Can. J. Sci. Math. Techn. Educ. (2020) 20:58–73
https://doi.org/10.1007/s42330-020-00076-9

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Modelling and Argumentation with Elementary School Students

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Published online: 9 March 2020

Abstract Argumentation and modelling are core scientific practices, and studies suggest that incorporating the specific practices in the teaching of science can engage learners. This is a qualitative study of a classroom of 10–12-year-old students working collaboratively in argumentation and modelling. The aim of the study was to explore how primary school students use their models whilst arguing about a socio-scientific issue and to explore whether and how the process of arguing is linked with the modelling process. In order to explore the aforementioned, a learning environment was designed to help students participate in the epistemic practices of argumentation and modelling. Our findings indicate that the students engage in argumentation by providing rebuttals, and there is an intersection of higher-level modelling cognitive processes and higher-level argumentation epistemic aspects. We hypothesize that the use of models might have contributed to high-level argumentation. Our findings point to the idea that if we want science teaching and learning to be more productive even for younger students, we should be developing the epistemic practices of modelling and argumentation in unison as a way to promote and support both practices and as a consequence to promote both content learning and reasoning skills.

Résumé L'argumentation et la modélisation sont des pratiques scientifiques fondamentales, et certaines études indiquent que, si on intègre ces pratiques spécifiques à l'enseignement des sciences, on incite les apprenants à participer plus activement. La présente est une étude qualitative portant sur une classe d'élèves de 10 à 12 ans qui ont travaillé en collaboration dans l'argumentation et la modélisation. Le but de l'étude était d'explorer comment les élèves du primaire utilisent leurs modèles alors qu'ils se penchent sur un problème socio-scientifique, et d'explorer les façons dont le processus d'argumentation est lié, ou non, au processus de modélisation. Pour ce faire, nous avons conçu un environnement d'apprentissage pour aider les étudiants à participer aux pratiques épistémiques que sont l'argumentation et la modélisation. Nos résultats indiquent que les étudiants participent à l'argumentation au moyen de réfutations, et qu'il y a une

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s42330-020-00076-9) contains supplementary material, which is available to authorized users.

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intersection entre certains processus cognitifs de modélisation de niveau supérieur et certains aspects épistémiques de l'argumentation, également de niveau supérieur. Nous émettons l'hypothèse que l'utilisation de modèles est susceptible de contribuer à une argumentation de haut niveau. Nos résultats indiquent que si nous voulons que l'enseignement et l'apprentissage des sciences soient plus productifs même pour les jeunes étudiants, il faut développer de concert les pratiques épistémiques de modélisation et d'argumentation, comme moyen de promouvoir et de soutenir les deux pratiques, et ainsi favoriser à la fois l'apprentissage des contenus et les capacités de raisonnement.

Keywords Argumentation · Elementary school science · Modelling · Mocioscientific issues (SSI)

Introduction

A major aim of recent science education reform documents (Achieve, 2013; NRC, 2012) is for students to engage in core scientific practices as a means to facilitate better understanding of the processes of science and the aspects of doing science (Bybee, 2011). Argumentation and modelling are both identified as core scientific practices in the K-12 Framework (NRC, 2012; Achieve, 2013) and are both under emphasis in reform documents around the world (Achieve, 2013; Eurydice, 2012). During the last decades, there has been a lot of emphasis in the science education community on both argumentation and modelling in science, but as distinct practices. For example, studies in the area of argumentation have placed an emphasis on identifying difficulties that students face with argumentation (Erduran et al., 2004; Jiménez-Aleixandre & Pereiro-Munoz, 2002; McNeill & Pimentel, 2010) and have proposed instructional approaches that can help enhance argumentation in the classroom (Jiménez-Aleixandre et al., 2000; Kelly & Takao, 2002; Kelly et al., 2007; Osborne et al., 2004; Sampson & Clark, 2010). More prominent difficulties for high school students are linked to their inability to understand the phenomenon they are studying and its underlying mechanisms (Naylor et al., 2006), making it difficult for them to provide convincing arguments. Research in modelling, on the other hand, has placed an emphasis on identifying difficulties that students face when modelling a phenomenon and on designing learning activities to engage learners in modelling (Campbell & Oh, 2015; Louca & Zacharia, 2015; Schwarz et al., 2009) and on the assessment of the modelling competence (see Nicolaou & Constantinou, (2014) for a review). Research findings suggest that when students are engaged in modelling-based learning, they gain, amongst others conceptual understanding of the phenomenon they model (Barab et al., 2000; Constantinou, 1999; Louca & Zacharia, 2011; Maia & Justi, 2009). More specifically, when learners engage in modelling, they can more easily visualize and understand specific parts of the phenomenon (Louca & Zacharia, 2015; Schwarz et al., 2009), develop and improve procedural knowledge and skills related to modelling (NRC, 2012) and develop an understanding on the nature of science and the way it works.

As evident in research studies (e.g. Windschitl et al., 2008), by incorporating the specific scientific practices in the teaching of science, we can engage learners not only with the content of science but also with the characteristics of the scientific knowledge. Nevertheless, students still face a number of difficulties when they engage in these two scientific practices. What we aim to explore in this paper is whether and how modelling and argumentation, if incorporated together into a lesson, can support or constrain one another. We hypothesize that the use of models can provide visual information to support the students in their effort to understand the underlying mechanisms of a phenomenon, construct their arguments and explain the phenomenon. At the same time, we hypothesize that the argumentation that takes place in groups can support the students in restructuring and improving their models to better represent the phenomenon. Therefore, the purpose of this study was to explore how 10–12-year-old students engage in the practices of argumentation and modelling and how one practice can support or constrain the other. More specifically, we aim to explore how argumentation occurs during modelling, what discussions occur during the different modelling phases and how they are linked to argumentation.

To our knowledge, research connecting the practices of modelling and argumentation in science is limited and mostly refers to college students (Mendonça & Justi, 2013; Passmore & Svoboda, 2012) and not younger students (10–12-year-old) that are the emphasis of this study. Furthermore, previous studies linking argumentation and modelling have not identified whether and how one practice can support or constrain the other through the use of empirical evidence.

Theoretical Framework

Our work is based on the notion that argumentation and modelling are processes used to develop or establish scientific knowledge. Romberg et al. (2005) claim that scientific arguments are central to scientific practice and refer to the process of explaining the material world through the use of symbolic objects. The relationship between the material and the symbolic world is expressed by the process of model construction (Giere, 1991). Establishing the validity of constructed models using evidence is the most important aim of scientific argumentation (Bazerman, 1988). In our perspective, it is through engaging in scientific practices that students will become familiar with the nature of scientific knowledge. By intertwining two core scientific practices, namely modelling and argumentation, we aim to highlight that they are not a set of distinct procedures, but rather processes that are interrelated, work synergistically and should be presented to the students in unison. In sum, the present study is grounded on the claim of Passmore and Svoboda who state that 'the model provides an important anchor to which argumentation can be attached and made productive' (Passmore & Svoboda, 2012, p. 1551–1552), and we are set out to explore how this happens in the settings of a classroom and how one practice might support or constrain the other.

Modelling

With the term models in this study, we refer to external representations of mental concepts (Krajcik & Merritt, 2012). Scientists use models to visualize and make sense of phenomena or to provide solutions to problems (Papaevripidou et al., 2007). We use the term model to denote an entity that meets three distinct requirements: (a) it *represents* the essential characteristics or an aspect of the phenomenon, (b) it *provides* a mechanism that accounts for the operation of the phenomenon and (c) it can be used to *formulate predictions* about changes and trends in observable aspects of the phenomenon (Papaevripidou et al., 2007). In our framework, models are not only constructed but, equally important, are also used to support socially grounded arguments about the nature of physical reality (Bazerman, 1988; Latour & Woolgar, 1979). In our modelling framework (Nicolaou & Constantinou, 2014), we focus on the three modelling practices, namely, constructing a model, using a model, comparing models, and evaluating and revising models (NRC, 2012; Schwarz et al., 2009). In this study, the students were engaged in the three modelling practices of constructing, using, evaluating and revising models.

Argumentation

Argumentation is 'a social process, where co-operating individuals try to adjust their intentions and interpretations by verbally presenting a rationale of their actions' (Patronis et al., 1999, p. 747–748). Additionally, argumentation is part of the practice of science for evaluating, refining and establishing new theories (Duschl, 1990; Holton & Brush, 1996) and is therefore considered a core element of the scientific enterprise (Fuller, 1997; Newton et al., 1999). In this study, we place an emphasis on argumentation, since by engaging students in argumentation, we can help understand the content of science and also the processes of science (e.g. Achieve, 2013; NRC, 2012; Osborne, 2014). A number of different theoretical frameworks have been used in science education to evaluate argumentation (e.g. Erduran et al., 2004; McNeill and Krajcik, 2011; Sampson & Clark, 2008) with each of the frameworks focusing on a different aspect of argumentation. For example, some studies emphasized on identifying the structural aspects of argumentation (Erduran et al., 2004), and others have focused on knowledge construction as part of the argumentation process (Jiménez-Aleixandre & Pereiro-Munoz, 2002; McNeill & Krajcik, 2011). In this study, we place an emphasis both on identifying the argument in a discussion and identifying the process of argumentation. Since we do not aim to analyze the quality or change of quality of arguments (e.g. Erduran et al., 2004) but only to identify argumentation when it happens, our choice of argumentation framework was based on selecting a framework that can be easily applied to classroom data to identify argumentation episodes.

Based on the aforementioned, and given the critique of the various frameworks for analyzing argumentation (e.g. Sampson & Clark, 2008), in this study, we use a modified version of the Claim Evidence Reasoning (CER) rebuttal framework as proposed by (McNeill & Krajcik, 2011). According to the CER,

> *claim* is a statement that answers a question or problem. *Evidence* is scientific data that supports the claim. The evidence can come from investigations students engage in firsthand or from research conducted online or in books that provide data. Last, *reasoning* provides a justification for why or how the evidence supports the claim. *Rebuttal* 'describes an alternative claim and provides counter evidence and counter reasoning for why the alternative claim is not appropriate' (McNeill & Martin, 2011, p. 53, emphasis added).

Therefore, in our work, we define argumentation as the process of engaging in reasoning about the evidence and providing rebuttals in order to defend or counter decisions about a knowledge claim. Studies in the last decade have identified a number of difficulties that students face when they engage in argumentation, and one of the issues that we seek to explore in this study is whether modelling practices can support students whilst they engage in argumentation, and help them overcome some of these difficulties. For example, Kuhn (1991, 1993, 2005) concluded amongst others that most people tend to be certain of their theories; even people who base their theories on pseudo-evidence believe that what they are saying is indeed genuine evidence; people tend to reason better on the subjects for which they have personal knowledge; people tend to assimilate any new information into existing theories and they express considerable certainty that new evidence supports their theories. We hypothesize that the use of models can support students when they are presenting their arguments and move them towards better-supported arguments.

Despite the connection between argumentation and modelling as scientific practices, only a few researchers attempted to link modelling and argumentation with the use of empirical evidence. Passmore and Svoboda (2012) for example argue about the need to make a connection between modelling and argumentation in the science classroom, since according to them 'the act of modelling in science is inherently an argumentative one' (p. 1551). Even though the aforementioned authors describe a detailed framework of how to connect the two practices, empirical evidence from the classroom about linking the two practices and how these can support or constrain each other is not provided. Mendonça & Justi (2013) in a study about modelling and argumentation identified argumentative situations in which students performed all of the modelling stages, and in a subsequent study (Mendonça & Justi, 2013), they presented an instrument for analyzing arguments produced during modelling. The aforementioned studies focused on the argumentation that occurs during modelling. On the contrary, the contribution of our study lies on that it focuses on how students engage in the practices of argumentation and modelling and how one practice can support or constrain the other.

Methods

This is an exploratory study of how 10–12-year-old students engage in the practices of argumentation and modelling and how one practice can support or constrain the other. More specifically, the research questions guiding this study are as follows: (a) What argumentation occurs during modelling? and (b) What kind of discussion occurs during the different modelling practices, and how does that link to argumentation? Since we seek to explore whether and how the process of arguing about the phenomenon is intertwined with the modelling process, a learning environment was designed to enable the students to participate in the scientific practices of argumentation and modelling (see Supplementary Materials for details).

Context of Instruction

The learning environment was designed based on project based learning (Krajcik et al., 1998), sociocultural theories of learning (Rogoff, 2003) and what we already know regarding how young students construct and use models (Louca & Zacharia, 2011). Based on our theoretical framework, modelling refers to constructing and using physical models to understand a phenomenon and explain or predict possible changes (Windschitl et al., 2008). The driving question guiding all lessons was 'What solution(s) do you propose as the more appropriate to deal with the excessive mosquitoes in your area?' The context was a local everyday issue, that of the excessive presence of mosquitoes due to waters in a nearby salt lake. Based on the problem, the teacher along with the researchers prepared a proposed structure for the curriculum. After each lesson, the teacher and the researchers discussed emergent issues and restructured the next lesson based on the discussions.

The purpose of the designed materials was to engage students with the practices of argumentation and modelling through the context of decision-making for an authentic issue (see Supplementary Materials for a detailed description of the lessons).

Participants

The participants of the study were 19, sixth graders (10–12 years old) from the same class of an urban elementary school in Europe, nine girls and ten boys, working in six groups of three or four students. Based on the school's curriculum, these students were taught science for two periods (40 minutes each) every week and were usually engaged in discussions and experimentation of scientific topics. They had no previous experience with modelling, but the teacher engaged them with argumentation without explicitly teaching the structure of the argument. The students were not used to group work in other subjects, but for their science class, they were assigned in groups. The same class structure was applied during the implementation of the project. One of the students was not a native speaker, and the teacher characterized the majority of them as average achievers.

Data Collection Process

During the two months of the implementation, all group interactions and whole classroom discussions were video recorded by two researchers who were present in all lessons. Additionally, both researchers kept research journals during all lessons that were used when necessary during the data analysis (e.g. to understand episodes from the videos). The students kept notebooks in which they recorded: their arguments, notes from the field study and any information relevant to their proposed solution. The researchers collected all notebooks after the end of the instruction, along with photographs of the models that were created by each group. The main source of data for this study was students' video-taped discussions; however, the rest of the data described here were used in cases where the meaning of the discussions was not clear.

Data Analysis Process

In order to address the two research questions, all videos from the groups and the whole classroom discussions were watched and the following steps were followed:

Phase 1: Modelling

Step 1: The researchers watched all videos and identified episodes in which students were engaged in a specific modelling practice (i.e. model construction, model use, model evaluation revision). The episodes were coded as such (e.g. model use). All the modelling practices are described in detail in Table 1.

Step 2: After identifying all episodes which included modelling practices (step 1), students' conversations during those episodes were coded for the cognitive processes, (as described by Sins et al., 2009—see Table 1 for details), in which they were engaged during modelling. Specifically, we are aware from previous studies that the process of modelling is a demanding learning task which entails specific cognitive processes of different difficulties (Hogan & Thomas, 2001; Löhner et al., 2005; Sins et al., 2009; Stratford et al., 1998). Based on empirical evidence, Sins et al. (2009) developed the cognitive strategies for modelling framework (see Table 2) which shows that most of the students use the following cognitive strategies during modelling: (a) analyzing the objects and factors to include in their model, (b) reasoning about the relations of their factors, (c) synthesizing a model by employing a series of strategies, (d) trying to explain the relationships and (e) tested their model, though in different ways and deepness. The aforementioned categories were used as a guiding framework in our analyses of students' modelling.

Phase 2: Argumentation

Step 1: During the second phase, all videos from all groups were watched again in order to identify episodes in which argumentation took place in the groups and/or during the whole classroom discussions. Argumentation in the discussions was identified by using the CER framework presented in the theoretical framework of the paper. Specifically, all argumentation episodes were identified, and then each episode was coded for the elements of argumentation as presented in the CER framework (see Table 3 for examples).

Step 2: After identifying the argumentation episodes, those episodes were open-coded to identify the context in which the students used their models. More specifically, the episodes were coded as either:

(a) argumentation with the use of the model: This category referred to argumentation episodes in which the students used their model in the process of argumentation and decision-making about the given issue. Specifically, they used their model to represent their solutions, to argue about the ecosystem or the introduced solution, to explain or predict a component or an element of their model or to show the

Table 1 Modelling practices

Modelling practice	Description
Model construction	Students construct their model to account for the phenomenon under study
Model use	Students use their model with an aim to predict the evolution of the phenomenon and decide upon the most suitable solution to the problem
Model evaluation (and revision)	Present the models to other groups for evaluation (intergroup evaluation)
	Present the model to other group members for evaluation (intragroup evaluation)

Table 2 Cognitive processes employed by students during modelling (adapted from Sins et al. 2009)

Cognitive process description	Representative quote
Analyze: Students talk about modelling elements. They identify factors that may be relevant or not to their model. They identify elements of the phenomenon that should be included in their model.	Student 17: The salt-lake has many plants. There are some small lakes with dirty water. Let's include them in the model since in there are many mosquitoes and shrimps.
Inductive reasoning: Students elaborate upon elements within or with respect to their model (involves mainly qualitative reasoning). They express hypotheses on how elements interact and on how they should behave in their model.	Student 13: The number of flamingoes was reduced because of the impact of the lethal gene.
Explain: Students explain to each other how elements within their model work or why they were included (or excluded). Sometimes, explanation is preceded by a clear-cut question of one of the students.	Student 2: We decided to introduce frogs in the lake. They eat the mosquitoes and other insects. You can see them here [in the model]. Those balls are the eggs and the larvae of the mosquitoes.
Evaluate: Students compare the data (the phenomenon) and their model. They determine if the model accounts for those data. Students revise their model to do so.	Student 19: Your model is nice, but it should include all the lake's organisms. For example, the eggs of the shrimps.

consequences of their solution. They used their model as a means to eliminate solutions or even as a way to represent an already 'known' consequence.

(b) argumentation without the model: This category referred to argumentation episodes in which the students argue about the solutions' feasibility, efficiency or consequences beyond their model—without actually showing or using their model.

At each of the abovementioned steps, categories were applied independently by two of the researchers to code 10% of identified episodes, and when agreement was reached, the rest of the lessons were coded

Table 3 Categories of argumentation

Category	Example
Evidence: Evidence is scientific data that supports the claim. The evidence can come from investigations students engage in firsthand or from research conducted online or in books that provide data	We saw many shrimps in the lake and here they are in our model. We made them with white clay. (Student 17)
Reasoning: Reasoning provides a justification for why or how the evidence supports the claim	(Our model shows that) the introduction of genetically modified mosquitoes will affect the number of flamingoes. There are fewer now. (Student 13)
Rebuttal describes an alternative claim and provides counterevidence and counter reasoning for why the alternative claim is not appropriate.	Student 13: the mosquitofish eats mosquitoes! Student 14: they will not survive…. Student 17: maybe they can… Student 14: what do you think Leda? Student 13: hm Student 17: It will be a continuous process. We will have to continuously bring mosquitofish in the Lake Student 13: no, maybe when they reproduce they give birth to large numbers of eggs, it depends… Student 14: I would also like to know what they eat, how much they eat, if there are 100 a day mosquitoes they will eliminate them? Student 13: They eat 1000 mosquitoes a day Student 14: aha, ok thanks.

independently. Inter-rater reliability for phase 1-step 2 was 80%, for phase 2-step 1 was 95% and for phase 2-step 2 was 78%. Any disagreement was resolved through discussion.

Findings

The analysis described in this section examined students' argumentation during modelling. More specifically, we firstly examined how students engaged in argumentation whilst they created, used and evaluated their models. Secondly, we examined whether the students used their models or not when they engaged in argumentation, and which elements of argumentation they mostly refer to during that time. Finally, we examined in what kind of discussions the students were engaged during argumentation and modelling.

Modelling Practices and Argumentation

Table 4 below presents in what argumentation elements the students engage during the modelling practices (namely creating models, using models and evaluating models).

Based on the analysis in Table 4, students provided evidence more frequently during the model creation and model evaluation phases, compared with the phase of using their model. On the contrary, data from Table 4 suggest that students used rebuttals during all modelling practices, but this is especially evident during the evaluation practice. Since the use of rebuttals during argumentation is considered a higher-level skill, we chose to examine how students used rebuttals by closely looking into the data set.

As evident in the quote presented in the supplementary materials, the students are using the model to help them present their solution in a more visual way. At the same time, the model offers the possibility for a discussion around the feasibility of the proposed solution since students from the other groups are questioning the solution. However, when evidence is needed, the students referred to their experience from the visit to the salt lake.

Argumentation With and Without the Use of Model

In order to explore how students use models whilst they engage in argumentation, we analyzed students' argumentation throughout the lessons, even when they were not using their model. More specifically, we analyzed all argumentation episodes, and these episodes where then grouped in two categories: (a) argumentation with the use of models and (b) argumentation without the use of models. Table 5 presents which argumentation elements (evidence, reasoning and rebuttal) are enacted by students when they use the model and when not.

As evident in Table 5, students engaged in discussing their evidence only with the use of their model. On the contrary, using reasoning and rebuttals occurred either with or without the use of their model. In order to explore how students use the model during argumentation and how the students engage in argumentation without the use of their model we explore the issue in detail below:

Table 4 Modelling practices and argumentation during all lessons

	Create model	Use model	Evaluate model	Total
Evidence	68	7	84	159
Reasoning		6		6
Rebuttal	1	3	18	22

Table 5 Model use and argumentation

	Without the model	With the use of the model
Evidence		159
Reasoning	7	6
Rebuttal	18	22

(a) With the use of model. The following quote is an example of how students talked about the ecosystem elements (i.e. flamingoes eat shrimps) with the use of their model during the model construction practice:

Student 6: I suggest adding that shrimp in the mouth of the flamingo.
Student 9: Why?
Student 6:Because flamingoes eat shrimps.
Student 12: A! Great idea! To show that flamingoes eat shrimps! I agree
Student 10: Me too, let's do it.

The example that follows indicates how students used evidence to support why a specific solution is appropriate for their problem, with the use of their model. Student 2 suggested the introduction of bats in the lake to solve the mosquito problem: 'One solution is the bats. We should introduce bats in the lake, because they eat mosquitoes'. Student 2 uses evidence about the suggested solution (bats eat mosquitoes) and proposes to include the bats in their model to solve the mosquitos' problem.

Additionally, students reasoned about the consequences of the introduced solution when using their model. For example, Student 4 provided the following reasoning '…the number of shrimps will increase. Shrimps are eaten by the flamingoes, which will be decreased due to the effect of the 'lethal gene' to the mosquitoes of the lake'. This student identified that the proposed solution would have an effect to the shrimps and then to the flamingoes of the lake. She expressed that reasoning during her group's effort to use the model as a platform to understand the implications of their solution.

Finally, rebuttals occurred during model use, when students discussed about the ecosystem's elements, or about a possible solution to the problem. For example, a group of students rebutted about the solution associated with chemical spraying to kill mosquitoes:

Student 15: We should spray with chemicals. Then the mosquitoes will be eliminated.
Student 2:But if we spray with chemicals then other animals will be affected.
Student 1: Spraying? I agree with Student 2. If we spray, other animals will die. See, it will affect the flamingoes (takes a Flamingo out of the model). It can affect other animals as well. Also we don't know if this will be good for the water of the lake.
Student 5: It will affect other animals, the shrimps, the flamingoes. We shouldn't use this as a solution.

(b) Without the use of model. Our analysis (Table 5) also indicates that argumentation happened without the use of model. For example, the students reasoned about the consequences of their solution or rebutted about the solutions and their feasibility without actually using their model, even though they had their models in front of them. The following extract is a representative example of how students were questioning the feasibility of the solution suggested by another group:

Student 17: Are there any bats in our country?
Student 15: Of course there are. But they don't visit the lake.
Student 16: They do, but rarely.
Student 14: Actually I saw bats a lot of times.
Student 15: It is not easy for the bats to eat the mosquitoes. How many mosquitoes will they eat? Five?
Student 13: Yes. How will you know where the bat is, or where the mosquito is, or where will it go?
Student 16: They could also leave the lake and visit the houses around the lake.
Student 13: It is a living creature. Imagine putting it here. We cannot force a bat do whatever we want. We shouldn't use this solution.

Additionally, the students were engaged in argumentation by reasoning about the consequences of the suggested solutions without the use of model. During the whole classroom discussion when the councillor visited the class, a group of students rejected the solution related to the introduction of the lethal gene to the mosquitoes, because this would have consequences to humans and to the rest of the lake organisms:

Student 16: The trees could be affected.
Student 14: A mosquito can escape, bite a human, and then humans could get sick.
Student 16: I agree with Student 14, infected (with the lethal gene) mosquitoes could cause much trouble.
Student 13: Yeah, mosquitoes could bite the shrimps, and us …
Student 16: and we could get sick.
Student 13: We should find a solution that will not affect the shrimps or the humans.

Therefore, what is evident from the analysis of students' discussions is that argumentation occurs with the use of the model, and by referring to the model helps the students choose a solution and represent it in their model. But argumentation also occurs without the use of the model. What is important to note however is that even when argumentation occurs without the model (the reasoning that takes place is still associated with how students understand the phenomenon through the model (e.g. see representative quote above).

Discussions that Occur During the Cognitive Processes of Modelling

As stated in the theoretical framework, we are aware that during modelling, different cognitive processes occur. In our work, we are using the cognitive processes identified by Sins et al. (2009), namely analyzing, evaluating and explaining the model, and engaging in inductive reasoning (also see Table 2 for an explanation of the categories). Based on our analysis of the cognitive processes and an open coding of the discussions taking place during those processes, it was evident that when students were engaged in argumentation and modelling, they practiced the following actions: (a) they cited claims, (b) they defended a claim, (c) they explained and (d) they requested information. In the analysis that follows, we present how argumentation is enacted within the specific cognitive processes of modelling.

(a) When analyzing the model. Evident in the analysis was that when students analyze their model, they were mostly citing a claim, or requesting further information. What follows is a representative episode from lesson 4. In this lesson, the students were asked to represent the various solutions in their model and discuss whether these are feasible and appropriate solutions for the problem. During this time, the students were engaged in the cognitive process of analyzing their model, whilst at the same time requesting further information or citing claims.

Student 14:	What does it mean to use genetically modified mosquitos?	Request information
Teacher:	Changing the genes of the mosquitoes in order to modify how they behave. For example, it could change them in a way that they cannot be reproduced. Read the information available in the evidence cards.	
Student 18:	Yes, but what happens if a genetically modified mosquito stings us?	Request information
Teacher:	I do not know, you have to check the information that you have.	
Student 18:	Will it hurt us as well?	Request information
Teacher	You can identify this concern in your proposed solution.	
Student 15:	The mosquitoes carry diseases.	Claim
Student 18:	Yes, the infected mosquitoes carry diseases.	Claim
Teacher:	The genetically modified mosquito is not infected. So your worry is whether this change in the gene of the genetically modified mosquito can somehow affect human beings?	
Student 14:	Can the genetically modified mosquito reproduce?	Request information
Student 13:	No.	Claim
Student 18:	It will not be able to reproduce. It will die and will not be able to reproduce.	Claim
Student 13:	It will die.	Claim
Student 18:	It will die on the spot.	
Student 13	They will not be able to reproduce, so they will eventually die.	Claim
Student 14:	But what is it going to happen to the mosquitoes that are genetically modified? Will they stay there forever?	Request information
Student 13:	Eventually the mosquitoes […]	
Student 18:	This is a good solution, but it can hurt us too.	Defend claim
Student 14:	But what is going to happen to those mosquitoes that are already genetically modified?	Request information
Teacher:	They will eventually die.	
Student 17:	OK, we got that, they will die without reproducing. But what is going to happen to the rest of the mosquitoes that are not genetically modified? Will they die too?	Claim + request information
Student 14:	They will die.	

(b) When evaluating the model. When the students were engaged in the cognitive process of evaluating their model, they were mostly providing claims, or defending a claim based on their knowledge. What follows is a representative episode from lesson 5. During this lesson, each group presented their models during a whole classroom discussion. In this episode, one of the groups presented its model that included the main lake and smaller lakes by the side, similar to the lake they visited. The quote below presents the evaluation of their model from other groups.

Student 1:	I think that it is original to have the smaller lakes next to the bigger one.
Student 10:	I believe that they have the best model because they represented what they actually saw.

Student 17:	What they did shows exactly where the mosquitoes are. But if they just created one big lake in the center the same way as all the other groups, that would not be very useful.	Claim
Student 4:	But we saw another model that also has smaller lakes by the side of the main lake.	
Students:	It was the model of group 2.	
Student 4:	Yes, the model created by group 2.	
Student 5:	What I did not like is that they did not include the larvae in the small lakes. There were larvae in the small lakes as well, we saw them when we visited the salt lake.	Defend claim

(c) When explaining. When engaging in the cognitive process of explaining, the students were at the same time engaged in defending a claim based on knowledge, explaining or predicting a fact and using knowledge. What follows is a representative episode from lesson 5, during which group 4 presented their model to the other groups.

Student 5:	How about larvae and eggs? You did not include them in the model but did you see them?	
Student 19:	Yes we did, but they were deep in the water and we could not represent them in our model	Defend claim
Student 14:	I like your model because you have the lake and you have sand all around, the same as when we visited the salt lake.	Claim
Student 5:	What is this green thing?	Request information
Student 19:	This is a frog	

(d) When engaging in inductive reasoning. When engaging in the cognitive process of inductive reasoning, the students were also defending a claim based on knowledge or explaining/predicting a fact. What follows below is a representative example from the last lesson, in which they are trying to explain their choice of solutions to the councillor, and at the same time rebut the solutions of other groups.

Student 15:	One solution would be to bring frogs to the salt lake to eat the mosquitoes and minimize the problem.	Explain
Student 14:	What if the frogs become a problem then?	Request information
Student 1:	Or if they leave from the lake and go somewhere else?	Request information
Student 2:	I disagree because the frogs cannot live in the salty environment so this is not a very good solution.	Defend claim

The analysis of students' argumentation and modelling as presented above suggests that students request information and ask questions that will help them to improve their models and also improve their arguments. It is especially evident that the model is acting as a visual aid for the students to understand the ecosystem/phenomenon and for the other groups to understand the proposed solution of their classmates. Furthermore, by discussing the models, the solutions and their limitations, the students engage in high-level argumentation, which includes reasoning and rebuttals.

Discussion and Implications

It is suggested by scholars that modelling and argumentation should have a central role in the teaching of science, and therefore, their relationship should be investigated (Passmore & Svoboda, 2012). Specifically, the aforementioned researchers state that the act of modelling in science is inherently an argumentative one. In this paper, we were set out to explore whether and how modelling and argumentation, if incorporated together into a lesson, can support or constrain one another. We hypothesized that the use of models can provide visual information to support the students in their effort to understand the underlying mechanisms of a phenomenon, construct their arguments and explain the phenomenon. At the same time, we hypothesized that the argumentation that takes place in groups can support the students in restructuring and improving their models to better represent the phenomenon. Therefore, the purpose of this study was the exploration of how 10–12-year-old students engage in the practices of argumentation and modelling and how one practice can support or constrain the other. In the following paragraphs, we discuss our findings in light of the two research questions of the study.

Research Question 1: How Argumentation Occurs During Modelling?

Our first research question focused on the analysis of students' arguments during the various phases of modelling and across all lessons. The purpose for doing so was to identify how elementary school students argue during the different modelling phases and therefore to explore how the two practices intersect. The first finding of our study suggests that students mostly engaged in discussing their evidence and, to a less extent, in reasoning and rebuttals. This finding is similar to previous studies which suggest that students and especially younger ones (Berland & Mcneill, 2010; Cavagnetto et al., 2010; Naylor et al., 2006) find it difficult to move beyond evidence to more complex processes. A second finding is that rebuttals occur more often than reasoning. This is in contrast to previous studies with younger students, which suggest that elementary school students cannot engage in high-level argumentation (Naylor et al., 2006). A third and important finding is that rebuttals occur mostly during the phase of model evaluation. In this phase, the students are asked to evaluate other students' models and justify their decision for their models and therefore support their decisions. Based on our reading of the literature, this is a new finding. This finding suggests that modelling, and especially the phase of model evaluation, can scaffold elementary school students towards better arguments since students are providing more rebuttals during model evaluation. This finding of how argumentation is supported in the different modelling practices is represented in Fig. 1 below.

Figure 1 presents the modelling practices (creating models, using models and evaluating models) and the elements of argumentation that are more evident in each one of the practices as it occurs from the findings in this study (e.g. see Table 4). The main implication from this figure is that each modelling practice can

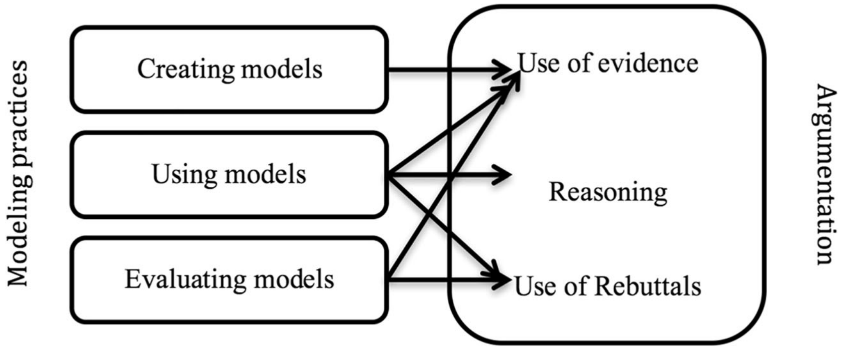

Fig. 1 How argumentation develops in the different modelling practices

support different argumentation phases, and if we want to support students in providing rebuttals, we should engage them in the modelling evaluation practice.

A fourth finding of our study (see Table 4 and Fig. 1) is that reasoning takes place when the students use their models to explain their decision, which suggests that modelling can help them better understand the phenomenon. Also, the better rebuttals might be linked to a better understanding of the content, which is also linked to modelling (Louca & Zacharia, 2011; Maia & Justi, 2009; Mendonça & Justi, 2013).

Research Question 2: What Discussions Occur During the Different Modelling Phases and How Does that Link to Argumentation?

Our second research question focused on the analysis of the cognitive process of modelling (analyze, evaluate, explain and inductive reasoning) and how these intersect with argumentation. In line with the findings of Stratford et al. (1998), we found that students engage in all cognitive processes for modelling when they construct models, which supports the idea that modelling is an act of understanding and helps students move beyond the provided information when they try to analyze, qualitatively relate, explain or evaluate the relationships within their model.

Additionally, the cognitive processes of evaluating and inductive reasoning seem to be intersecting with higher-level argumentation. Löhner et al. (2005) suggested that the generation of hypotheses and the model evaluation are the cognitive processes that are associated with more productive modelling. Therefore, the sixth finding of this study is that there is an intersection of higher-level modelling cognitive processes and higher-level argumentation. To our knowledge, previous studies have not explored this issue, but what we know from studies in argumentation with elementary school students is that they do not easily engage in high level of argumentation (Naylor et al., 2006). We hypothesize that the use of models might have contributed to high-level argumentation. This finding suggests that if we want students to develop the use of high-level argumentation, we need to support high modelling cognitive processes and vice-versa.

Research in argumentation and modelling has been focusing primarily on older students, since researchers support that the reasoning needed to engage in argumentation and modelling is complex for younger students (Sadler & Fowler, 2006; Louca & Zacharia, 2008). In our study, we have used an SSI context, and modelling with younger students, and our findings suggest that the students were able to engage in the processes of argumentation and modelling and provide feasible solutions for the problem. The main contribution of this paper is that we have provided empirical evidence from a classroom that indicates that the practices of argumentation and modelling can support each other. Specifically, based on our findings, the model evaluation practice seems to support students in providing rebuttals and a higher-level skill and using evidence to support their claims. We hypothesize that this is due to the interactions which take place between the students during the model evaluation since the students are explicitly asked to explain their model or their solution as shown on the model, and therefore, they need to support their decisions during the discussions. Our finding is supported by previous studies with younger students (Cavagnetto et al., 2010; Louca & Zacharia, 2008; Papaevripidou et al., 2007; Naylor et al., 2006), and the main implication arising from our study is that modelling can support higher-level argumentation, especially when students engage in the practice of model evaluation.

Our findings suggest that curriculum developers and teachers should focus on engaging students in modelling and argumentation together, since specific aspects of modelling (e.g. model evaluation) seem to support the development of specific aspects of argumentation (using rebuttals).

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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