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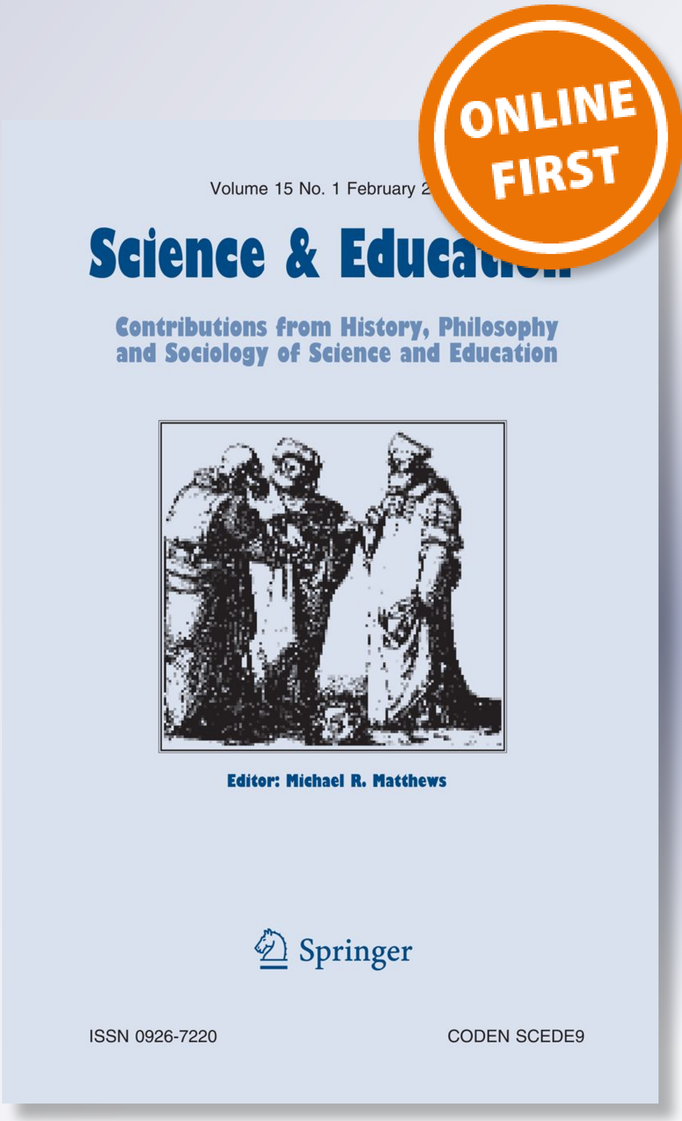

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Understanding Students' Reasoning: Argumentation Schemes as an Interpretation Method in Science Education

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Abstract The purpose of this paper is to investigate the argumentative structure of students' arguments using argumentation schemes as an instrument for reconstructing the missing premises underlying their reasoning. Building on the recent literature in science education, in order for an explanation to be persuasive and achieve a conceptual change it needs to proceed from the interlocutor's background knowledge to the analysis of the unknown or wrongly interpreted phenomena. Argumentation schemes represent the abstract forms of the most used and common forms of human reasoning, combining logical principles with semantic concepts. By identifying the argument structure it is possible to retrieve the missing premises and the crucial concepts and definition on which the conclusion is based. This method of analysis will be shown to provide the teacher with an instrument to improve his or her explanations by taking into consideration the students' intuitions and deep background knowledge on a specific issue. In this fashion the teacher can advance counterarguments or propose new perspectives on the subject matter in order to persuade the students to accept new scientific concepts.

1 Introduction

Science education cannot be conceived of as a mere accumulation of facts (Bell 2004) or a simple transmission of truths, carried out without considering the reasoning and dialogical dimension leading to the understanding of new ideas (Osborne 2010, p. 463). The idea of "transferring information" hides a fundamental dimension of teaching, persuasion. The explanations presented by a teacher need to be tailored to the interlocutors' knowledge and interests, underscoring the relevance and importance of the information provided (Sutton 1996, p. 146; see also Martins et al. 2001). Teaching, on this view, is an act of persuasion,

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or rather an act aimed at leading the interlocutor to a conceptual change by means of justifications (relevant and accepted by the learner) supported by evidence. The goal of conceptual change, the modification of deep beliefs (Chi and Roscoe 2002), can be revealed and developed through a dialogical process of interpretation and argumentation. Starting with naive conceptions, students are led to identifying their incomplete conceptions and developing them. In short, the process of teaching can be thought of as a dialogical and argumentative process, whose purpose is to change the learners' views on a specific problem.

In recent years, several studies have been developed introducing argumentation theory in educational contexts (Sampson and Clark 2008; Schwarz and De Groot 2007). In particular, the practice of argumentation has been addressed from two distinct but interrelated perspectives: the dialogical one, focused on the activity of supporting claims by means of reasons, and the more structural one, centered on the construction of arguments. On the one hand, the nature of classroom conversations has been investigated considering argumentative practices such as providing evidence to support a viewpoint, or rebutting and questioning other positions (Driver et al. 2000; Schwarz and De Groot 2007; Jimenez-Aleixandre et al. 2000; Duschl et al. 1999). On this view, dialogical argumentative activities can be seen as instruments for promoting critical reasoning (see Pera and Sahea 1991; Koballa 1992; Osborne 2010). On the other hand, other studies have taken into account a more specific dimension of argumentation, the construction of arguments. Theories on argument structure have been applied to science education in order to help students to better elaborate their written arguments. Analytic models have been developed to improve the articulation of the field-independent relationships, such as between premises and conclusion (Kelly and Takao 2002), or the filed-dependent ones, namely between specific evidence, warrants and claims (Sandoval and Millwood 2005). In this framework, the Toulmin's model of argument (TAP, Toulmin argument pattern, as developed in Osborne et al. 2004) has been used as an educational tool for improving students' understanding of scientific problems and for assessing the quality of argumentation in classrooms (including both the support of claims and the rebuttals) (Erduran and Jimenez-Aleixandre 2008). On this perspective, the students' arguments can be improved by teaching them how to construct better arguments, namely arguments complete in all their components (including, in addition to data and claims, also other elements that are usually missing, such as backings or warrants).

This paper addresses a specific issue in the aforementioned dialogue between argumentation theory and science education, the problem of reconstructing the previous knowledge underlying students' arguments. Our purpose is to show how a specific development of Toulmin's theory of warrants, argumentation schemes, can be used as an instrument for revealing students' background knowledge. Argumentation schemes are prototypical patterns of argument representing the structure of the semantic and logical relation between premises and conclusion. Their scope is more limited than the Toulmin's model, as they do not represent several components of the macro-structure of arguments, such as qualifiers, data and rebuttals. However, their more specific object of analysis allows one to examine in depth the implicit premises needed for an argument to be complete from a semantic and logical perspective. We maintain that they can be used as an instrument for reconstructing the implicit or unexpressed premises in students' arguments (Konstantinidou et al. 2010), bringing to light the conceptual background underlying their reasoning concerning scientific matters. By recognizing the argumentation schemes underlying the student's reasoning, the teacher can retrieve the unexpressed premises on which the student's conclusion is based and the crucial concepts that need to be corrected or developed. This analytical instrument will be illustrated through some case studies, showing how the

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reconstruction of the implicit dimension of arguments can reveal background knowledge, which in its turn can become crucial for the dialogical process of learning.

2 Background Knowledge and Instruments of Interpretation

Conceptual change is deeply related with the problem of the learner's prior or background knowledge (Limón 2001, p. 375). The process of persuasion and development or restructuring of the students' incomplete beliefs crucially depends on the knowledge they hold (Sutton 1996, p. 146; see also Martins et al. 2001). However, how is it possible to know the others' mind? How is possible to understand the beliefs and the assumptions of our interlocutors? A possible answer can be found in the concept of argument. Students interpret scientific facts and advance predictions based on arguments grounded on prior knowledge that can be more or less complete (Osborne 2005, pp. 371–372). The reconstruction of the implicit dimension of arguments (Braet 1999; Levi 1995) allows one to understand the reasons or the principles supporting a specific view, so that they can be later addressed during the teaching activities. For this reason we will show how a component of Toulmin's model, the warrant, can be further specified and used for the reconstruction of the implicit premises and the tacit concepts underlying an argument.

2.1 Persuasion and Background Knowledge

Previous knowledge is of crucial importance in education (Roschelle 1995). Learners have their own "private understanding" of scientific concepts and laws, which is often incomplete and "fraught with preconceptions" (Mestre 1994). For this reason, students' ideas of scientific phenomena often differ from the concepts commonly accepted in the scientific community. Such background knowledge can affect the learners' understanding and interpretation of scientific texts and explanations, which risk being incorporated into and adapted to their pre-existing views (Guzzetti et al. 1993; Bransford et al. 2000, pp. 10–11). Moreover, such prior knowledge, even if fragmented and different from the accepted scientific ideas, is considered as reasonable by the students. It is borne out by reasons that are not properly scientific, but that need to be addressed and rebutted by stronger or more complete scientific arguments. On this perspective, background knowledge is a hidden dimension of learning that need to be brought to light and properly taken into account; otherwise scientific texts or arguments risk leaving unaffected the learner's conceptual system, not triggering any conceptual change (Southerland et al. 2001; Duit 1999).

Background knowledge and the reasons on which it is based need to be retrieved and analyzed, so that it can be attacked and confronted with more intelligible, more plausible or more predictive scientific conceptions (Hewson 1992, p. 11; Posner et al. 1982). For this reason, in this process argumentation plays a crucial role (Osborne et al. 2004, p. 995; Carey 2000, pp. 13–14). On Hewson's view, the process of learning is inherently related with the rebuttal of prior beliefs conflicting with the new, scientific ones (Hewson 1992). A new conception that is inconsistent with the student's background knowledge cannot be accepted until the learner is aware of the root of the conflict and becomes dissatisfied with his prior ideas. The latter ones need to be reconstructed and rebutted by stronger and more explicative reasons. For instance, a scientific concept such as a thermodynamic law needs to be not only understood, but also accepted as the best (most predictive) model (Songer and Linn 1991, p. 763).

Teaching can be, therefore, considered as an argumentative activity based on the interlocutors' background experience for two reasons (Baker 2003, p. 48). First, teaching is

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aimed at modifying and developing the students' "private understanding", showing the limits thereof, or building on it in order to account for new phenomena (Chi and Roscoe 2002). Second, arguments are crucial instruments for both investigating the students' background knowledge, on which they base their claims, and providing reasons supporting the incompleteness of the interlocutors' private understanding and the reasonableness of a scientific model. The application of argumentation models to science education has taken into consideration mainly the first dimension of arguments. However, argumentation theory can provide also a useful instrument for retrieving what students leave unexpressed in their argument, and revealing their prior knowledge.

2.2 From Toulmin's Argument Pattern to the Analysis of Warrants

In science education several studies have focused on the analysis of argument structure. In particular, the TAP was conceived as method for improving the quality of argumentation in classrooms, pointing out the different components of an argument that need to be made explicit in order for the communication to be more effective and lead to less misunderstandings (Erduran 2008, p. 57). According to this model (see Simon and Richardson 2009, p. 473), an argument is constituted of an interconnected set of an assertion believed to be true, namely the claim (*C*), based on justifications consisting of data (*D*) connected to the claim by a warrant ("since *W*"), which can be substantiated by backings (*B*). The arguments can be rebutted by rebuttals (*R*), namely counter-arguments directed against the data, the warrant or the backings, which indicate under which circumstances the stated claim would be correct. Qualifiers (*Q*) describe the strength of the inferences and how universally they can be applied and are valid (Toulmin 1958). The model can be represented as follows (Fig. 1).

This pattern is focused on the macro-structure of arguments and not on the content of a specific piece of reasoning. The nature of the warrant, namely the semantic and logical relation between data and claim, is not specified. Moreover, the model is not aimed at investigating the logic of arguments, the connection between premises and conclusions is not outlined, nor a criterion for evaluating the reasonableness or the validity of an argument is provided (see also Simon 2008).

An attempt to develop this model towards argument content analysis is the identification of categories of argument. On this perspective, arguments are classified according to their semantic content, in order to evaluate the quality of students' reasoning and their argumentative strategies (Duschl et al. 1999; Duschl 2007; Ozdem et al. 2011) and improve the

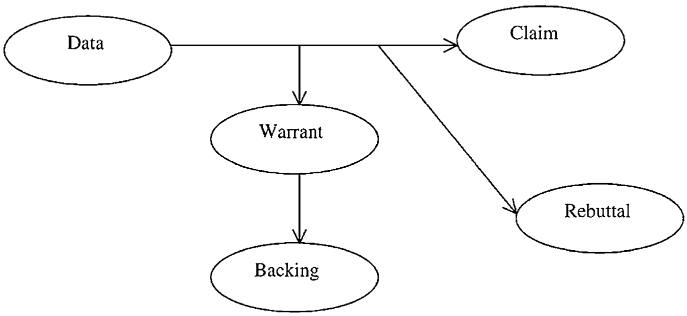

Fig. 1 Toulmin's structure of argument analysis (Toulmin 1958)

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dialectical process of attacking and defending viewpoints (Nussbaum 2011). Building on this proposal, we maintain that the content analysis of arguments can play a deeper and more fundamental role than a dialectical procedure. By identifying the nature of the students' arguments and revealing the premises they leave unexpressed, it is possible to access (even if tentatively) their prior knowledge. In this fashion it is possible to make students aware of the incomplete ideas on which they ground their reasoning, and consequently question or attack them to promote conceptual change.

In order to explain the foundation of this proposal it is useful to show how the idea of argument content analysis has been developed. Toulmin (1958) analyzed arguments as claims, supported by data, by means of a warrant. For instance, as represented in Fig. 2 below, in order to support the claim that "A coat cannot warm up a snowman", the students may proceed from the warrant, that "Coats keep the warmth of a body" and the datum that "A snowman is not warm".

Well-constructed and complete arguments can provide understanding of students' underlying knowledge of science. However, the deep reasons supporting their specific opinions are often hidden (Walton and Reed 2005, p. 348). For instance, in the argument above, the speaker grounds his reasoning on the concepts of warmth and warmth preservation. Such concepts are not defined by the student, but represent his deepest criteria for explaining reality.

The passage from argument analysis to reasoning and, therefore, warrant analysis can be found in Toulmin's *The Uses of Argument*, where he defines warrants as "general, hypothetical statements, which can act as bridges, and authorize the sort of step to which our particular argument commits us" (Toulmin 1958, p. 91). These warrants can be different in nature: they can be grounded on laws, principles of classification, statistics (Toulmin 1958, pp. 98, 116), authority (Toulmin 1958, p. 198) causal relations or ethical principles (Toulmin 1958, p. 162). This generic idea was further developed by Toulmin et al. (1984), who classified arguments according to their structure. Arguments were divided in nine classes (analogy, generalization, sign, cause, authority, dilemma, classification, opposites and degree) depending on their possible types of warrant (Toulmin et al. 1984, p. 199).

Toulmin's concept of warrant is crucial for describing the types of argument. However, it cannot be used for reconstructing the quasi-logical structure of an argument, and, as a consequence, the unexpressed premises thereof. Building on Toulmin's idea of warrant, Hastings developed the idea of the "modes of reasoning", that is, prototypical patterns of argument organized according to the type of warrant. On his view, an argument pattern consists of a set of abstract premises supporting a viewpoint (Hastings 1963). Every argument can be classified according to some categories (example, classification, definition, sign, cause, circumstance, comparison, analogy, testimony) and fit into one of the patterns, so that the hidden premise can be retrieved according to the abstract premise.

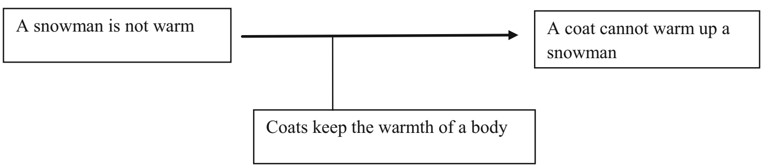

Fig. 2 Example of Toulmin's structure of argument analysis

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2.3 Argumentation Schemes

Walton developed Hastings' proposal, inquiring into the relationship between the principles of reasoning and the semantic relation between premises. The patterns of arguments were labeled as argumentation schemes, abstract structures merging together an inferential relation, or rule, systems of reasoning and logical rules (Walton and Macagno 2006; Macagno and Walton 2009). Argumentation schemes do not simply correspond to the warrant leading from the premise to the conclusion (for instance, "The assertion of the existence of *B* on the presence of *A* is on the basis of a causal correlation between the occurrence of *A* and *B*"). They are stereotyped forms of reasoning structures proceeding from a specific rule of inference (such as *modus ponens*), where both the premises and the conclusion are represented as abstract propositions. The abstract structure of argumentation schemes can be illustrated with the following argument from Cause to Effect (Walton 1995, pp. 140–141):

Argumentation scheme 1. Argument from cause to effect

Causal link:	Generally, if *A* occurs, then *B* will (might) occur
Factual premise:	In this case, *A* occurs (might occur)
Conclusion:	Therefore in this case, *B* will (might) occur

Every argumentation scheme is associated with a set of questions that point out the critical dimensions of the argument, the features of the premises or the relation between premises and conclusion that can be potentially attacked.

Critical questions

CQ1: How strong is the causal generalization?
CQ2: Is the evidence cited (if there is any) strong enough to warrant the causal generalization?
CQ3: Are there other causal factors that could interfere with the production of the effect in the given case?

The argumentation scheme from cause to effect represents one of the possible combinations of semantic relations and logical properties. Argumentation schemes proceed from rules of different types of reasoning, which can be inductive (for instance, argument from example, such as "The coat did not cause the melting of the snowman yesterday. Therefore it has no effect on it"), deductive (argument from classification, cause, authority, etc.), defaultive (argument from ignorance, such as "I have never noticed that snowmen with a coat melt. Therefore they do not melt") or abductive (argument from best explanation, such as "Snowmen with a coat on melt. Therefore the coat causes the melting").

Argumentation schemes can be used as instruments for guiding the process of reconstruction of explicit and implicit premises. Since they represent the structure of the argument, if the scheme is identified, it is also possible to apply it to the incomplete argument and specify the abstract form of the unstated premise. For instance, if we consider the following argument,

The snowman is not warm; therefore the coat cannot warm it up.

We notice that the conclusion is an event or a state of affairs (the coat cannot warm up the snowman) shown to be resulting from another event or state of affairs (the snowman is not warm). By applying the argument scheme, we can find the implicit premise that "the absence of warmth of the snowman is the cause of the coat's failure to warm it up". On this perspective, the structure and the content of the premise and the conclusion lead to the

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application of an argument scheme, which is a guide for the reconstruction of the content and the logical form of the premise. However, the premise reconstructed does not reveal the speaker's previous knowledge about thermal conductivity. For this purpose we need to investigate the concepts underlying the use of a scheme.

2.3.1 Argumentation Schemes and Underlying Concepts

Argumentation schemes represent different types of material relations, which are combined in different patterns to support a specific conclusion. The crucial step is to analyze how argumentation schemes apply to real arguments, or rather how real arguments represent instances of abstract concepts. The problem that we want to address is how a property in a real argument can count as a cause, a definition, an effect, etc. In order to investigate this process, we need to start from the analysis of the application of argumentation schemes. For instance, a student can apply the rule that, "The coat causes the snowman to melt" proceeding from different premises. He can consider the melting as an effect of the warmth transferred by the coat, or as the result of a difference of temperature. This implicit classification is crucial to understanding what lies beneath the structure of a scheme.

The process of reconstructing the dark-side knowledge underlying the use of scheme can be described using the ancient theory of *topoi*. Natural reasoning can be conceived as a combination between a rule of reasoning (such as the *modus ponens*: if p then q; p; therefore q) with a material, or rather semantic, relation between the concept (see Stump 1988, p. 6; Walton and Macagno 2006; Walton et al. 2008, chap. 8). For instance, we can consider the following reasoning:

> The snowman is not warm; therefore the coat cannot make it melt.

The relationship between the premise and the conclusion can be classified as a causal one. However, by reconstructing the implicit premise, in this case "The snowman's warmth is the (*efficient cause*?) of the coat's making it melt", it is possible to retrieve some crucial concepts underlying the classification of the body's warmth as a cause of the melting. We can represent the possible implicit premises underlying the student's reasoning as follows (Table 1):

By retrieving the causal link and the concepts underlying it, it is possible to identify the possible premises left unexpressed by the student. The reconstructions can be made based on the most reasonable explanation of the reasoning, but they can be asked to the interlocutor. From the successive steps, it is possible to derive the specific rule of inference used, which, in this case, corresponds to the causal law. This specification of the principle of inference is the link between the argumentation scheme and the actual argument. It allows one to build the actual and specific rule used in the reasoning.

Table 1 Reconstructing implicit premises

Reconstructions of the principle of inference	The warmth of a body is the *cause* of the coat's effect of making it melt
	Melting is brought about by an increase of (*warmth? temperature*?)
	The warmth of a body is the *cause* of the increase of (*warmth*? *temperature*?)
Reconstructed premises	1. The coat has an effect only if the body is warm
	2. The coat causes the increase of (*warmth*? *temperature*?) of a warm body

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The same process of reconstruction applies to the other schemes. In particular, we will take into consideration another typical pattern of reasoning commonly used in students' arguments, argument from analogy. This scheme is represented as follows (Walton 1995, pp. 135–136):

Argumentation scheme 2. Argument from analogy

Similarity premise:	Generally, case *C1* is similar to case *C2*
Factual premise:	Proposition *A* is true (false) in case *C1*
Conclusion:	Proposition *A* is true (false) in case *C2*

Critical questions

CQ_1: Is *A* true (false) in *C1*?
CQ_2: Are *C1* and *C2* similar, in the respects cited?
CQ_3: Are there important differences (dissimilarities) between *C1* and *C2*?
CQ_3: Are there important?
CQ_4: Is there some other case *C3* that is also similar to *C1* except that *A* is false (true) in *C3*?

What is crucial is to understand the principle underlying the analogy, namely the property under which *C1* and *C2* fall. Reasoning from analogy can be described as a three-step process (Macagno and Walton 2009): *1.* A common property, relevant for the attribution of predicate (*A*), is identified in, or rather abstracted from, the two terms of comparison, *C1* (the primary subject, or rather the subject that we want to classify) and *C2* (the analogous). For instance, a snowman can be compared to a human being if we consider both as *bodies*. *2.* The predicate (*A*) is attributed to the generic abstracted property. *3.* The conclusion is drawn deductively from the generalization, that is, the predicate (*A*) is attributed to the subject (*C2*).

Argumentation schemes, therefore, can be used to specify the implicit dimension of students' reasoning and the prior knowledge that their tacit premises can hide. They can be used as maieutic instruments to identify the needed clarifications, or guidelines for possible explanations. The implicit premises or concepts on which the students' arguments are based on reflect their background knowledge, which can be developed, clarified or questioned. In (Nussbaum 2011), for instance, the critical questions of argumentation schemes were used as a guideline for the analysis and discussion of students' arguments.

3 Applying Argumentation Schemes as Instruments of Interpretation

In the sections above we have pointed out how students' background knowledge can be reconstructed in an argumentative perspective, so that it can become the starting point of educational activities. In order to illustrate how this application of argumentation schemes works in practice, in this section we will present an activity was conducted in a classroom and later analyzed. In verbal argumentation, knowledge is generally fluid and it is difficult to provide an exact record of the participants' commitments. On the contrary, in argumentative writing the interlocutors are faced with a product, and, accordingly, they set out clearly their commitments. For this reason, we have chosen a written predictive activity, within the framework of the predict-observe-explain (POE) structure (Champagne et al. 1980; Simon and Richardson 2009, pp. 483–484).

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3.1 Methods

3.1.1 Goal of the Activity

The purpose of this activity consists in the production of arguments by the students, so that the structure of their reasoning can be made explicit and the implicit concepts can be identified through the application of argumentation schemes. The aim is to show how this theoretical tool can reveal background knowledge and provide a starting point for further activities of analysis and discussion, which have been proposed (in a purely tentative fashion) in the last part of this section.

3.1.2 Participants

The participants were pre-service teachers, enrolled in the second year of the training program at the University of Barcelona. The activity was conducted with two groups of students, amounting to a total of 40 students, 80 % of which were female. Students of this program normally don't have a significant scientific background and no particular knowledge of argumentation. These kinds of tasks are part of the syllabus of the course.

3.1.3 Task Description

This study is focused on the activities concerning a task representing a problem of thermal conductivity. The purpose of this task is to present alternative ideas in a visually accessible and appealing format. In this fashion, it is possible to elicit the students' ideas and provide suitable challenges that might lead to a further development of their ideas (Keogh and Naylor 1996). Both groups had to analyze a cartoon in which three children discuss about the proposal of wrapping a snowman in a coat. The claim of the first kid is that the snowman should be wrapped in a coat, as it will keep it cold; according to the second, the coat will make it melt; according to the third, the coat will not make any difference. The students were requested to provide their opinion by choosing between the conclusions of the three children, supporting their claims with arguments. In particular, they had to fulfill the following instructions and answer the following questions:

1. Which one of the three kids' opinions is correct? Explain why.
2. Explain the most important words that you have used in your argument.

They were asked to define in writing the crucial implicit or explicit concepts on which they based their arguments. For instance, if the reasoning hinged on the transference of "heat", the concept of "heat" was to be defined. The results were later discussed orally, and the different definitions compared, explained and corrected.

This problem was used in two different parts of the activity: first, the students had to solve the task individually; then, they have to discuss in groups the ideas that they previously reported in writing, questioning or challenging the opinions of the other classmates and defending their own. The duration of the first part of the activity was of 15–20 min, and consisted in answering the questions in Catalan, Spanish or English. The duration of the following discussion was approximately of 1 h. This interaction was videotaped and transcribed.

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3.2 Analysis

The process of analysis, focused on the written part of the activity, was performed in two phases.

The first phase (*phase 1*) was aimed at identifying the types of argument used by the students (Walton et al. 2008). For this purpose, their reasoning was reconstructed by applying the proper argumentation schemes and retrieving the explicit and implicit premises. This part of the analysis was performed independently by the two researchers and the results were later compared. The results of the analysis coincided in more than 90 % of the cases.

In *the second phase* (*phase 2*) the goal was to investigate the students' background knowledge underlying their arguments. Such knowledge could be revealed by reconstructing their implicit premises. The definitions of the crucial concepts (or better keywords) used in each argument were taken into consideration, showing the relationship between the mistaken conclusion and the unclear or incomplete crucial concepts on which the causal law applied were based. The types of arguments were analyzed at two levels. First, the argument structure was reconstructed by applying the proper argumentation schemes and making the tacit premises explicit. Second the argument was assessed by evaluating the strength of the link between premises and conclusion.

3.3 Results

3.3.1 Phase 1: Identification and Reconstruction of the Arguments

The majority of the arguments provided by the students were based on the scheme from cause to effect (more than the 80 %), while only the 10 % of the arguments were analogical. The types of reasoning used and their proportion can be explained considering the type of activity. The task was aimed at predicting a possible *effect* of an action. Therefore, it required a pattern of reasoning grounded on implicit (argument from analogy) or explicit causal relationships (cause-to effect argument). Moreover, the experiment was made on groups of students with a higher level of education, who had learned the basic concepts of heat conduction and scientific laws in their previous years. Because of this level of education, they had some background knowledge about the laws governing temperature and heat. For this reason, they built their arguments using the strongest possible pattern, even though the causal law was incorrect. The same experiment, when repeated in secondary schools, elicited noticeably different results. The rate of the arguments from analogy in this case was much higher (up to 40 %), even though the dominant argumentation scheme was still the cause to effect argument. The use of this argument by lower educational level students indicates a stronger use of implicit principles, underscoring the importance of the process of reconstructing the tacit premises in order to address their background knowledge (Konstantinidou 2013).

The frequency of the arguments collected in the test performed on the university students is summarized in the table below. There is not a perfect correspondence between arguments and answers, as in some cases more than one argument was advanced to support the conclusion (analogy supporting a causal relation), while some students (2) did not support their claim with any argument (Table 2).

The second phase of the analysis was focused on the reconstruction of both causal and analogical arguments identified in the first phase. In both types of argument the link between premises and conclusion was often expressed, even though in some cases it

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Table 2 Claims and argumentation schemes

Claim	Type of argument			
	Analogy	%	Causality	%
Don't put it on, it will melt	2	25	6	75
It will keep it cold	4	21	15	79
It will make no difference	3	17	15	83
Unclear			1	

needed to be retrieved. Below we illustrate the process of argument reconstruction by analyzing four arguments (two causal and two analogical) taken from the students' answers:

Causal argument 1

> (He is right) The boy with the coat, because the coat does not heat or cool, but it maintains (preserves the same temperature) the heat, so it will keep the same temperature even though it is low.

Argument reconstruction

Factual premise: The temperature of the snowman is low
Causal link: The coat maintains the heat
Conclusion: The coat will maintain the low temperature of the snowman

In this case, the student made explicit the causal principle ("The coat maintains the heat"). However, the causal link can be sometimes missing, and it needs to be retrieved from the explicit elements and the structure of the argument scheme. For instance, we can consider the case below:

Causal argument 2

> […] if the kids are on a beach and have brought the snow from another place, it does not matter whether they put a coat on the snowman, it will melt because the temperature outside does not allow the snowman to be frozen. […] If they put the coat on the snowman, it will make the snowman melt more quickly.

The structure of this argument can be reconstructed by applying the argument from cause to effect, using the factual and causal premises that can be found in the text. Argument reconstruction

Factual premise: The external temperature is high and the snowman needs a low temperature
Implicit causal link: *The coat increases the transfer of the high external temperature*
Conclusion: The coat will make the snowman melt more quickly if the external temperature is high

In this argument, the missing premise can be retrieved by filling in the argument scheme (from cause to effect) with the conclusion and the stated premise.

In analogical arguments the causal principle can be reconstructed through the explanation provided by the student to support the similarity:

Analogical argument 1

> I think who is right is the one that says it will keep the temperature and the cold, and that will stop it from melting, since the coats what they do is to keep our body temperature and not cool us. Thus, the coat will keep the temperature at 0 °C.

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Here the structure of analogical reasoning is applied and the common property between the primary subject and the analogous is identified:

Argument reconstruction

Generally, case C1 is similar to case C2:	Putting the coat on us is similar to putting the coat on a snowman
Common property:	We put the coat on to maintain the temperature
Common property (*abstract*):	The coat maintains the temperature and the cold
Premise:	The temperature of the snowman is low
Conclusion:	The coat maintains the low temperature (cold) of the snowman

In this case, the student reconstructed the analogy (omitting the premise in brackets) drawing explicitly the conclusion. In other cases, such as in the following one, the principle underlying the analogy is not stated, and, therefore, needs to be reconstructed.

Analogical argument 2

> At first, any person would think that the girls is right, as we wear coats to avoid being cold; therefore it would be reasonable to think that with the coat the snowman will melt more quickly.

Here the property supporting the analogy, namely the characteristic common to the primary subject and the analogous, needs to be retrieved as follows:

Argument reconstruction

Generally, case C1 is similar to case C2:	Putting the coat on us is similar to putting the coat on a snowman
Common property:	We put the coat on to avoid being cold
Common property (*abstract*):	*The coat prevents the body or the object on which it is put from being cold*
Premise:	The coat is put on a snowman
Conclusion:	The coat prevents the snowman from being cold

The causal link can be made explicit by considering in which respect the action of putting the coat on a body and the one of wrapping a snowman in a coat are similar. The possible explanation is that both actions prevent the covered entity from being cold. However, other causal links are possible. In order to understand more clearly the background knowledge, the missing premise needs to be specified further, by analyzing, in this case, the reason why the coat prevents the lowering of the temperature.

The reconstruction of the arguments shows two types of reasoning underlying the reasons given by the students to support their claims: argument from cause to effect and argument from analogy. In the first case, the causal principle is presented as part of the background knowledge, while in the second case it is drawn from an observation of reality. In both cases the causal principles can be explicit or implicit. In casual arguments the missing causal link, left unstated by the student, can be mechanically reconstructed. On the contrary, the retrieval of the causal link in analogical arguments can be more complex, as the concepts under which the cause and effect fall are implicit. Analogical arguments can be used when the causal principle is unknown to draw a conclusion based on experience instead of previous knowledge (Juthe 2005, p. 4). Depending on the relevant dimension of the observed reality (coats put on *bodies*; coats put on *warm* bodies …) the conclusion will be different.

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3.3.2 Phase 2: Analyzing the Grounds of Students' Reasoning—Words and Causal Relations

The evaluation of the students' uses of schemes consisted in two criteria: the nature of the implicit or explicit causal principle, and its application to the facts observed to draw a conclusion. An argument can support a wrong conclusion because one of the premises is wrong, or because the conclusion does not follow from the premises. In the first case the incorrect conclusion follows from incomplete background knowledge, including both scientific laws and scientific concepts. In the second case, the problem is simply a mistake of reasoning, which can be corrected by pointing out the logical inconsistency.

The causal premise can be incomplete, or it can simply proceed from incorrect concepts and be wrongly applied to the facts of the case. A clear example of the first option is the following:

Causal argument 3

> The guy on the left is right "Do not put your coat on a snowman. It will melt it", because the ice is at a specific temperature, and if we put a coat on it, the temperature will rise and thus it will melt.

Argument reconstruction

Factual premise:	The snowman is at a low temperature
Implicit Causal link:	The coat increases the temperature of the body on which it is put
Conclusion:	The coat will make the temperature of the snowman rise

In this case the causal principle is incorrect, as the coat is simply an insulator, and not an agent.

The causal principle can be partially correct, but the concepts underlying it can be incomplete, determining a wrong application of the rule to the case. For instance, the causal argument 1 above proceeds from a partially correct causal link, "The coat *maintains* the *heat*", wrongly applied to the factual premise. The low temperature of the snowman cannot be considered as a subtype of "heat"; furthermore, coats cannot "maintain" the "heat" in the sense that they cannot prevent the transfer of temperature. Here, even though the effect of the coat as an insulator is partially expressed, there are two conceptual mistakes. Not only is the effect of the coat on a body misstated, but also the concepts underlying it are incorrect, as the student considers the temperature as the transfer of energy between two bodies at a different temperature (heat).

Finally, the causal law can be wrongly applied to the case, leading to a wrong conclusion. For instance, we can consider the case below:

Causal argument 4

> I think that the kid saying that [the coat] will keep [the snowman] cold and prevent it from melting is right. I make myself clearer: the coat works as an insulator between the outside temperature and the temperature of the body (in this case the snowman) on which it is put. During the winter, when we are cold, the different layers of clothes that we wear create a microclimate between the clothes and our body, as they keep the heat produced by our body. In the same way, we deduce that the temperature of the snowman is lower than the outside temperature; if we cover the snowman, it will not lose the cold temperature.

Argument reconstruction

Causal link 1:	The coat is an insulator (and keeps the temperature)
Implicit Causal link 2:	*The heat transfers from the body of the higher temperature to the body of lower temperature*

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Factual premise 1:	The outside temperature is higher that the temperature of the snowman
Factual premise 2:	The coat is put on the snowman
Conclusion:	The coat will prevent the snowman from melting

The causal law is correct, but it is wrongly applied to the case. The problem lies in its application to the factual premise 1: the student claims that the outside temperature is higher that the temperature of the snowman. We know from direct experience that a snowman is something really cold, which is usually made in winter when the outside temperature is low. However, such temperature is usually neither lower, nor much higher than the snowman's one. The conclusion would be much different if the snowman was made in Alaska or in a desert. The reconstruction of the implicit causal law and the comparison with the factual premise can help the student understand the mistaken application of a principle to a case, correcting the reasoning mistake.

The aforementioned analysis underscores the crucial relationship between arguments and underlying concepts. Argumentation schemes can be used to specify the unexpressed premise, identifying the background knowledge used to support the student's conclusion. The importance of reconstructing the implicit premises of students' arguments can be shown by investigating the nature of the mistaken conclusions. In the following table the answers of the students have been reconstructed and classified according to the type of argument and causal principle. The correct causal laws have been reported in the light-grey boxes; the mistaken concepts are represented in italics; the unclear or vague concepts that the student needs to clarify are marked in bold; the mistaken causal law are underlined. From the tables below we can notice how the most critical principles are no. 2 (The coat maintains the temperature) and no. 3 (The coat has no effect on the snowman): in 2 there is a disproportion between the apparently correct, even if vague, principle, and the mistaken application; in 3 the principle is not specified and the conclusion is correct (Tables 3, 4).

We can notice from the tables above how incorrect predictions or unsuccessful grounding of correct answers were based on vague concepts such as "to maintain", "heat" or "cold". Such notions revealed the students' incomplete knowledge of some fundamental scientific principle, such as the thermodynamic laws. For this reason, in order to understand

Table 3 Causal principle and claims in causal arguments

Cause-effect	Don't put it, it will melt	It will keep it cold	It will make no difference
1. The coat acts as an insulator.		2	4
2. The coat *maintains* the temperature		7	5
3. The coat has *no effect* on the snowman			5
4. The coat *maintains* the *heat*			1
5. The coat protects the snowman from the *heat*		1	
6. The coat captures the *cold*		5	
7. The coat increases the temperature	3		
8. The weight of the coat makes the snow melt	1		
9. The coat makes the heat enter	1		

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Table 4 Causal principle and claims in analogical arguments

Analogy	Don't put it, it will melt	It will keep it cold	It makes no difference
1. The coat acts as an insulator		1	
2. The coat *maintains* the temperature		2	2
3. The coat has *no effect* on the snowman			1
4. The coat increases the temperature	1		

Table 5 Definitions and claims

To maintain	Don't put it on, it will melt	It will keep it cold	It makes no difference
A. To extend a certain temperature in time			7
B. To keep, preserve a certain temperature		10	
C. To protect from the heat		1	

the origin of students' incorrect reasoning, they were asked to define the terms used, and in particular the concept of "maintaining the temperature" (Table 5).

The incorrect definition of "maintaining the temperature" as the "preservation of the temperature" shows a deep misunderstanding: the students hold that the transfer of temperature can be blocked by an insulator, not only slowed down. A conceptual mistake reveals an incomplete understanding of the law governing the transfer of temperature.

The request of defining (both in writing and later orally) the concepts underlying the arguments achieved two results. On the one hand, the students without any knowledge of transfer of temperature (5, 6, 7, and 8 above) were unable to define the basic concepts on which their arguments were based (cold, heat, temperature). On the other hand, when faced with the exercise of defining their terms (submitted before the classroom discussion), four students changed their arguments and therefore conclusions[1] accordingly with their specification of the concepts used.

3.4 Implications for Further Research: Use of Critical Questions and Counterarguments

The aforementioned process of reconstruction is accurate, but it requires knowledge and practice of the argumentation schemes. However, for practical purposes three crucial dimensions of this model can be underscored, in order to be more easily used by teachers. First, specific implicit premises, used to support the conclusion, need to be retrieved by reconstructing the argument structure. Second, the students' arguments can be classified according to the semantic relations between premises and conclusion, so that the nature of the unexpressed premises (for instance causal or analogical links) can be specified. Third, the critical questions can provide a guideline for assessing a piece of reasoning, highlighting the critical aspects that can be later addressed or criticized. These characteristics of argumentation schemes can be applied to two types of activities. First, simplified versions

[1] Students no: 9, 16, 23, 29.

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of argumentation schemes can be provided to students for discussions in small groups, where they are requested to develop their reasoning following the argument patterns. In this fashion, the students need to make all the crucial premises explicit. Second, critical questions can be used for the dialectical activity of questioning and rebutting arguments, developing the students' background knowledge.

Critical questions can be used for requesting clarifications on the implicit dimension of the reasoning, and the structure of the student's argument can be used for a dialectical activity of confronting the learner with conflicting evidence or stronger contrary arguments (Limón 2001). In particular, an argument can be attacked and rebutted in three extremely effective ways (Damer 2001; Juthe 2009). The first strategy, called the *Method of displaying the flawed argument scheme*, consists in reconstructing the standard form of the argument and displaying the abstract pattern of the argument scheme on which it is based. In this fashion, its flawed character is shown. The second way, the *Method of counter-exampling*, is aimed at presenting an example that falsifies the universal generalization of the premises of the attacked argument. The method of counter-exampling can also be employed to show that a conclusion does not follow from true premises, that is, that the argument is invalid. One could describe a possible situation in which the premises are true and the conclusion false. A third way of attacking faulty reasoning is perhaps the most imaginative and effective of the strategies, and is called the *Absurd example method*. The faulty patterns of reasoning are shown without appealing to technical jargon or rules. What Damer calls the ''absurd example method'' is actually the method of refuting an argument by presenting an analogous parallel argument that is clearly flawed because it has clearly true premises whereas its conclusion is obviously untrue or unacceptable. This method of refutation works by revealing that two arguments (the target, provided by the interlocutor, and the analogous) are similar, and the hearer needs to either withdraw and correct his argument, or accept the absurd conclusion of the analogous (Juthe 2009).

These possible further activities were experimentally addressed in the second part of the study (which was tape recorded), where a possible application of this theoretical background was experimented. The purpose was simply to outline possible and tentative basic ideas for teaching using argumentation schemes. The goal of the activity was to address the students' background knowledge underlying their written arguments by asking critical questions, criticizing their reasoning and attacking them with counterarguments. Since the arguments attacked were the ones brought forward by the students themselves, the attacks addressed their own background knowledge and their own perspective on a problem, making the cognitive conflict potentially meaningful to them, and, therefore, potentially successful (Limón 2001). The students were provided with the structure of the argument from cause to effect and from analogy, and then their arguments were analyzed and questioned using the critical questions. Moreover, depending on the arguments, the reasoning was challenged by parallel arguments (counter-analogies), by requests of clarification (the students were requested to define and give examples of the concepts underlying their definitions by asking question such as "What is cold?" "What is temperature?" "What does 'to keep' mean?"), or by *reductio ad absurdum* (in which the laws bearing out causal arguments were applied to instances leading to unacceptable conclusions).

4 Conclusions

Recent literature in science education shows an increasing interest in the application of the argumentative tools to teaching strategies and methods. In particular, it has been

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emphasized that by understanding and improving students' reasoning it is possible to enhance both teaching effectiveness and learning abilities. However, such approaches have focused on the structure and the completeness of arguments, but their nature, their logical properties and their content have not been investigated yet. In particular, the argumentation theories applied so far to science education have not addressed the problem of retrieving the implicit premises of students' arguments. The starting point of our inquiry is the issue of background knowledge and its relevance for conceptual change. On this view, in order for an explanation to be persuasive and achieve a conceptual change, it needs to proceed from the interlocutor's background knowledge to the development of incomplete concepts.

The purpose of this paper is to build on a specific development of Toulmin's ideas of warrant and types of warrants, namely argumentation schemes theory. Argumentation schemes can provide an instrument for investigating the problem reconstructing implicit premises of students' arguments, which can lead to understanding some useful aspects of their background knowledge. The application of argumentation schemes to science education presented in this paper can be used for analyzing, reconstructing and improving students' reasoning, and bringing to light the students' prior knowledge on a specific issue. The process of reconstructing and interpreting arguments is grounded on the concept of natural patterns of reasoning. Argumentation schemes are abstract representations of the most used and common forms of human reasoning. They combine logical principles (axioms of logic and types of reasoning) with semantic concepts such as cause, sign, definition, etc., and allow one to identify and reconstruct the missing premises needed for an argument to support the conclusion. The empirical application of the schemes to science education consists in a two-step process. First, an argument is analyzed, identifying the type of scheme used and the premises supporting the conclusion. Second, the basic concepts underlying the material link of the argument are identified, retrieved and defined. In this phase, the student is requested to analyze and reflect on the notions underlying his reasoning about a specific scientific phenomenon.

The application of argumentation schemes to science education can have further developments. Even though the process of premise reconstruction is complex, the classification of the structure of arguments and the nature of warrants can be of practical help for identifying the elements left unexpressed by the student, so that they can be investigated through the use of critical questions or attacked by means of counterarguments.

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