Cultural Studies of Science Education
https://doi.org/10.1007/s11422-025-10248-4

ORIGINAL PAPER

Ninth-grade students' interactions and co-construction of arguments during a teaching unit on soil science

Francisco Sóñora[1] · Vanessa Sesto[2] · Isabel García-Rodeja[1]

Received: 28 July 2018 / Accepted: 31 January 2025

Abstract

In the last decades, extensive research has been conducted on argumentation and classroom discourse, but few studies have developed combined analyses on interaction patterns and co-construction of arguments. In this paper, we analyse the discussion of a group of ninth-grade students (ages 14–15) concerning soil science, with the aim of investigating the co-construction of arguments and the interactions in a naturalistic context. In order to collect data, pupils' discussions during a session were recorded in audio and video files. The session was framed in a teaching unit in which the students were presented with a land allocation problem, and they had to solve it using information about soil properties. A network to analyse interactions and Toulmin's scheme to analyse argumentation were used. The results suggest that the roles adopted by the pupils and the teacher were different from those of a traditional classroom, and that the tasks succeeded in encouraging the pupils to reason and discuss. On the other hand, when analysing the co-construction of the arguments, we observed that the quality of discourse was not the same in all the analysed episodes. In the first one, an argument with a greater articulation of ideas is constructed, whereas in the last one, we found different ideas that were merely juxtaposed, constructing parallel arguments. We conclude that the quality of the classroom dialogue is high when the participants manage to articulate ideas that interact with each other, referring to the remaining ideas during the process of constructing meanings.

Keywords Discourse analysis · Argumentation · Soil science · Secondary school students

✉ Isabel García-Rodeja
isabel.garcia-rodeja@usc.es

Francisco Sóñora
francisco.sonora@usc.es

Vanessa Sesto
vanessa.sesto@rai.usc.es

[1] Departamento de Didácticas Aplicadas, Universidade de Santiago de Compostela, Avenida Xoán XXIII s/n, 15782 Santiago de Compostela, A Coruña, Spain

[2] IES Marco de Camballón, Xunta de Galicia, Rúa do Camballón, nº24, 36590 Vila de Cruces, Pontevedra, Spain

Published online: 28 May 2025

Resumen
En las últimas décadas, se ha llevado a cabo una amplia investigación sobre la argumentación y el discurso en el aula, pero pocos estudios han analizado de forma combinada los patrones de interacción y la co-construcción de argumentos. En este trabajo se analiza la discusión de un grupo de estudiantes de noveno grado (14 a 15 años) sobre el suelo, con el objetivo de analizar la co-construcción de argumentos y las interacciones en un contexto real. Para la recogida de datos, se grabó en audio y video la discusión de los estudiantes durante una sesión. La sesión estaba enmarcada en una unidad didáctica en donde se presentó a los estudiantes un problema de ordenación del territorio, el cual tuvieron que resolver usando información acerca de las propiedades del suelo. Para el análisis de las interacciones se utilizó una red sistémica y para el análisis de los argumentos se utilizó el esquema de Toulmin. Los resultados sugieren que los papeles adoptados por los estudiantes y el profesor son distintos a los de una clase tradicional, y que las tareas animaron a los estudiantes a razonar y discutir. Por otro lado, al analizar la construcción de argumentos, se observó que la calidad del discurso no fue la misma para los tres episodios analizados. En el primer episodio se construyó un argumento con una mayor articulación de ideas, mientras que en el último episodio encontramos distintas ideas que se hallan meramente yuxtapuestas construyendo argumentos en paralelo. Concluimos que la calidad del diálogo en el aula es alta cuando los participantes logran articular ideas que interactúan haciendo referencia al resto de ideas en el proceso de construcción de significados.

Research in teaching science has taken a new focus in recent years, with the aim of finding out how pupils build on their knowledge in a specific setting (the classroom) by interacting with their classmates, the teacher or the teaching materials (Palincsar 1998). This change of focus is due to a change in the theoretical perspective brought about by the realisation that learning in a classroom does not exclusively rely on individual cognitive abilities and that social factors are also important in the construction of knowledge (O'Loughlin 1992). Social constructivism defines learning as a process of social and cultural nature through which students' ideas are structured and restructured (Colomina, Mayordomo and Onrubia 2001). So arguably, knowledge is co-constructed through interactions with others, thus creating meanings for the people who participate in those interactions (Omodan 2022). In fact, contemporary research in science education supports the notion that all knowing has a dialogical origin (Kim and Roth 2018). Furthermore, from the social constructivist perspective, learning in the classroom should occur in settings which reflect the real world (Hennessy 1993). In line with this model of thought, the role of the teacher includes the role of facilitator to challenge ideas and deduce meaning through multiple interactions among students (Barak 2017). The term 'dialogic teaching' can carry various definitions (see Kim and Wilkinson 2019). For Robin Alexander (2017), it means viewing the classroom as a place where students make questions, adopt varying perspectives and collaboratively develop shared meanings.

To discover what kind of knowledge students construct in classroom settings and how they do so, we must understand the use of the main tool available for this task, the discourse (Rodrigues and Thompson 2001). The term *discourse* suggests both the dialogue and non-verbal elements which students and teachers use to communicate. The non-verbal elements can mean mention gestures, prosody and silence, while the verbal elements that characterise the discourse comprise the language utilised by teachers and students, and include both teacher–pupil and pupil–pupil interactions (Singh 2019). On the other hand, with the term *dialogue*, as per Stein Dankert Kolstø's (2018) definition, we want to refer to scenarios in the classroom in which points of view are shared between different interlocutors and dialogue can be established both between the teacher and the entire class, as well as between a group of students with and without the teacher's presence.

Discourse can be dominated by a univocal or a dialogic function of language (Keys and Bryan 2001). The former involves a one-way transmission of information, whereas the latter favours expression of ways of thinking and reflection on ideas and involves the creation of mechanisms for generating and expanding knowledge.

From this perspective, it is understood that dialogic discourse allows us to make public, modify, contrast, negotiate and reconstruct ideas during interaction with others (e.g. Alexander 2017).

According to Eduardo Mortimer and Philip Scott (2003), the basic characteristic of dialogic discourse in science classrooms is that the varying points of view held by students are considered. Dialogic discourses can occur in several ways depending on the participants. It also depends on whether the discourse takes place between peers; some examples would be the case of students discussing in a small group, or between a group of students and the teacher, or between the teacher and the whole class. Another element to consider in dialogic discourse is the degree of interanimation of ideas, meaning the degree to which the ideas of others are compared, contrasted and developed. For us, it can be expressed in the degree of articulation of ideas in the co-construction of arguments. For instance, there is a low level of interanimation of ideas when the teacher is speaking to the whole class, since the teacher simply asks the students to make their ideas explicit. If the teacher also compares and contrasts the students' points of view with the ideas of school science, the level of interanimation of ideas is higher (Scott, Mortimer and Aguiar 2006).

In any case, teaching and learning science are discursive activities (Lemke 1990). Learning science implies learning a new dialect, and learning the dialect of science takes place in face-to-face conversations with others (Erickson 2012). There is extensive study in the field of science education that deals with argumentation (e.g. Jiménez-Aleixandre and Erduran 2007) and classroom discourse (e.g. Nielsen 2013), but there is far less research focussed on interactions analysis aimed at understanding interaction as well as the co-construction of arguments in a small group in scientific classrooms (e.g. González-Howard 2019). This study constitutes a new contribution to the available knowledge because it aims to describe the co-construction of arguments performed by a group of students during a preliminary task of a teaching unit related to soil science, and to find out the contribution made by the discourse process to the construction of arguments in science lessons. We have decided to address this issue because, despite the fact that the sustainable use of soil is a significant challenge closely related to climate change and the loss of diversity, few researchers approach the soil from a didactic point of view (Fernández, Sesto and García-Rodeja 2017). The following are the research questions:

1. What types of interactions occur within a group?
2. How is the co-construction of arguments developed?

Discourse and interaction patterns

Studies on classroom discourse establish an archetypal interaction sequence performed by the teacher. This sequence comprises three elements: (1) initiation, which usually corresponds to the teacher's question; (2) response, which usually corresponds to the student's intervention; and (3) evaluation, where the teacher participates in order to assess the previous intervention. This sequence is usually referenced to as IRE (Mehan 1979). These studies generally assume that the initiation-response-evaluation (IRE) sequence allows teachers to control the classroom discourse because they are the ones asking questions, and guide and evaluate students' responses (Candela 1998).

The notion of 'school culture' refers to the norms, values and practices that are shared in a school. In some cases, the school culture may favour IRE interaction patterns as a way to control students' understanding of certain concepts. The IRE pattern can be linked to the fact that in most scholastic didactic interactions, there is always a correct answer to be reached. According to Kathleen Hogan, Bonnie K. Nastasi and Michael Pressley (2000), this reflects the notion of the teacher as the one who asks questions and the students as the ones who answer. In addition, it is possible to affirm that in conventional classes, the dialogue is more concerned with transmitting and clarifying concepts than with seeking explanations about a phenomenon or natural situations.

The IRE sequence seems to be common for some teachers (Faruji 2011). Paul Newton, Rosalind Driver and Jonathan Osborne (1999), and José María Oliva and José Antonio Acevedo (2005), when collecting information about teaching science in secondary schools in England and Spain, found that classroom discourse was dominated by teachers and tended not to foster reflective discussion on scientific issues. These findings were widely reported in other studies (Alexander 2001). In the context of an IRE interaction pattern, students generally give only one response and there are few opportunities for them to practise communication strategies and engage in reflective discussion. Emily Van Zee and James Minstrell (1997) understand reflective discourse as dialogues within the classroom setting, in which students express their own ideas, and teachers and students participate in a wide range of question exchanges that help students articulate their ideas and try to understand the way of thinking of others.

Lindsay Cornelius and Leslie Rupert Herrenkohl (2004) point out the importance of overcoming the barriers of existing structures in the science classroom, where the teacher talks and the students participate by answering the teacher's questions and receive feedback on their responses. The main goal of the new structures is to produce what Randi Engle and Faith Conant (2002) call productive disciplinary engagement. This approach might help students to progress intellectually. This progression can be inferred from, among other things, the development of new ideas and a better understanding of the discipline.

On the other hand, Scott, Mortimer and Aguiar (2006) characterise classroom discourse by means of a framework called communicative approach, which describes the dialogue between teacher and students along two dimensions. One dimension establishes a continuum between dialogic and authoritative discourse, while the other encompasses interactive and non-interactive talk. Scott, Mortimer and Aguiar (2006) suggest that a tension between authoritative and dialogic discourse is necessary, and that authoritative interventions should follow dialogical exchanges with the aim of developing a scientific view. Moreover, these authors point out that an authoritative format of discourse can be used for the introduction of new ideas, but this must be followed by the opportunity for dialogical and exploratory implementation of ideas. Samuel Otten, Christopher

Engledowl and Vickie Spain (2015) conducted a study that provides examples of dialogical interactions and where the need for a balance between univocal discourse and dialogic discourse is discussed. Due to the complexity of dialogic interactions, these authors point out the need of further research.

Apart from the teacher-led talk with students, several authors found that small group discussions that focus on solving open-ended problems are a way to effectively engage students in the collaborative production of knowledge (Damşa 2014). The interactions that take place in the small group are productive when they lead to actions that contribute to an increased shared understanding of concepts. Neil Mercer and Christine Howe (2012) suggest that exploratory talk is useful in reaching consensus when there are conflicting conceptualisations. This kind of discussion 'in which students engage critically but constructively with each other's ideas' (Mercer and Wegerif 1999, p. 86) allows the construction of shared knowledge and the critical evaluation of the quality of this knowledge.

Argumentation

Frans van Eemeren and Rob Grootendorst (2004) define argumentation as a 'verbal, social and rational activity aimed at convincing a reasonable critic of the acceptability of a standpoint by putting forward a constellation of propositions justifying or refuting the proposition expressed in the standpoint' (p. 1). Meanwhile, Jonathan T. Shemwell and Erin Marie Furtak (2010) define discussion as an exchange of ideas in which multiple participants explain what they think and why they think so. Discussion is a more flexible way of exploring ideas and sharing perspectives.

Previous studies in the field of science education have shown that there are several reasons for introducing argumentative practices in science classrooms (Zohar and Nemet 2002). Firstly, the social constructivist model suggests that opportunities for reflective interaction should be given, for example, through discussion and argumentation, to support the construction of knowledge (Osborne 2010). Educators must give students the opportunity to take part in activities that require them to argue, because social constructivism considers that scientific knowledge is generated through conclusions, and argumentation plays a very important role in reaching conclusions and constructing explanations (Siegel 1995). Secondly, argumentation is also important in terms of scientific literacy. Several authors highlight the importance of argumentation in decision-making and consider this act to be fundamental for an education aimed at democratisation (Grace 2009). Michael Ford (2008) adds that if students are not empowered to criticise ideas by assessing the evidence, they will accept the ideas that seem plausible and/or the ideas of the individual with greater influence, for example, the teacher in a discussion with the whole class or a particular student working in a small group. Thirdly, argumentation helps students appreciate the epistemological basis of science by themselves. Since argumentation is a core epistemic practice in science, it is a way of engaging students in the processes and practices of scientific work, so that they can understand how scientific theories are developed (Bricker and Bell 2008). On the other hand, argumentation is a central goal of science education because it engages students in a complex scientific practice in which they justify and construct knowledge claims (Berland and McNeill 2010).

For all these reasons, as Leema Kuhn Berland and Brian Reiser (2009) summarise, teachers should engage students in the scientific practice of argumentation, so they can express their ideas, give meaning to complex phenomena and actively participate in classroom discussions. These tasks require students to defend their ideas by providing supporting evidence, question the claims of others, examine competing arguments and revise their ideas for greater consistency (Berland and Reiser 2009). On the other hand, Mijung Kim and Wolff-Michael Roth (2018) report studies which show that children from an early age can construct and evaluate arguments based on evidence. In addition, several research have confirmed that argumentation can be used as a pedagogical method to help students think critically, solve problems and make decisions regarding their lives as individuals, as members of a society and as world citizens. In line with this finding, we could mention the papers of Chrysi Rapanta and Mark K. Felton (2022), Deanna Kuhn (2019) and Osborne, Henderson, MacPherson, Szu, Wild and Yao (2016).

However, as Rosalind Driver, Paul Newton and Jonathan Osborne (2000) point out, few opportunities are given to students in the science classroom to construct and evaluate arguments. Leema Kuhn Berland and David Hammer (2009) emphasise that students can argue, but they do not generally do so because they fail to perceive the science classroom as a setting demanding argumentation. Nevertheless, other authors claim that argumentation must be explicitly taught, because students need to learn how to express and justify claims before they are able to argue (Simon, Erduran and Osborne 2006).

Most studies conducted on argumentation in recent decades have adopted a structure commonly known as Toulmin's Argumentation Patterns or TAP (e.g. Kim and Roth 2018). This analytical tool has been widely used both to instruct in the way of constructing arguments in science lessons (Erduran, Simon and Osborne 2004) and to evaluate the quality of students' arguments (Cavagnetto, Hand and Norton-Meier 2010). This analytical structure is described in detail in the following section.

Methodology for context-specific settings

A qualitative methodological approach has been adopted in this study. Its purpose was to investigate a phenomenon in context-specific settings (Taylor and Bodgan 1998). As explained in subsequent sections, the participants' interventions for each task were qualitatively categorised, and thus, the individuals' interactions and the type of actions that take place were detected. Similar to other investigations of qualitative nature (e.g. Fyttas, Komis, Kaliampos and Ravanis 2023), a statistical analysis with the calculation of percentages for each category was then performed. The data by itself did not provide answers to the research questions posed. It was necessary to process and analyse them in an orderly and coherent manner to discern patterns and relationships (Monje 2011). It is important to note that the introduction of numerical values does not alter the qualitative nature of the research, as they are used to quantify the intensity of the pattern observed in data. The numerical values are simply a tool to aid in the understanding of the observed qualitative patterns.

On the other hand, it is important to bear in mind that this type of research involves the intensive study of a small sample of students, so this study does not seek to generalise results and conclusions to other works of a similar kind; however, qualitative studies may indeed be compared to others. The existence of comparable results or common patterns is the factor allowing for a certain degree of generalisation.

Participants

The research was conducted at a secondary school located in a rural area of north-western Spain. The participants were thirty ninth-grade students (14–15 years old) attending natural science lessons. The students presented a low academic achievement level. The class was divided into eight small groups of three or four students. In order to preserve their anonymity, the names of participants are pseudonyms and begin with the letter of the group to which they belong.

Instructional context

This study was carried out as part of a research programme on the argumentation skills of secondary school science students, involving the use of classroom discourse analysis techniques and teachers collaborating as researchers (Duschl 2003). This project comprised a series of units on environmentally relevant issues. This study focuses on one of these units, which addressed soil science. In a prior unit, the students had participated in another teaching sequence focussed on external geological processes.

The unit was constructed to be up to par with SEPIA design principles (Duschl and Gitomer 1996). The project design principles refer to the importance of prior knowledge to facilitate new learning, so that learning activities should facilitate the transfer of knowledge to new situations and be contextualised and situated. Moreover, learning environments must involve both dialogue with teachers and dialogue between peers, and scenarios must be crafted in which students' thinking and reasoning emerge in order to promote the development of argumentation skills. The main contents of the unit that we have used as the context of the study are the following: (1) factors involved in soil formation, (2) soil composition and structure, (3) uses of soil, (4) soil weathering and (5) restoration. The unit was broken down into four phases:

- *Phase 1. Introduction* The pupils were given a fictional land allocation problem in the guise of a request for help by their local town council, whose budget was supposedly too small to afford a consultant. Students had to decide how to allocate three available plots of land to use as a football pitch, a garden of a gardening school and a block of council offices. They had to consider existing data on the properties of each plot.
- *Phase 2. Approaching the problem* The students looked up basic information on the formation, composition, management and reclamation of soil. They were helped by the teacher and used the teaching materials for it.
- *Phase 3. Evaluating the data* The pupils applied the knowledge from Phase 2 to the fictional data in characterising the three plots to obtain a solution to the problem.
- *Phase 4. Final report* Each group presented a final report with reasoned conclusions.

Therefore, the unit also complies with the four principles proposed by Engle and Conant (2002), aimed at fostering a productive disciplinary engagement. The content was difficult to some extent because the teacher presented the students with a land allocation problem. The students received a dossier with relevant information to solve the challenge posed. They were given authority, as they had to activate their knowledge and make use of the available information to solve the problem.

Data sources and analytical methods

To analyse the interactions between the students and the teacher, all sessions in this unit were videotaped and the sound was recorded with external microphones for enhanced sound quality. The video recordings used as data collection instrument allowed us to unequivocally identify the participation of each student within the group. Through the video recordings, the students' interactions with their peers and the teacher were identified, as well as the use they made of the material provided. In this way, a clear description of the discussion and actions that took place during the session was obtained. In the present study, we focussed on one group's interaction during a session. This session corresponds to the beginning of Phase 2 which focussed primarily on activating students' knowledge through questions. The students could make use of the dossier with relevant information whenever they needed it. The following questions were discussed by the participants:

1. How long does it take soil to be formed? Why? (a) Between 1 and 100 years, (b) between 100 and 15,000 years, (c) between 15,000 and 1,000,000 years or more.
2. Where do the materials that form the soils come from?
3. Why are soils fertilised with manure more fertile than those containing inorganic fertilisers?

The first question is aimed at students expressing their ideas about the approximate age of the soil. Understanding the time it takes to form a soil brings us closer to the broader idea of soil as a non-renewable natural resource which is essential for life. The second question is aimed at students expressing their knowledge about the materials that form the soil. From a scientific point of view, the soil is the result of the interaction between different factors, among which we can mention climate, organisms, relief, time and parental materials (Happs 1981). The third question is aimed at students reflecting on the use of organic and inorganic fertilisers and activating their knowledge about different fertilisation practices.

These questions are crafted to activate and construct ideas that are essential to comprehend the importance of soil as a non-renewable resource and to understand how to make a more sustainable use of it. We consider that they would be suitable questions to rouse discussion considering the different conceptions that students show on these issues (Fernández, Sesto and García-Rodeja 2017).

To facilitate the understanding of the analysis method, we first describe the tool we have used to analyse the interactions and, secondly, the tool used to analyse the argumentation.

Analysis of interactions by means of a systemic network. As James Gee (1998) points out, discourse in the classroom reflects both the actions and the language of a community of people. To outline what pupils and the teacher do and how they do it, we have designed a network with which we analyse actions (Fig. 1). This is a modified version of the observational framework designed by Robert Hollon, Charles Anderson and Edward Smith (1980) and Newton, Driver and Osborne (1999) using a systemic network (Bliss, Monk and Ogborn 1983). According to John Ogborn (1994), a systemic network can be seen as a context-independent grammar that defines a *language* constructed to describe the data. The basic elements of a systemic network are Bar and Bra. The first is a notation used to represent a group of exclusive choices, and the latter is a notation used to represent a group of choices that happen simultaneously or a co-selection.

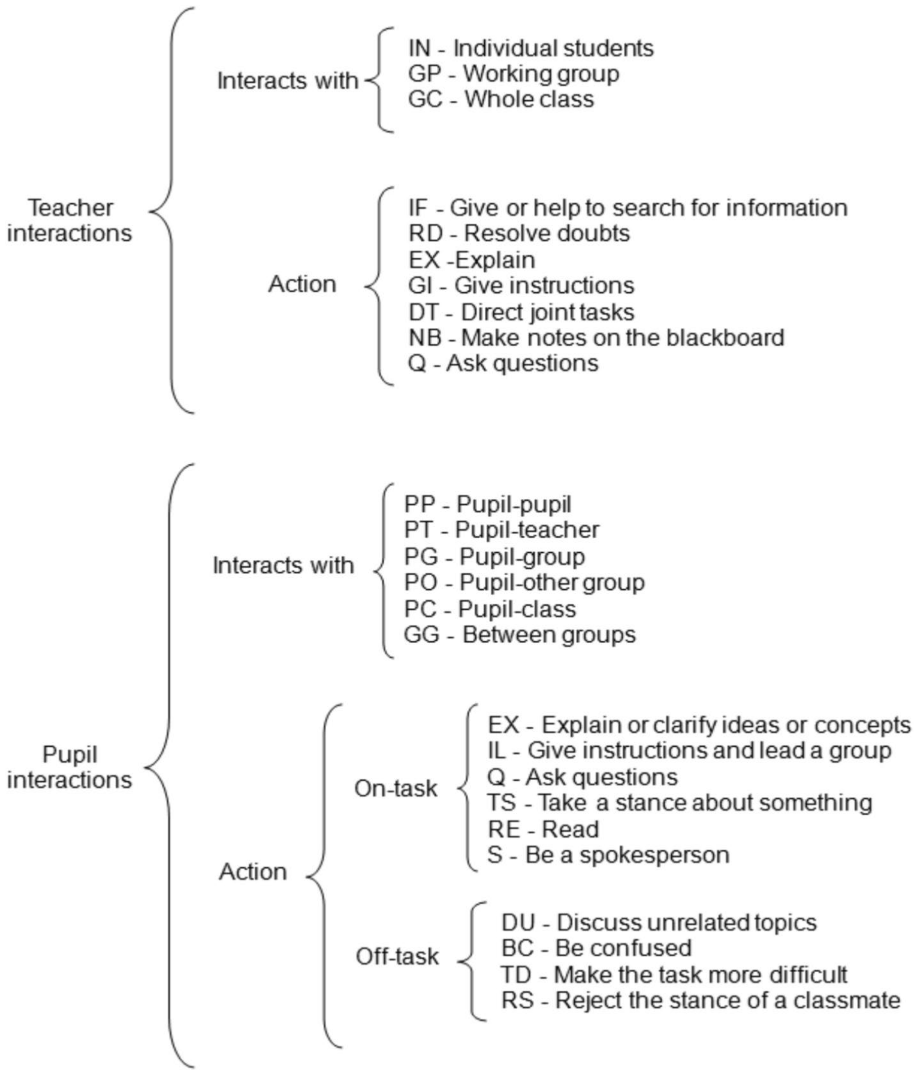


Fig. 1 Systemic network to describe pupil and teacher interactions. Modified according to Hollon, Anderson and Smith (1980) and Newton, Driver and Osborne (1999)

To analyse the discourse, conventional turns were taken as units of analysis. As Kathleen Hogan (1999) states, 'a turn began when a person took the floor in a conversation and ended when another person took the floor' (p. 387). As we can see in Fig. 1, the systemic network constructed for the analysis consists of two basic aspects about the teacher and the students, that is, the individual involved in the interaction and the action that takes place. These aspects are represented in the first two keys, meaning that there is a group of choices that happen simultaneously.

We have analysed who interacts with the teacher and the students, and the type of actions that take place. The teacher might interact with an individual student (IN), with the working group (GP) or with the whole class (GC). The teacher's actions can be intended to give information or help in the search for it (IF), solve doubts (RD) or explain (EX), among others. Students might interact within their own group (PG), with individual students (PP) or with the teacher (PT), among others. Students' actions may include discussing unrelated topics (DU), asking questions (Q) or rejecting the stance of a classmate (RS), among others (Fig. 1).

All the interactions that took place during the lessons were classified independently by two of the authors to provide a certain degree of triangulation. When comparing the author's coding of 80 randomly selected interactions, a 92% level of interrater reliability was obtained.

Analysis of argumentation through Toulmin's scheme. Regarding the analysis of the argumentation, Toulmin's scheme allows us to identify the relationships between statements and the way pupils negotiate and construct arguments within the context of the activity. Argumentation involves making statements (Lyons 1995) and much of the importance of the discussion process lies in the structures in which these are integrated. We have introduced some changes to the original argument scheme proposed by Stephen Toulmin (1958), considering different proposals from classroom discourse analysis, following the line of Clotilde Pontecorvo and Hilda Girardet (1993) and Erduran, Simon and Osborne (2004). Thus, for the purposes of this study, we categorised the elements of students' arguments as:

- Claims: Conclusions whose merits are sought to establish.
- Warrants: Statements that justify the connection between data and conclusions.
- Backing: Knowledge of a theoretical nature used to support the warrant.
- Hypothetical and empirical data: Facts mentioned as the basis of the conclusions.
- Challenges: Statements questioning the validity of a claim.
- Opposition: Any claim that denies what has been claimed by another, with or without giving reasons.
- Concessions: Any claim that concedes something to an addressee, admitting a point claimed in the dispute.
- Qualifiers, qualification or restriction: Statement specifying the conditions for the hypothesis or conclusion.
- Rebuttals: Specifying the conditions for discarding the hypothesis or conclusion.

With the purpose of providing a certain degree of triangulation and increasing the validity of the qualitative study, the analysis of argumentation was carried out independently by two of the authors, using a modified version of Toulmin's scheme.

Results: Interactions and actions

Firstly, we present the results regarding the analysis of the interactions. In the second part of this section, the results regarding analysis of the argument together with the analysis of the participants' interactions and the type of actions they develop are included.

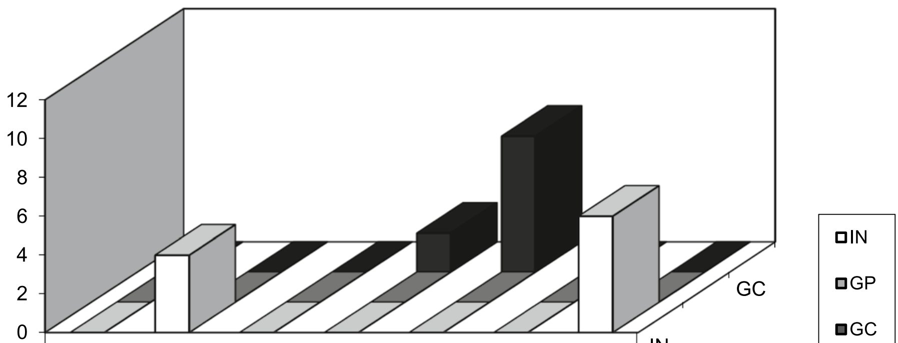
Analysis of the patterns of interaction

A total of 301 contributions were made during the session, nineteen (6.4%) of which were made by the teacher. As shown in Fig. 2, ten of these interactions took place with an individual student (IN) and nine with the whole class (GC). No interactions have been reported between the teacher and the working groups.

The teacher's interactions with individual pupils (IN) included two types of actions. Four contributions (21.1%) referred to the resolution of doubts (RD) and six (31.6%) concerned asking questions (Q). Teacher's interactions with the whole class (GC) also comprised two different actions. Two contributions (10.5%) referred to giving instructions (GI) and seven (36.8%) involved directing joint tasks (DT). Therefore, students performed the task with little intervention from the teacher. The few interventions of the teacher were mainly oriented to solve doubts raised by the students or give instructions on the execution of the task.

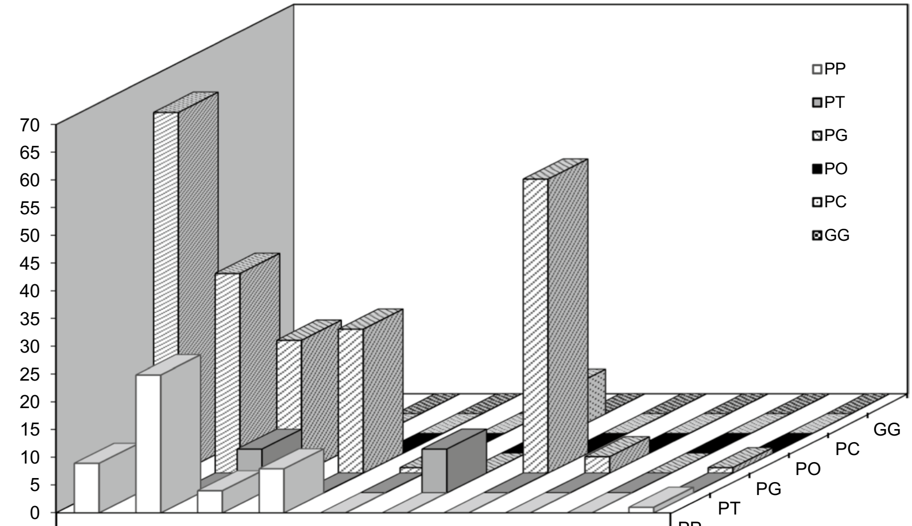
A total of 282 interactions were established between the students. The frequency distribution, considering the type of interaction, was the following: 47 (16.7%) pupil–pupil (PP), 16 (5.7%) pupil–teacher (PT), 209 (74.1%) pupil–group (PG), 2 (0.7%) pupil–another group (PO) and 8 (2.8%) pupil–class (PC). As shown in Fig. 3, most of the students' interactions were aimed at explaining or clarifying ideas or concepts to the working group (65, 23.0%). The pupil–pupil dialogue was very scarce and pupil–teacher interactions were even less frequent, and usually consisted of asking questions.

Of the pupils' contributions, 224 (79.4%) were on-task and 58 (20.6%) did not relate directly to the topic in question, although some contributions that emerged from the off-task discussion were related to scientific issues.



	IF	RD	EX	GI	DT	NB	Q
IN	0	4	0	0	0	0	6
GP	0	0	0	0	0	0	0
GC	0	0	0	2	7	0	0

Fig. 2 Classification of teacher's interactions according to the addressee (Individual student, IN; Working group, GP; Whole class, GC) and the action (Giving information or helping to search for it, IF; Solving doubt, RD; Explaining, EX; Giving instructions, GI; Directing joint tasks, DT; Taking notes on the blackboard, NB; Asking questions, Q). The white colour represents the interactions with an individual student (IN), the grey colour represents the interactions with a working group (GP) and the black colour represents the interactions with the whole class (GC). The height of the bars corresponds to the number of actions of each type developed in each interaction. For instance, of a total of ten IN interactions, the RD action was developed in four of them



	EX	IL	Q	TS	RE	S	DU	BC	TD	RS
PP	9	25	4	8	0	0	0	0	0	1
PT	0	0	8	0	0	8	0	0	0	0
PG	65	36	24	26	1	0	53	3	0	1
PO	0	0	2	0	0	0	0	0	0	0
PC	0	0	0	0	0	8	0	0	0	0
GG	0	0	0	0	0	0	0	0	0	0

Fig. 3 Classification of students' interactions according to the addressee (Pupil–pupil, PP; Pupil–teacher, PT; Pupil–group, PG; Pupil–another group, PO; Pupil–class, PC; Between groups, GG) and the action (Explaining or clarifying ideas or concepts, EX; Giving instructions and leading a group, IL; Asking questions, Q; Taking a stance about something, TS; Reading, RE; Being a spokesperson, S; Discussing unrelated topic; DU; Being confused, BC; Making the task more difficult, TD; Rejecting the stance of a classmate, RS). The white colour represents the pupil–pupil interactions (PP), the grey colour represents the pupil–teacher interactions (PT), the diagonal stripes represent the pupil–group interactions (PG), the black colour represents the pupil–another group interactions (PO), the dots represent the pupil–class interactions (PC) and the black squares represent the interactions between groups (GG). The height of the bars corresponds to the number of actions of each type developed in each interaction. For instance, of a total of 16 PT interactions, the Q action was developed in eight of them

The contributions made on-task for each of the established categories were as follows: 74 (26.2%) explaining or clarifying ideas or concepts (EX), 61 (21.6%) giving instructions and leading the group (IL), 38 (13.5%) asking questions (Q), 34 (12.1%) taking a stance about something (TS), 1 (0.4%) reading (RE) and 16 (5.7%) being a spokesperson (S). Most of the contributions involved giving explanations, giving instructions, asking questions and taking a stance about something. The percentage of explanations was higher than that of the questions because each question can lead to several explanations, either complementary or opposite. There was also a significantly high number of contributions in the category of *giving instructions and leading a group*, which correspond to the contributions made to direct the discussion (e.g. when one student tried to focus the discussion) or logistical contributions (e.g. contributions made in order to organise the task).

The results show that the teacher adopted a neutral role, avoiding the contribution of information or the evaluation of a student's interventions. Most of the interactions were between the groups of students to express their ideas and make sense of others' ideas. In addition, the interactions that have been analysed have some characteristics of the productive disciplinary engagement. Engle and Conant (2002) indicate that students can be considered to show greater disciplinary engagement when they make important contributions to the topic under discussion and they are almost not involved in *off-task* activities.

Analysis of argumentation

Argumentative statements are commonly observed when students engage in problem solving situations. Students provide claims as a way of answering a question. In this section, we analysed the discussion of the group of students to find out how the connections between the main parts of the arguments (claim, data and justification) occur. Specifically, in this paper we present the analysis of three excerpts of the transcribed discourse, which comprise 110 of the 301 total interactions. The analysis consisted of identifying the parts of the discussion that correspond to arguments. Arguments are defined as those parts of the discussions involved in reaching conclusions using hypothesis and data to justify, agree or oppose, among others. The term 'discussion' will be used as a broad term to include talking about a subject, exploring ideas and sharing perspectives.

In Excerpt 1 (Table 1), three of the four students that compose the group (Agustín, Alfonso and Álvaro) participated with the teacher in the discussion. They had to answer the question about how long it takes for the soil to form. This excerpt allows us to observe how these three students constructed arguments when trying to answer a question, talking to each other, interacting with the teacher and seeing how they were able to justify their statements and provide data, in this case, both hypothetical and empirical.

The participants drew their conclusions based on the option they considered as the correct choice among the different possibilities provided in the question. They reached their conclusion by discussing all the options and rejecting those that they did not consider to be correct. Thus, in the reconstructed argumentation scheme (Fig. 4), we considered a complex argument where the warrant in the principal argument is composed of two subsequent arguments. The first option refers to the shortest time interval (1 to 100 years) and the hypothetical data considered when discarding this is that the mountains would be much more pointed. The implicit warrant is that the mountains would be less eroded.

The option *one million years or more* was rejected with the warrant that the mountains would be more eroded because more time would have passed. The backing in this argument (here, students' knowledge or general ideas are being employed, and not strictly scientific ideas) is related to the concept of erosion. This concept is linked to long intervals of time, and the process of soil formation is understood as a process of sedimentation of eroded material coming from mountains.

In the next excerpt (Table 2), all the students of the group (Agustín, Alfonso, Álvaro and Antonio) participated in the discussion about the origin of the materials that form the soil. In this excerpt, these students discussed among themselves without the presence of the teacher.

This argument was constructed almost entirely by Agustín, and he supported it with basic knowledge of geological processes. Alfonso opposed him stating that the parent rock could not form soil, since it was not part of it. He expressed this by stating 'you can't make something from nothing'. However, he ended up supporting Agustín's proposal by asking, 'why can't they have come from a piece that broke off from the rock?' because the reply to this question was the conclusion previously established by Agustín.

Table 1 Transcription of the Excerpt 1 in which the following question was answered: How long does it take soil to be formed? Why? (a) Between 1 and 100 years, (b) between 100 and 15,000 years, (c) between 15,000 and 1,000,000 years and (d) 1,000,000 years or more

Speaker	Statement	Analysis of argumentation	Pupil interactions	Teacher interactions
Agustín	We chose b, which is between 100 and 15,000 years	Claim	PC-S	
	It couldn't be between 1 and 100 years…	Claim	PC-S	
	because the mountains would be much more pointed…	Hypothetical data		
Agustín	And if it was a million years or more…	Challenge	PC-S	
Agustín	… they would be much more eroded because more time would have passed	Warrant	PC-S	
Teacher	What do you mean that they would have been more eroded?			GC-Q
Agustín	Everything would be flatter	Hypothetical data	PC-S	
Alfonso	This would be like Holland	Hypothetical data	PG-EX	
Álvaro	I don't know if that's right	Challenge	PG-Q	
Agustín	What? I think so		PG-TS	
Teacher	What do you mean that it would be flatter?			GC-Q
Agustín	I mean that there would be more soil and fewer rocks	Hypothetical data	PC-S	
Teacher	Why would there be more soil and fewer rocks?	Challenge		GC-Q
Agustín	Because there are many stones…	Empirical data	PC-S	
Teacher	Yes?			GC-DT
Agustín	There wouldn't be so much stone in the countryside	Hypothetical data	PC-S	
	and there would be more soil, more dust, there would be more topsoil because in some areas the topsoil isn't very deep	Empirical data	PC-S	

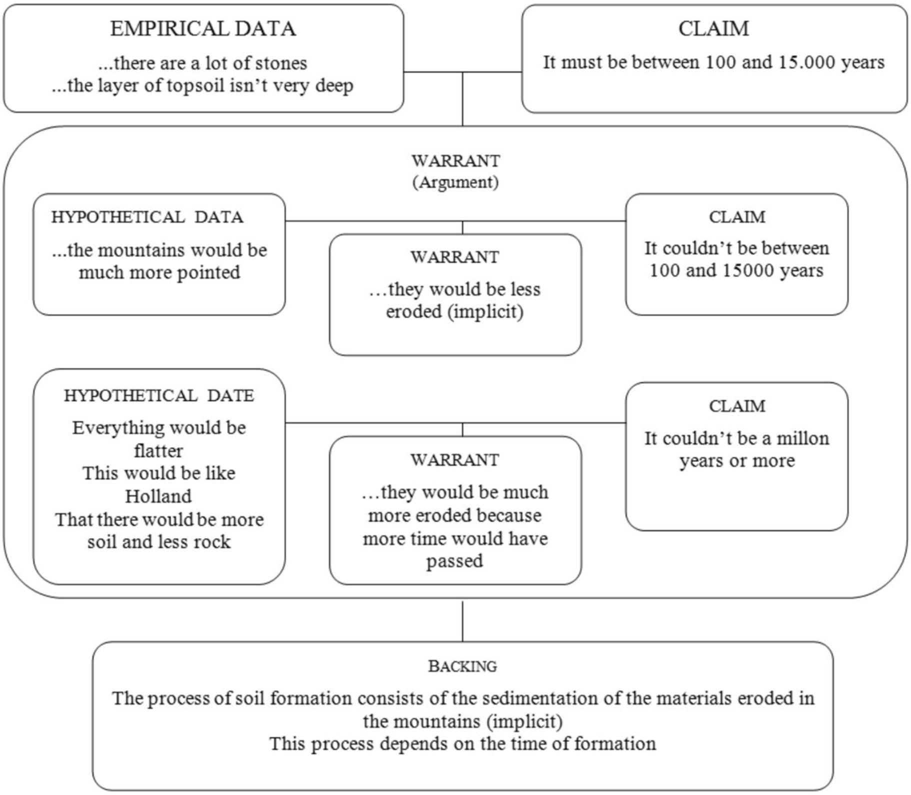


Fig. 4 Reconstructed argumentation scheme of Excerpt 1 in which the following question was answered: How long does it take soil to be formed? Why? **a** Between 1 and 100 years, **b** between 100 and 15,000 years, **c** between 15,000 and 1,000,000 years and **d** 1,000,000 years or more

The stance taken by Alfonso in this excerpt does not seem to be related to the substance of the argument (Fig. 5); rather, it was aimed at asserting himself within the group and disputing the leadership of Agustín. He showed this attitude throughout the teaching unit. This explains why, once the conclusion was drawn, Alfonso said to Agustín, 'Ha, ha, that made you work, eh?'.

In the next excerpt (Table 3), the four members of the group (Agustín, Alfonso, Álvaro and Antonio) participated in the discussion on why soils fertilised with manure are more fertile than those fertilised with inorganic fertilisers. In this excerpt, the students discussed among themselves without the presence of the teacher.

This argument (Fig. 6) is the least clear of the three arguments analysed and, likewise, the conclusion proved to be more indirect and less convincing for the group. In fact, the group discussed the issue again because Agustín was not sure about the conclusion. The first warrants were supplied by Antonio who stated 'the ones that are fertilised with manure have got more', and by Agustin, who listed the different types of inorganic fertilisers in a statement that was completed when he outlined the uses of each.

This argument shows two clear differences in relation with the previous ones. First, in the use of warrants and backing obtained from the pupils' own experiences. All of them come from families in which agricultural and livestock activities have an economic

Table 2 Transcription of the Excerpt 2 in which the following question was answered: Where do the materials that form the soils come from?

Speaker	Statement	Analysis of argumentation	Pupil interactions
Agustín	Let's see. Where do the materials that form the soils come from? Are they always above the materials from which they originate?	Focussing on the question	PG-IL
Alfonso	No		PG-TS
Agustín	First question. Let's start with the first things. Don't start at the end. Where do they come from? Do you know?		PP-IL
Alfonso	From other materials	Claim	PG-TS
Agustín	From the parent rock…		PG-EX
Álvaro	That's it		PG-TS
Agustín	They come from the parent rock		PG-TS
Agustín	The parent rock…	Claim	PG-TS
Agustín	…that was eroded	Warrant	PG-EX
Antonio	Are they always above it?		PG-Q
Alfonso	Listen. (to Agustín) The issue is that you can't make something from nothing	Challenge	PP-IL
Agustín	What?		PP-Q
Alfonso	In other words, if there's no rock you can't make anything from it, and you can't make something from nothing	Challenge	PP-EX
Agustín	But look, listen, listen, listen… where do the materials that form the soils come from? Where do they come from? From the parent rock	Claim	PP-TS
Antonio	But, are they always above it?		PG-Q
Agustín	Well, that's another question		PG-IL
Agustín	Why do they come from the parent rock?		PG-Q
Álvaro	Because it was eroded	Warrant	PG-EX
Alfonso	Because you can't make something from nothing	Challenge	PG-TS
Agustín	Of course, so they must come from the parent rock…	Claim	PG-TS
Alfonso	Why can't they have come from a piece that broke off from the rock?	Challenge	PG-Q
Agustín	But that piece is the same as the parent rock… it's part of the parent rock	Warrant	PG-EX
Alfonso	…but before that it was magma		PG-EX

Table 2 (continued)

Speaker	Statement	Analysis of argumentation	Pupil interactions
Agustín	Well… that comes from the parent rock just the same. The parent rock breaks and makes sand. The sand gets broken up and makes dust. It makes everything. They come from the parent rock	Backing	PG-EX
Álvaro	Everything comes from the same place		PG-TS
Alfonso	Ha, ha, that made you work, eh?		PG-IL

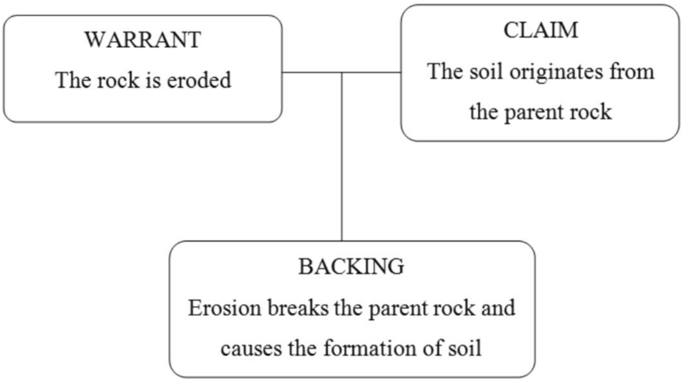


Fig. 5 Reconstructed argumentation scheme of Excerpt 2 in which the following question was answered: Where do the materials that form the soil come from?

significance. Secondly, the discussion diverged to unrelated topics not involved in the argument. As an example, Antonio led the conversation to the cultivation of bamboo when he commented, 'I'm going to see if I can grow some canes, man'. John Leach and Phil Scott (2002) consider that dialogue is fruitful when students have the necessary conceptual elements to be able to discuss. If dialogue is proposed in advance, the students will be unable to discuss because they do not have enough knowledge, or a discussion will take place that will evolve towards sterile aspects for the proposed learning objectives (Leach and Scott 2002).

Excerpt 3 can serve as example of how extracurricular experiences are activated in discourse. The arguments were constructed around knowledge that was not acquired in the school, and this knowledge was established as a legitimate source of new knowledge (Candela 1998). Here, the mediating role of the teacher needed to relate everyday knowledge and knowledge of school science and help structure the ideas seems to be lacking. We also see how, in the end, students tried to prove the validity of their ideas by looking up information in the dossier.

Discussion

As Berland and Hammer (2009) point out, traditional class discussions are framed by the idea that the teacher is the one who transmits the information and who should direct the discussion, so that most interactions are established between the teacher and the students. According to this approach, the implicit ideas and norms are that the knowledge can be transmitted and the teacher's ideas must be accepted, and the best way to accomplish this is to control the classroom discussions. Nevertheless, from a socio-constructivist and dialogic teaching perspective, interactions between classmates should be encouraged, as this is the best way to articulate, activate and revise ideas, as well as to construct and reconstruct knowledge (e.g. Alexander 2017).

According to the first research question that refers to the type of interactions that take place within a group, the use of the analytical framework designed to describe the interactions between the students and the teacher allowed us to examine the roles played by them during the activity through a categorisation of the actions. The results we obtained show

Table 3 Transcription of the Excerpt 3 in which the following question is answered: Why are soils fertilised with manure more fertile than those containing inorganic fertilisers?

Speaker	Statement	Analysis of argumentation	Pupil interactions
Antonio	Why are soils fertilised with manure more fertile than those containing inorganic fertilisers?	Focussing	PG-IL
Antonio	Because the ones that are fertilised with manure have got more…		PG-EX
Álvaro	Because manure is better than fertiliser	Claim	PG-EX
Agustín	They are all fertilisers, man!		PG-EX
Álvaro	Manure is better	Claim	PG-EX
Antonio	5 × 5 × 5 is a fertiliser, isn't it?		PG-Q
Agustín	or 15 × 15 × 15, or 10 × 10 × 10. It depends on what you use it for	Backing	PG-EX
Álvaro	10 × 10 × 10?		PG-Q
Agustín	10 × 10 × 10 is used for lawns, 15 × 15 × 15 is used for grass for feeding cows and I don't know what 5 × 5 × 5 is used for. For house plants	Backing	PG-EX
Álvaro	And 4 × 12 × 8, what about it?		PG-Q
All	Laughs		
Agustín	I've only heard of these…		PG-Q
Álvaro	For potatoes		PG-EX
Álvaro	A lot of people use 4 × 12 × 8 for potatoes instead of manure because 15 × 15 × 15 is really strong	Backing	PG-EX
Agustín	Or 15 × 15 × 15, but they aren't use much		PG-EX
Álvaro	15 × 15 × 15 is the strongest of all of them	Backing	PG-EX
Agustín	I know, it's *Nitramon*		PG-TS
Álvaro	You can use it on the roots of pine trees…		PG-EX
Álvaro	…you put it on the roots and they grow faster. You make a hole		PG-EX
Agustín	15% N, 15% K and 15% P		PG-EX
Álvaro	You put the fertiliser in the bottom and the pine tree on top		PG-EX
Antonio	But do you not put the fertiliser on top?		PG-Q
Álvaro	But you can't touch the surface…		PG-EX
Álvaro	…because if you touch the root it burns		PG-EX

Table 3 (continued)

Speaker	Statement	Analysis of argumentation	Pupil interactions
Agustín	Yes, it burns and dies		PG-EX
Antonio	But if you put it in the bottom of the hole you would burn the roots		PG-TS
Agustín	You put it in the bottom and put a layer of soil on top, add some water and it dissolves, then after all that, you put it in		PG-EX
Álvaro	Yes, the pine tree on top and that's it…		PG-EX
Álvaro	and now we've to finish doing that… what… we're not here to talk about pines	Focussing	PG-IL
Antonio	I'm going to see if I can grow some canes, man		PG-DU
Agustín	What? What?		PG-Q
Antonio	Canes		PG-DU
Agustín	Canes? … These…		PG-Q
Antonio	Bamboo canes		PG-DU
Agustín	There are loads of them on our land		PG-DU
Álvaro	Where I live too		PG-DU
Antonio	I've got about five, just small		PG-DU
Agustín	If you came there, man… they must be a metre high or more…		PG-DU
Antonio	And that's a lot, is it?		PG-DU
Alfonso	You get them four metres high		PG-DU
Agustín	Mine, well they're not mine, I haven't got any, the ones that are there are about 2 or 2.5 m		PG-DU
Alfonso	There beside the river they're about 4 m high		PG-DU
Agustín	I can't reach them?		PG-DU
Antonio	They grow at the river because there's water		PG-DU
Agustín	They have to have water, or else…		PG-DU
Agustín	Right, come on, work… inorganic fertiliser	Focussing	PG-IL
All	They read in silence		
Álvaro	I'd put it like this… because the manure…		PG-EX

Table 3 (continued)

Speaker	Statement	Analysis of argumentation	Pupil interactions
Agustín	Is better than the…		PG-EX
Agustín	Let's see… let's find it here, does it put it here or not? (He reads a page from de dossier)		PG-IL
All	They read in silence		
Antonio	Because since it's got more chemical components	Warrant	PG-EX
	and… it fertilises the plants better, and the soil		

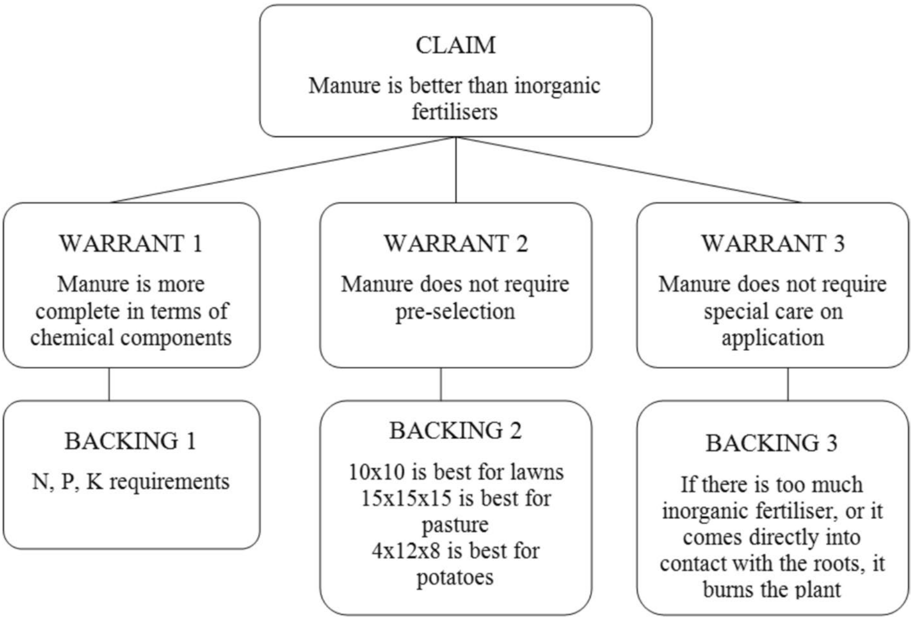


Fig. 6 Reconstructed argumentation scheme of Excerpt 3, in which the following question was answered: Why are soils fertilised with manure more fertile than those containing inorganic fertilisers?

that the roles played by the students and the teacher during the discussion were different from those of the traditional classroom discussions. The classroom discussion was not dominated by the teacher, whose role was similar to that of another classmate. To understand the roles assumed by the teacher, it must be considered that this session corresponds to the start of Phase 2, which focussed primarily on activating students' knowledge through questions. It is noteworthy that 74.1% of the pupil interactions occurred between a student and the working group (PG) and most of the pupil interactions were aimed at explaining or clarifying ideas or concepts to the working group. These results are crucial, as the interactions between a student and the working group (PG) are necessary for the argumentation processes in a small group because they encourage discussion so that all ideas can be considered. Another result of interest is the high percentage of IL interactions (giving instructions and leading a group) that take place in the group since they show the students' concern about coordinating intellectual work.

The teacher typically asked questions in order to lead the students to try to express their ideas (for example, 'what do you mean they would have eroded more?'). The teacher also challenged the students' thinking (for example, 'why would there be more land and fewer stones?'), and only as a last resort did the teacher provide the information the students requested. The task required students to share their thinking and pool their knowledge, thus creating a context to examine their ideas. The results reveal that the conversations focussed mainly on the discussion of pupils' ideas. The students spent most of their time throughout the conversations explaining their ideas or trying to clarify them.

On the other hand, the role of promoters of reflection is important in developing the reasoning processes of the group (Hogan 1999). In Excerpt 1, the teacher adopted this role by participating in an extended series of question exchanges that helped students to better articulate their beliefs and conceptions. In Excerpt 2, the role of promoters of reflection was played by a pupil (Alfonso) who challenged the ideas expressed by the other members of the group. In these excerpts, the fact that the discussion was not under the teacher's control allowed the students to express their ideas more freely, revising them to better face the challenges and co-construct new arguments. Dialogic discourse could involve students working together to understand any point of difference as they develop their explanations. The agreement and disagreement in point of view constitute an ongoing dialogical interanimation of ideas (Scott, Mortimer and Aguiar 2006). In Excerpt 3, it is interesting to observe that students established connections between the content of the task and their everyday knowledge, in this case about the use of fertilisers. It must be noted that these students come from a rural environment, so they have an extensive knowledge about different types of fertilisers and how to use them. Therefore, the students made substantive contributions to the topic under discussion, although these contributions did not help in the construction of a more sophisticated argument. The students were involved in the task and in the pupil–pupil interactions that involved one student trying to understand the thinking of another, but the dialogue was unproductive. As conceived by Engle and Conant (2002), it did not constitute an improvement in the quality and sophistication of arguments, and the development of new ideas and disciplinary understanding. Perhaps, if the teacher had been present, he could have helped to structure the speech in order to construct more sophisticated arguments. As previously mentioned, there seems to be a consensus on the importance of dialogic discourse, since this communicative approach allows for the opportunity to construct and evaluate arguments, relate conclusions with evidence and construct explanations and counterarguments (Kelly, Crawford and Green 2001). However, there are authors who point out the importance of establishing a tension between the dialogic and the authoritative discourse, understanding the latter as a discourse that is more focussed on the content from the perspective of the discipline, so that it is more effective in helping students construct certain ideas. In Excerpt 3, there is a low level of articulation of ideas, what Scott, Mortimer and Aguiar (2006) call low interanimation of ideas. The discourse is dialogical as different ideas are pointed out, but there is no attempt to work on these views through comparing and contrasting. Scott, Mortimer and Aguiar (2006) point out that changes in communicative approaches are essential for students to learn science in a meaningful way. However, they consider that, in a sequence of teaching in which new ideas are introduced, there must be a tension between dialogical and authoritative interventions focussed on the scientific vision.

Regarding argumentation, the analysis of the discussion using Toulmin's scheme allowed us to identify arguments and evaluate the complexity of the argumentation. The backings used by the students give us an idea of the complexity and adequacy of their models, which they construct throughout the discussion. For example, in the first excerpt, students used the term *erosion* to refer to the process by which soil is formed. The idea behind their conversation seems to be that soil is formed by the breakdown of the rocks from the mountains. Then, the resulting material is transported and undergoes sedimentation, so that over time everything becomes flatter. These ideas are similar to those described by John Happs (1981) in a study on students' understanding of soil, and in a more recent study carried out with 15- and 16-year-old students (Fernández, Sesto and García-Rodeja 2017). It is interesting to compare the scientifically accepted definitions of the terms *erosion* and *weathering* with the meanings used by the pupils. *Weathering* refers to chemical, physical or biological decay of rocks in situ, near or on the surface. *Erosion* is defined as any of the processes by which debris or rock material is loosened or dissolved and removed from any part of the Earth's surface, and includes weathering, solution, corrosion and transportation (Dove 1997). Dove (1997) points out that most students appreciated that weathering occurs in situ, while erosion involves the movement of the agent and the material it transports. In Excerpt 2, the term *erosion* is used once again to describe how rock breaks down to form sand and soil. In this excerpt, the discussion shows the difficulty that students had in accepting the idea that soils can be formed in situ. In this case, the teacher's intervention would be appropriate to assist students to clarify their ideas and distinguish erosion from weathering, which had been addressed in previous lessons. In any case, the non-intervention of the teacher at that moment may be due to the impossibility of meeting the needs of the eight groups that are working in the classroom at the same time. The teacher must pay attention to the construction of knowledge in the eight working groups and sometimes misses opportunities to make substantial contributions to help the construction of knowledge though relevant information or clarifying ideas.

It has been pointed out (Keys 1997) that the type of arguments constructed by the students depend on their personal theories concerning scientific issues. However, there are issues that they have not yet thought about, so they are activating ideas while constructing arguments, which come from their own personal theories based on knowledge already provided on other issues, knowledge from their own daily experience and ideas that emerge and are consolidated during the discussion of the activity. In Excerpt 3, the pupils frequently referred to their personal experiences during argumentation. Therefore, the discussion was enriched with the pupils' knowledge, gained from their lives in a rural environment.

Regarding the second research question that refers to the co-construction of arguments, this study shows the active participation of students in the process of knowledge construction during classroom discussion, and it analyses how students debate and argue, and how this can contribute to or hinder the processes of construction and legitimisation of knowledge (Candela 1998). The transcriptions show that the discursive construction does not always evolve towards shared meanings. Such is the case in Excerpt 2, where substantial ideas were provided by a single student, or in Excerpt 3, where arguments in parallel were constructed. As Sum Mi Yun and Heui-Baik Kim (2015) state, group discussions tend to be dominated by the most outspoken and advantaged students, so the higher-status students generally make more contributions during the process of constructing arguments, further benefitting from the acquisition of knowledge.

When analysing the arguments, we can see that the discursive interaction is not the same quality in all cases. In the first excerpt, the students are able to activate their knowledge by making it explicit, discussing ideas and co-constructing arguments. In the second excerpt, there is less interaction between their ideas, and only one student constructs the argument. However, it is important to highlight the role played by Alfonso, who continually challenged the ideas of his classmate Agustín, helping to further elaborate knowledge. In the third excerpt, there were more interventions, but less interaction between ideas, or what Scott, Mortimer and Aguiar (2006) call a lower level of interanimation, so arguments in parallel were constructed (e.g. Hogan 1999). The differences may be due to the fact that not all the questions were equally productive in promoting argumentation. The first question consisted of several options about the time it can take for a soil to form could encourage students to express their ideas and opinions. The second question aimed to deepen the understanding of a phenomenon such as soil formation could encourage discussion in the classroom. The third question referred to a relevant topic in the life of the students, and could encourage them to make interventions. Nevertheless, this question is conceptually more complex since it asks for explanations about a statement, which could lead to lower quality discursive interactions (see Carvalho and Paulo 2004).

To summarise, it is clear that the learning environment created in the classroom encouraged the students to reason and discuss actively.

Implications for science education, limitations and further research

It has been noted that including argumentation in teaching science helps to foster students' critical thinking, reasoning and decision-making on critical issues for citizens, as well as on scientific and socio-scientific issues in which informed decisions must be made (Roberts and Gott 2010). Moreover, the dialogical nature of argumentation encourages students to engage in the development of knowledge through social interactions, allowing them to be introduced to the culture of science in the class setting (Kim, Anthony and Blades 2014).

Nowadays, it is critical that students develop argumentative skills. To exercise these skills, students should have the opportunity to learn how to structure their own ideas and analyse their opinions and those of others. Scientific discourse should exhibit clarity of argument, precision in distinguishing among the various factors that might be relevant to the phenomena discussed, and consistency of facts. These qualities should therefore be developed by pupils during their scientific training. This applies to all students, not only to those who intend to pursue a scientific career, because modern day citizens are continually called upon to have opinions about matters of public or private concern, which will be based on the reports or declarations of professional scientists.

More research is needed to clarify what the role of the teacher should be at different times during the activities, to be more effective in helping students to engage in increasingly higher quality discourses, so that there are opportunities to articulate ideas that may evolve to become more sophisticated and in accordance with scientific ideas.

Recognising the limitations of this study, we would like to emphasise that our aim is not to generalise results to other cases, given the qualitative nature of the research involving a single classroom context. However, this study does allow for comparisons with other studies of a similar nature, contributing to the knowledge of how students co-construct arguments related to soil science, and what types of interactions are developed. In addition, similar to the study of Mijung Kim and Wolff-Michael Roth (2018), another strength is the development of the systemic network for the analysis of interactions that can be used in similar science classroom contexts. Future research on the analysis of argumentation should be improved by incorporating aspects that allow a more detailed analysis of the collective construction of arguments.

We hope that this paper related to the implementation and analysis of classroom discourse will encourage other teachers to change the conversational patterns in their classrooms in order to offer better opportunities for argumentation.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature. Funding was provided by Ministerio de Ciencia, Innovación y Universidades (Grant No. EDU2015-66643-C2-2-P). (PID2022-137010OB-I00 RESEARCH PROJECT, FUNDED BY MCIN/AEI/10.13039/501100011033/FEDER, UE).

References

Alexander, R. (2001). *Culture and pedagogy: International comparisons in primary education*. Blackwell.

Alexander, R. (2017). *Towards dialogic teaching: Rethinking classroom talk*. Dialogos.

Barak, M. (2017). Science teacher education in the twenty-first century: A pedagogical framework for technology-integrated social constructivism. *Research in Science Education, 47*, 283–303. https://doi.org/10.1007/s11165-015-9501-y

Berland, L. K., & Hammer, D. (2009). *Tension between epistemology of scientific argumentation and institutional expectations for student and teacher roles.* Paper presented at the Annual Meeting of the American Educational Research Association, April 13–17, 2009, San Diego.

Berland, L. K., & McNeill, K. L. A. (2010). A learning progression for scientific argumentation: Understanding student work and designing supportive instructional contexts. *Science Education, 94*(5), 191–216. https://doi.org/10.1002/sce.20402

Berland, L. K., & Reiser, B. J. (2009). Making sense of argumentation and explanation. *Science Education, 93*(1), 26–55. https://doi.org/10.1002/sce.20286

Bliss, J., Monk, M., & Ogborn, J. (1983). *Qualitative data analysis for educational research*. Falmer Press.

Bricker, L. A., & Bell, P. (2008). Conceptualizations of argumentation from science studies and the learning sciences and their implications for the practices of science education. *Science Education, 92*(3), 473–498. https://doi.org/10.1002/sce.20278

Candela, A. (1998). Students' power in classroom discourse. *Linguistics and Education, 10*(2), 139–163. https://doi.org/10.1016/S0898-5898(99)80107-7

Carvalho, A. M. P., & Paulo, S. (2004). Building up explanations in physics teaching. *International Journal of Science Education, 26*(2), 225–237. https://doi.org/10.1080/0950069032000052072

Cavagnetto, A., Hand, B. M., & Norton-Meier, L. (2010). The nature of elementary student science discourse in the context of the science writing heuristic approach. *International Journal of Science Education, 32*(4), 427–449. https://doi.org/10.1080/09500690802627277

Colomina, R., Mayordomo, R., & Onrubia, J. (2001). El análisis de la actividad discursiva en la interacción educative. Algunas opciones teóricas y metodológicas [Analysis of discursive activity in educational interaction. Some theoretical and methodological options]. *Infancia y Aprendizaje, 24*(1), 67–80. https://doi.org/10.1174/021037001316899929

Cornelius, L. L., & Herrenkohl, L. R. (2004). Power in the classroom: How the classroom environment shapes students' relationships with each other and with concepts. *Cognition and Instruction, 22*(4), 467–498. https://doi.org/10.1207/s1532690Xci2204_4

Damşa, C. I. (2014). The multi-layered nature of small-group learning: Productive interactions in object-oriented collaboration. *International Journal of Computer-Supported Collaborative Learning, 9*(3), 247–281. https://doi.org/10.1007/s11412-014-9193-8

Dove, J. (1997). Student ideas about weathering and erosion. *International Journal of Science Education, 19*(8), 971–980. https://doi.org/10.1080/0950069970190809

Driver, R., Newton, P., & Osborne, J. (2000). Establishing the norms of scientific argumentation in classrooms. *Science Education, 84*(3), 287–312. https://doi.org/10.1002/(SICI)1098-237X(200005)84:3%3c287::AID-SCE1%3e3.0.CO;2-A

Duschl, R. A. (2003). Assessment of inquiry. In J. M. Atkin & J. Coffey (Eds.), *Everyday assessment in the science classroom* (pp. 41–59). NSTA Press.

Duschl, R. A., & Gitomer, D. H. (1996). *Project SEPIA design principles.* Paper presented at the Annual Meeting of the American Education Research Association (AERA), April 8–13, 1996, New York.

Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction, 20*(4), 399–483. https://doi.org/10.1207/S1532690XCI2004_1

Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse. *Science Education, 88*(6), 915–933. https://doi.org/10.1002/sce.20012

Erickson, F. (2012). Qualitative research methods for science education. In B. J. Fraser & K. G. Tobin (Eds.), *Second international handbook of science education* (pp. 1451–1469). Springer.

Faruji, L. F. (2011). Discourse analysis of questions in teacher talk. *Theory and Practice in Language Studies, 1*(12), 1820–1826. https://doi.org/10.4304/tpls.1.12.1820-1826

Fernández, A., Sesto, V., & García-Rodeja, I. (2017). Modelos mentales de los estudiantes de secundaria sobre el suelo [Secondary students' mental models about the soil]. *Enseñanza de las ciencias: Revista de investigación y experiencias didácticas, 35*(2), 127–145. https://doi.org/10.5565/rev/ensciencias.2217

Fyttas, G., Komis, V., Kaliampos, G., & Ravanis, K. (2023). Mental representations and cognitive schemata of ninth grade students for the refraction of light. *Education Sciences, 13*(5), 467. https://doi.org/10.3390/educsci13050467

Ford, M. (2008). Disciplinary authority and accountability in scientific practice and learning. *Science Education, 92*(3), 404–423. https://doi.org/10.1002/sce.20263

Gee, J. P. (1998). What is literacy? In R. Spack & V. Zamel (Eds.), *Negotiating academic literacies: Teaching and learning across languages and cultures* (pp. 51–60). Lawrence Erlbaum Associates.

González-Howard, M. (2019). Exploring the utility of social network analysis for visualizing interactions during argumentation discussions. *Science Education, 103*(3), 503–528. https://doi.org/10.1002/sce.21505

Grace, M. (2009). Developing high quality decision-making discussion about biological conservation in a normal classroom setting. *International Journal of Science Education, 31*(4), 551–570. https://doi.org/10.1080/09500690701744595

Happs, J. C. (1981). *Soils. Science Education research unit. Working Paper 201.* Waikato University.

Hennessy, S. (1993). Situated cognition and cognitive apprenticeship: Implications for classroom learning. *Studies in Science Education, 22*(1), 1–41. https://doi.org/10.1080/03057269308560019

Hogan, K. (1999). Sociocognitive roles in science group discourse. *International Journal of Science Education, 21*(8), 855–882. https://doi.org/10.1080/095006999290336

Hogan, K., Nastasi, B. K., & Pressley, M. (2000). Discourse patterns and collaborative scientific reasoning in peer and teacher-guided discussions. *Cognition and Instruction, 17*(4), 379–432. https://doi.org/10.1207/S1532690XCI1704_2

Hollon, R., Anderson, C. W., & Smith, E. L. (1980). *A system for observing and analysing elementary school science teaching: A user's manual*. Michigan State University Press.

Jiménez-Aleixandre, M., & Erduran, S. (2007). Argumentation in science education: An overview. In M. Jiménez-Aleixandre & S. Erduran (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 3–27). Springer.

Kelly, G. J., Crawford, T., & Green, J. (2001). Common task and uncommon knowledge: Dissenting voices in the discursive construction of physics across small laboratory groups. *Linguistics and Education, 12*(2), 135–174. https://doi.org/10.1016/S0898-5898(00)00046-2

Keys, C. W. (1997). An investigation of the relationship between scientific reasoning, conceptual knowledge model formulation in a naturalistic setting. *International Journal of Science Education, 19*(8), 957–970. https://doi.org/10.1080/0950069970190808

Keys, C. W., & Bryan, L. A. (2001). Co-constructing inquiry-based science with teachers: Essential research for lasting reform. *Journal of Research in Science Teaching, 38*(6), 631–645. https://doi.org/10.1002/tea.1023

Kim, M., Anthony, R., & Blades, D. (2014). Decision making through dialogue: A case study of analyzing preservice teachers' argumentation on socioscientific issues. *Research in Science Education, 44*, 903–926. https://doi.org/10.1007/s11165-014-9407-0

Kim, M., & Roth, W. M. (2018). Dialogic argumentation in elementary science classrooms. *Cultural Studies of Science Education, 13*, 1061–1085. https://doi.org/10.1007/s11422-017-9846-9

Kim, M. Y., & Wilkinson, I. A. (2019). What is dialogic teaching? Constructing, deconstructing, and reconstructing a pedagogy of classroom talk. *Learning, Culture and Social Interaction, 21*, 70–86. https://doi.org/10.1016/j.lcsi.2019.02.003

Kolstø, S. D. (2018). Use of dialogue to scaffold students' inquiry-based learning. *Nordic Studies in Science Education, 14*(2), 154–169. https://doi.org/10.5617/nordina.6164

Kuhn, D. (2019). Critical thinking as discourse. *Human Development, 62*(3), 146–164. https://doi.org/10.1159/000500171

Leach, J., & Scott, P. (2002). Designing and evaluating science teaching sequences: An approach drawing upon the concept of learning demand and a social constructivist perspective on learning. *Studies in Science Education, 38*(1), 115–142. https://doi.org/10.1080/03057260208560189

Lemke, J. L. (1990). *Talking science: Language, learning and values*. Ablex Publishing Corporation.

Lyons, J. (1995). *Linguistic semantics: An introduction*. Cambridge University Press.

Mehan, H. (1979). 'What time is it, Denise?': Asking known information questions in classroom discourse. *Theory Into Practice, 18*(4), 285–294. https://doi.org/10.1080/00405847909542846

Mercer, N., & Howe, C. (2012). Explaining the dialogic processes of teaching and learning: The value and potential of sociocultural theory. *Learning, Culture and Social Interaction, 1*(1), 12–21. https://doi.org/10.1016/j.lcsi.2012.03.001

Mercer, N., & Wegerif, R. (1999). Is 'exploratory talk' productive talk? In K. Littleton & P. Light (Eds.), *Learning with computers: Analizing productive interaction* (pp. 79–101). Routledge.

Monje, C. A. (2011). *Metodología de la investigación cuantitativa y cualitativa. Guía didáctica [Quantitative and qualitative research methodology. Didactic guide]*. Universidad Surcolombiana.

Mortimer, E. F., & Scott, P. H. (2003). *Meaning making in secondary science classrooms*. McGraw-Hill Education.

Newton, P., Driver, R., & Osborne, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education, 21*(5), 553–576. https://doi.org/10.1080/095006999290570

Nielsen, J. A. (2013). Dialectical features of students' argumentation: A critical review of argumentation studies in science education. *Research in Science Education, 43*, 371–393. https://doi.org/10.1007/s11165-011-9266-x

Ogborn, J. (1994). The nature of modelling. In H. Mellar, J. Bliss, R. Boohan, J. Ogborn, & C. Tompsett (Eds.), *Learning with artificial worlds: Computer based modelling in the curriculum* (pp. 11–15). The Falmer Press.

Oliva, J. M., & Acevedo, J. A. (2005). La enseñanza de las ciencias en primaria y secundaria hoy. Algunas propuestas de futuro [Teaching science in primary and secondary school today. Some future proposals]. *Revista Eureka sobre enseñanza y divulgación de las ciencias, 2*(2), 241–250. https://revistas.uca.es/index.php/eureka/article/view/3923

O'Loughlin, M. (1992). Rethinking science education: Beyond Piagetian constructivism toward a sociocultural model of teaching and learning. *Journal of Research in Science Teaching, 29*(8), 791–820. https://doi.org/10.1002/tea.3660290805

Omodan, B. I. (2022). The potency of social constructivism on classroom productivity in universities. *Studies in Learning and Teaching, 3*(1), 36–45. https://doi.org/10.46627/silet.v3i1.97

Osborne, J. F. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science, 328*(5977), 463–466. https://doi.org/10.1126/science.1183944

Osborne, J. F., Henderson, J. B., MacPherson, A., Szu, E., Wild, A., & Yao, S. Y. (2016). The development and validation of a learning progression for argumentation in science. *Journal of Research in Science Teaching, 53*(6), 821–846. https://doi.org/10.1002/tea.21316

Otten, S., Engledowl, C., & Spain, V. (2015). Univocal and dialogic discourse in secondary mathematics classrooms: The case of attending to precision. *ZDM, 47*, 1285–1298. https://doi.org/10.1007/s11858-015-0725-0

Palincsar, A. S. (1998). Social constructivist perspectives on teaching and learning. *Annual Review of Psychology, 49*, 345–375. https://doi.org/10.1146/annurev.psych.49.1.345

Pontecorvo, C., & Girardet, H. (1993). Arguing and reasoning in understanding historical topics. *Cognition and Instruction, 11*(3–4), 365–395. https://doi.org/10.1080/07370008.1993.9649030

Rapanta, C., & Felton, M. K. (2022). Learning to argue through dialogue: A review of instructional approaches. *Educational Psychology Review, 34*(8), 791–820. https://doi.org/10.1007/s10648-021-09637-2

Roberts, D., & Gott, S. (2010). Questioning the evidence for a claim in a socio-scientific issue: An aspect of scientific literacy. *Research in Science & Technological Education, 28*(3), 203–226. https://doi.org/10.1080/02635143.2010.506413

Rodrigues, S., & Thompson, I. (2001). Cohesion in science lesson discourse: Clarity, relevance and sufficient information. *International Journal of Science Education, 23*(9), 929–940. https://doi.org/10.1080/09500690010025076

Scott, P. H., Mortimer, E. F., & Aguiar, O. G. (2006). The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons. *Science Education, 90*(4), 605–631. https://doi.org/10.1002/sce.20131

Shemwell, J. T., & Furtak, E. M. (2010). Science classroom discussion as scientific argumentation: A study of conceptually rich (and poor) student talk. *Educational Assessment, 15*(3–4), 222–250. https://doi.org/10.1080/10627197.2010.530563

Siegel, H. (1995). Why should educators care about argumentation? *Informal Logic, 17*(2), 2–18. https://doi.org/10.22329/il.v17i2.2405

Simon, S., Erduran, S., & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. *International Journal of Science Education, 28*(2–3), 235–260. https://doi.org/10.1080/09500690500336957

Singh, S. (2019). Classroom discourse and effective learning of students. *International Journal of English, Language, Literature and Humanities, 4*(7), 214–222.

Taylor, S. J., & Bodgan, R. (1998). *Introduction to qualitative research methods: A guidebook and resource*. Wiley.

Toulmin, S. (1958). *The uses of argument*. Cambridge University Press.

Van Eemeren, F. H., & Grootendorst, R. (2004). *A systematic theory of argumentation: The pragma-dialectical approach*. Cambridge University Press.

Van Zee, E. H., & Minstrell, J. (1997). Reflective discourse: Developing shared understandings in a physics classroom. *International Journal of Science Education, 19*(2), 209–228. https://doi.org/10.1080/0950069970190206

Yun, S. M., & Kim, H. B. (2015). Changes in students' participation and small group norms in scientific argumentation. *Research in Science Education, 45*(3), 465–484. https://doi.org/10.1007/s11165-014-9432-z

Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching, 39*(1), 35–62. https://doi.org/10.1002/tea.10008

Francisco Sóñora is a part-time professor in science education at the University of Santiago de Compostela (Spain) and science teacher in secondary school. His research mainly focuses on climate change literacy.

Vanessa Sesto is a science teacher in secondary school and Ph.D. in the area of didactics of experimental sciences at the University of Santiago de Compostela (Spain). Her research aims to explore students' understanding of matter and its transformations.

Isabel García-Rodeja is a tenured professor in science education at the University of Santiago de Compostela (Spain). Her research mainly focuses on inquiry-based science learning, and the socio-environmental aspects related to Environmental Education, specifically climate change and soil science literacy.