (1978). Socio-cognitive conflict and structure of individual and collective performances. *European Journal of Social Psychology, 8*, 181–192.

Muhonen, H., Rasku-Puttonen, H., Pakarinen, E., Poikkeus, A., & Lerkkanen, M. (2017). Knowledge-building patterns in educational dialogue. *International Journal of Educational Research, 81*, 25–37. https://doi.org/10.1016/j.ijer.2016.10.005.

Nussbaum, E. M., & Sinatra, G. M. (2003). Argument and conceptual engagement. *Contemporary Educational Psychology, 28*, 384–395. https://doi.org/10.1016/S0361-476X(02)00038-3.

Nystrand, M., Gamoran, A., Kachur, R., & Prendergast, C. (1997). *Opening dialogue: Understanding the dynamics of language and learning in the English classroom.* New York: Teachers College Press.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211–227. https://doi.org/10.1002/sce.3730660207/full.

Reznitskaya, A., & Gregory, M. (2013). Student thought and classroom language: Examining the mechanisms of change in dialogic teaching. *Educational Psychologist, 48*(2), 114–133. https://doi.org/10.1080/00461520.2013.775898.

Reznitskaya, A., Kuo, L., Clark, A., Miller, B., Jadallah, M., Anderson, R. C., & Nguyen-Jahiel, K. (2009). Collaborative reasoning: A dialogic approach to group discussion. *Camb. J. Educ. 39*(1), 29–48. https://doi.org/10.1080/03057640802701952.

Rivard, L., & Straw, S. (2000). The effect of talk and writing on learning science: An exploratory study. *Science Education, 84*(5), 566–593. https://doi.org/10.1002/1098-237x(200009)84:5<566::aid-sce2>3.3.co;2-l.

Ruthven, K., Hofmann, R., Howe, C., Luthman, S., Mercer, N., & Taber, K. (2011). The epiSTEMe pedagogical approach: Essentials, rationales and challenges. *Proceedings of the British Society for Research into Learning Mathematics*. *31*. *Proceedings of the British Society for Research into Learning Mathematics* (pp. 131–136).

Sampson, V., & Clark, D. (2009). The impact of collaboration on the outcomes of scientific argumentation. *Science Education, 93*(3), 448–484. https://doi.org/10.1002/sce.20306.

Sharma, M., Millar, R., Smith, A., & Sefton, I. (2004). Students' understanding of gravity in an orbiting space-ship. *Research in Science Education, 34*, 267–298. https://doi.org/10.1023/B:RISE.0000044605.00448.bd.

Stake, R. E. (2000). *The art of case study research.* Thousand Oaks, CA: Sage.

Tolmie, A., Howe, C. J., Mackenzie, M., & Greer, K. (1993). Task design as an influence on dialogue and learning: Primary school group work with object flotation. *Social Development, 2*(3), 183–201.

van Eemeren, F. H., & Grootendorst, R. (1992). *Argumentation, communication, and fallacies: A pragma-dialectical approach.* Hillsdale, NJ: Lawrence Erlbaum.

Vosniadou, S. (2013). Conceptual change in learning and instruction: The framework theory approach. In S. Vosniadou (Ed.). *International handbook of research on conceptual change* (pp. 11–30). New York, USA: Routledge. https://doi.org/10.4324/9780203154472.ch1.

Watts, M. (1982). Gravity—Don't take it for granted!. *Physics Education, 17*(3), 116–121. https://doi.org/10.1088/0031-9120/17/3/306/meta.

Wells, G. (1999). *Dialogic inquiry: Towards a sociocultural practice and theory of education.* Cambridge: Cambridge University Press.