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Combining debates and reflective activities to develop students' argumentation on socioscientific issues

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Abstract

This study aimed to investigate the evolution of students' written argumentation on socioscientific issues (SSIs) during a sequence combining two teaching strategies: debate practice on SSIs and reflective activities on the argumentation produced by students. The quality of their argumentation was assessed considering a set of norms characterizing argumentation practice on SSIs: three generic norms (i.e., justification, others, and questioning norms) and three specific norms (i.e., complexity, uncertainties, and open-endedness norms). The 2-year sequence was implemented by teachers from different disciplines in two classes with students aged 16–18. In total, it consisted of four debates on different SSIs and involved four reflective activities following a progression, allowing for the discussion of the generic and specific norms of argumentation on SSIs. The debates were all computer-mediated and held synchronously in the classroom. They involved students developing their argumentation in a written form. Overall, the results showed positive changes, even if limited, regarding the appropriation of both the generic and specific norms of argumentation on SSIs. The more pronounced changes

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were observed considering the initial level of the quality of student argumentation in the debates: Students whose initial level was low tended to justify their arguments more frequently, while those with a higher initial level tended to question the claims and arguments more often. Furthermore, at the end of the sequence, students easily coordinated several aspects of the debated SSI, but rarely mentioned knowledge uncertainties and stakeholders of the SSI. These findings imply that combining debates on SSIs with reflective activities is an effective teaching strategy deserving to be disseminated in classroom practices, although two specific norms (i.e., uncertainties and open-endedness norms) require more in-depth treatment.

KEYWORDS
argumentation, secondary school, socioscientific issues

1 | LEARNING TO ARGUE ON SOCIOSCIENTIFIC ISSUES: WHY AND HOW?

Many of the questions that shake our society today involve science. Some examples are as follows: Should we authorize the use of genetically modified organisms (GMOs) in agriculture? Should we continue exploring hydrocarbons in the seas? Should air transport pollution be taxed? These socioscientific issues (SSIs) testify to the social embedding of science and can display some aspects of the functioning of science, such as the role of data and their various possible interpretations, or the tentativeness of scientific knowledge and the uncertainties associated with it. Therefore, studying SSIs with students in the classroom is a way to develop their understanding of the nature of science (NOS; Eastwood et al., 2012; Karisan & Zeidler, 2017; Leung, 2020; Simonneaux, 2007; Zeidler et al., 2002). Beyond such instrumentalization of SSIs, some authors believe that the students' ability to engage in debates on such issues should be an integral part of their scientific literacy (Capkinoglu et al., 2020; Driver et al., 2000; Sadler, 2004a). The challenge is that students, as future citizens, should be able to take part in an informed way in the debates and decision-making concerning the SSIs that are now central to the democratic life of our societies (Kolstø, 2001). In this respect, they should essentially learn to argue about SSIs (Evagorou & Dillon, 2020; Morin et al., 2017; Sadler, 2004b; Simonneaux & Simonneaux, 2005).

How can teaching contribute to this goal? How can students be trained to develop quality arguments about SSIs? One strategy is to engage students in debates on these issues, so that they practice producing arguments and confront opposing viewpoints and counterarguments (Atabey & Topçu, 2017; Capkinoglu et al., 2020; Grace, 2009; Morin et al., 2014; Osborne et al., 2004; Tal & Kedmi, 2006; Zohar & Nemet, 2002). The measured impact of such a strategy was positive with respect to students' argumentation on the SSIs investigated during the

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intervention, but it was limited when considering transfer to new SSIs (Osborne et al., 2004). A second strategy is to provide students with reflective activities on their own argumentation about SSIs, so that they become aware of how they argue and learn the criteria for quality argumentation on these issues. Previous studies examining the contribution of reflective activities on students' argumentation about various topics show a positive impact on their skills to argue in general (Felton, 2004; Iordanou, 2010; Iordanou & Constantinou, 2015; Iordanou & Rapanta, 2021; Kuhn et al., 2008; Shi, 2019). However, these studies did not consider the specificities of argumentation in the context of SSIs. To the best of our knowledge, no studies have been conducted on reflective activities dealing with the specific features of argumentation about SSIs, and assessing the effects of such activities on the quality of students' argumentation on SSIs.

This is what motivated this study which investigated the effects on students' argumentation about SSIs of a teaching sequence combining the two teaching strategies: repeated practice of argumentation through several debates on SSIs, and reflective activities about argumentation on SSIs. To allow students to analyze and discuss their argumentation during reflective activities, this argumentation must be made available to them. For this purpose, a simple solution is to implement the debates in written form using computers with an appropriate software, so that the arguments produced by the students are automatically recorded and remain accessible (Kuhn et al., 2008). Regardless of this practical issue, computer-mediated debates are favored in many studies because they enable all students to participate simultaneously and offer them more time to construct their arguments than oral debates do (Asterhan & Eisenmann, 2011; Clark et al., 2007). In the frame of our study, we decided to perform computer-mediated debates synchronously in the classroom both to favor high-quality argumentation and facilitate the implementation of reflective activities. The sequence took place over 2 years with the same students (ages 16–18) from two different classes. It was composed of four teaching units, each focusing on a different SSI (e.g., hydrocarbon exploration, GMO crops, or glyphosate). The general research question of this study can be constructed as follows: How does the quality of students' written argumentation on SSIs evolve when implementing a strategy combining synchronous computer-mediated debates and reflective activities?

In what follows, we first present the theoretical framework which is centered on the notions of generic and specific norms of argumentation on SSIs. The methods and main results of previous studies on the impact of debate practice and reflective activities are reported. The advantages of using computer-mediated debates are put forward. We subsequently describe the methodology of our study, which employs a design experiment method, followed by the results and their discussion. The latter opens up several avenues, both in teaching strategies and students' learning of argumentation on SSIs.

2 | ARGUMENTATION ON SSIs

2.1 | Generic norms

Argumentation can be described as a *social practice* based on a set of *norms* (Kuhn et al., 2013; Nussbaum, 2021). The norms of argumentation correspond to standards shared by individuals who participate in the practice of argumentation, that is, the criteria that participants believe to characterize good argumentation and that are therefore worthy of being respected (Kuhn et al., 2013). In other words, every participant is expected or prompted to meet these standards

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(Ryu & Sandoval, 2012). Some of these norms are *generic*, that is, common to all contexts in which argumentation is practiced, while others are *context-specific*, that is, dependent on the context in which the argumentation is practiced (Weinstock et al., 2004). In what follows, we propose a theoretical framework to describe argumentation on SSIs in terms of three generic norms—justification, others, and questioning—and three norms specific to SSIs—complexity, uncertainties, and open-endedness. We do not claim that the three generic norms selected represent an exhaustive set of norms that can describe argumentation in all its complexity. However, they seem to us to be both fundamental for quality argumentation and accessible to students in secondary school. The first two generic norms, on the one hand, and the third generic norm, on the other, have been put forward by different authors in the context of studies focused on students' appropriation of these respective norms. Bringing these three generic norms together is therefore a proposal to simply highlight aspects of argumentation already present in the literature. By contrast, the statement of the three SSI-specific norms is an original proposal that draws on the literature on SSIs to identify characteristics that can be expressed in terms of argumentation norms.

The first generic norm of argumentation is about justification (Kuhn, 1991; Kuhn et al., 2013; Weinstock et al., 2004) and can be stated as follows:

- Claims made in an argumentation must be supported with one or more justifications (*justification norm*).

Argumentation is a process in which arguments are produced and evaluated (Duschl & Osborne, 2002; Jiménez-Aleixandre & Erduran, 2007). Justification is a fundamental element of an argument: a justification must necessarily be associated with a claim in order to constitute an argument, and thus provide a ground to believe in this claim. Depending on the context, different forms of justification are acceptable: evidence, consistency with already accepted knowledge, reference to a rule, compliance with certain values, and so forth.

The second generic norm of argumentation concerns the consideration of others' arguments (Kuhn, 1991; Kuhn et al., 2013; Weinstock et al., 2004) and can be formulated in the following way:

- The arguments expressed by the other interlocutors who take part in the argumentation must be considered in the construction of one's own arguments (*others norm*).

An important feature of argumentation is that it is a dialogical process involving several interlocutors, real or fictional (Plantin, 2005). It is through the successive contributions of the interlocutors that the argumentation develops, that new arguments are produced, evaluated, accepted, or rejected. The arguments formulated by others represent an essential driving force for the production of one's own arguments. Arguments are thus produced successively by the different interlocutors according to a dynamic of exchange. In this respect, argumentation can be modeled in terms of "argumentative moves" (Van Eemeren et al., 2007), that is, statements that take into account the arguments of others, and develop or criticize them. For example, these argumentative moves can consist of conceding another's argument and qualifying one's own claim, or developing another's claim with an additional justification, or on the contrary, refuting it with an opposing claim or a counterargument.

The third generic norm of argumentation is about questioning (Chin & Osborne, 2010; González-Howard & McNeill, 2019; Nussbaum, 2021) and can be stated as follows:

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- The various claims and justifications formulated in an argumentation should be questioned (*questioning norm*).

Doubt is one of the main drivers of argumentation (Plantin, 2005). It consists in questioning the grounds for the claims and encourages one to evaluate them by examining the justifications and counterarguments. In the frame of an argumentation, a claim is not always formulated from the start with a justification. It is precisely one of the objectives of argumentation to question the claim and to look for such a justification. The latter can in turn be questioned and other justifications, or a justification of this first justification, can be sought. In this respect, argumentation corresponds to a retroactive process that starts from a claim and moves up the chain of its possible justifications (Schwarz & Baker, 2017). Under the pressure of questioning, the interlocutors are led to strengthen their claims by providing new justifications, or on the contrary to qualify them, to make concessions, or even to renounce them if the justifications prove to be too weak or the counterarguments too strong. Questioning is a driving force of argumentation that provides it with direction and purpose (Chin & Osborne, 2010).

2.2 | Context-specific norms

Besides the generic norms, argumentation is governed by context-specific norms. For instance, in the context of experimental science, two specific norms are usually highlighted: Claims must be justified by empirical evidence and be consistent with the accepted theories (Bricker & Bell, 2008; Duschl, 2007; Fensham, 2012; Grooms et al., 2018; Jiménez-Aleixandre & Crujeiras, 2017). Regarding the context of SSIs, the norms of argumentation can be clarified in relation to the features of this kind of issues. Although they involve science, SSIs are not purely scientific issues. Rather, they can be defined as "social issues with conceptual and procedural connections to science" (Sadler, 2009, p. 2). More precisely, based on several descriptions of SSIs offered in the literature (Bravo-Torija & Jiménez-Aleixandre, 2012; Fensham, 2012; Morin et al., 2014; Sadler, 2009; Sadler et al., 2007; Simonneaux, 2007), three main features of these issues can be distinguished: they are *complex*, characterized by *uncertainties*, and *open-ended*. We postulate that argumentation about an SSI must consider each of these features to allow a fine understanding of it and informed decisions to be made. This leads us to identify three norms of argumentation specific to the context of SSIs.

The first specific norm is about complexity and can be stated as follows:

- Argumentation on an SSI must take into account and put in relation its multiple aspects (*complexity norm*).

To fully understand an SSI and make an informed decision about it, it is necessary to develop an argumentation that does not limit itself to taking into account its scientific or technical aspects. The latter has to be considered in relation to the other aspects of the SSI, such as its environmental, sanitary, social, economic, political, or axiological aspects. For instance, argumentation on the issue of legalizing GMO crops should consider and relate its multiple aspects which may be scientific (e.g., the types of genetic modifications made and their consequences), technical (e.g., productivity), environmental (e.g., reduced use of pesticides or possible impact on biodiversity), sanitary (e.g., addressing malnutrition), social (e.g., food traditions in the face

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of food standardization), economic (e.g., survival of small farms), political (e.g., application of the precautionary principle), or axiological (e.g., prioritizing productivity or environment).

The second specific norm of argumentation on SSIs deals with uncertainties:

- Argumentation on an SSI has to consider the uncertainties inherent to the knowledge called upon, as well as the uncertainties concerning future evolutions in the world (*uncertainties norm*).

Some of the knowledge used in arguments about an SSI is not stabilized. This knowledge has a limited domain of validity, and beyond this domain of validity, it involves uncertainties. For example, the long-term impacts of GMOs on the environment remain uncertain to a large extent. A second type of uncertainty associated with SSIs is related to the unpredictable nature of future evolutions in the world, for example at the level of human societies, technologies, or the environment. These future evolutions are sometimes described in terms of risks related to human actions (Morin et al., 2014). Taking both types of uncertainty into account appears essential to develop a balanced and critical argumentation on an SSI.

Finally, the third specific norm of argumentation on SSIs concerns their open nature and can be stated as follows:

- Argumentation on an SSI has to acknowledge the multiple acceptable viewpoints of the different stakeholders of the SSI (*open-endedness norm*).

Unlike a scientific problem for which ideally a unique and consensual solution can be found, an SSI is by nature an ill-structured problem, that is, a problem whose solution is multifaceted and undetermined (Sadler, 2009). Scientific knowledge can provide justifications for a viewpoint or a decision about an SSI, but it does not offer a single solution. Other types of justifications should also be considered, especially those related to the interests, values, and value systems (i.e., the order of importance of values; Kolstø, 2006) of the SSI stakeholders. Indeed, these contribute to the construction of the different possible viewpoints and decisions about an SSI (Herman et al., 2021; Kolstø, 2006; Lee & Grace, 2012; Rundgren et al., 2016; Zohar & Nemet, 2002). In the frame of an argumentation on an SSI, these interests, values, and value systems constitute a means—alternative or complementary to knowledge—to justify a viewpoint or decision on an SSI. For this reason, several viewpoints are acceptable and must be considered when developing the argumentation.

It can be noticed that these three specific norms echo to some extent the skills of socioscientific reasoning (SSR), a construct developed by Sadler and his colleagues (Romine et al., 2017; Romine et al., 2020; Sadler et al., 2007). These skills are required "for making sense of and taking informed positions on SSI" and are described as follows: "recognizing the inherent complexity of [SSI] and therefore not jumping to naïve conclusions; understanding that SSI are subject to ongoing inquiry and being able to identify information that is missing; analyzing SSI from multiple perspectives and appreciating the unique concerns of various stakeholders; exhibiting reflective skepticism in the processing and analysis of information about SSI from potentially biased sources" (Romine et al., 2020, p. 2982). However, one point of divergence should be stressed. The skill related to skepticism and biased sources refers to the idea that the stakeholders involved in an SSI select and interpret evidence according to their perspectives without necessarily being aware of it. We prefer to avoid the use of the expression "biased sources" as it suggests that there would be objective sources. Information always has a

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subjective dimension in the sense that it inevitably depends on the source perspective and involves data selection and interpretation processes (Barzilai & Weinstock, 2020). Even factual information is always "theory laden" (Hanson, 1958) as is widely accepted in the philosophy of science. Furthermore, this subjective dimension can be considered as already included in the open-endedness norm, since it is linked to the viewpoints, interests, and values of the different stakeholders.

Besides, it should be stressed that the features of SSIs underlying the specific norms of argumentation bear some relationship. Depending on their interests, values, or value systems, stakeholders may emphasize some aspects of the SSI over others (for example, by judging that the economic aspect is more important than the environmental aspect when it comes to making a decision on the legalization of GMO crops). The complexity of an SSI thus contributes to its open nature, that is, to the multiplicity of acceptable viewpoints on that SSI. Furthermore, the uncertainties associated with an SSI may weaken or question the justifications supporting a given viewpoint and make it acceptable to hold an alternative viewpoint. These uncertainties therefore also contribute to the open nature of SSIs.

3 | TEACHING STRATEGIES TO HELP STUDENTS BETTER ARGUE ON SSIs

3.1 | A first teaching strategy: Practicing debates

3.1.1 | Positive effects reported in a set of studies

The main teaching strategy pointed out to develop the quality of students' argumentation on SSIs is to provide them with an opportunity to debate on these issues. A set of studies (Atabey & Topçu, 2017; Capkinoglu et al., 2020; Grace, 2009; Morin et al., 2014; Osborne et al., 2004; Tal & Kedmi, 2006; Zohar & Nemet, 2002) has been carried out to investigate the effects of interventions involving debates on SSIs (Table 1). Depending on the study, the debates take place either in small groups and/or with the whole class, orally (in most studies) or in written form (in the study of Morin et al., 2014 based on computer-mediated debates). These debates may be the only activity carried out by the students during the intervention (in the studies of Grace, 2009, and Morin et al., 2014), or they may be associated with a variety of other activities, such as searching for information, undertaking laboratory activities, field trips, making presentations to other students, writing a letter, or composing a poster to communicate their arguments (in the other studies). In addition to students' activities, some of the interventions include explicit instruction about argumentation, for instance, by explaining the structure of an argument and/or the criteria for distinguishing poor from informed arguments [in the studies of Capkinoglu et al. (2020) and Zohar and Nemet (2002)]. Overall, these studies show a positive effect of the interventions on the quality of students' argumentation concerning the SSIs investigated during these interventions. This result is obtained with students in middle school, high school, and university, hence involving different ages, starting from 11 years old.

The outcomes yielded by these studies cannot be directly compared as different methods were used to assess the intervention effects (Table 1). First, different types of data were collected and compared to assess the quality of students' argumentation on SSIs at the beginning and at the end of the intervention: individual writings (Atabey & Topçu, 2017; Grace, 2009; Zohar & Nemet, 2002), small-group writings (Morin et al., 2014; Tal & Kedmi, 2006), small-group oral

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TABLE 1 Studies on the effects of debate practice on students' argumentation about SSIs

Authors of the study	Age of students	Intervention (number and types of debates, and additional activities)	Method (data collection, comparison, and analysis)
Zohar & Nemet, 2002	12–18 years	- Two whole-class oral debates - The teacher provides explicit instruction on argumentation	*Data collection and comparison*: comparison of argumentation quality in individual writings at the beginning/end of the intervention; comparison of argumentation quality in the two whole-class oral debates *Criteria to assess argumentation quality*: occurrence of justified arguments, alternative arguments, and rebuttals; occurrence of explicit conclusions, number of justifications
Osborne et al., 2004	12–13 years	- Nine whole-class oral debates - Nine small-group oral debates - *Additional student activities*: making presentations, and writing letters or producing posters to communicate their arguments	*Data collection and comparison*: comparison of argumentation quality in whole-class oral debates at the beginning/end of the intervention *Criteria to assess argumentation quality*: occurrence of arguments including only a claim or a counterclaim, a claim with data, warrant, or backing, and with one weak or strong rebuttal, or multiple rebuttals
Tal & Kedmi, 2006	15–17 years	- Whole-class oral debates (unspecified number) - Small-group oral debates (unspecified number) - *Additional student activities*: searching for information, hands on lab-activities and field trips	*Data collection and comparison*: comparison of argumentation quality in writings produced by small-group at the beginning/end of the intervention *Criteria to assess argumentation quality*: number of justifications, use of scientific knowledge, synthesis of counter-claims and rebuttals, number of aspects of the SSI
Grace, 2009	15–17 years	- One small-group oral debate	*Data collection and comparison*: comparison of argumentation quality in individual writings at the beginning/end of the intervention *Criteria to assess argumentation quality*: occurrence of arguments being functional, justified, and including consideration of alternatives

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TABLE 1 (Continued)

Authors of the study	Age of students	Intervention (number and types of debates, and additional activities)	Method (data collection, comparison, and analysis)
Morin et al., 2014	Graduate students	- Two written argumentation in small-groups - One written debate between the groups of the same university - One written debate with cross-national groups	*Data collection and comparison*: comparison of argumentation quality in writings produced by small-group at the beginning/end of the intervention *Criteria to assess argumentation quality*: taking into consideration the various aspects (environmental, social, and economic) of the SSI, the dynamics of the associated socio-eco-systems, the different knowledges, the conditions of validity of knowledges and the techno-scientific risks, the values involved, and/or relationships between private and collective interests
Atabey & Topçu, 2017	11–12 years	- One oral debate in groups - *Additional student activities*: laboratory activities, field trips, and producing and presenting posters or slogans about the SSI	*Data collection and comparison*: comparison of argumentation quality in individual writings at the beginning/end of the intervention *Criteria to assess argumentation quality*: occurrence of accurate and/or complete claim, accurate and/or sufficient evidence to support the claim, accurate and/or complete reasoning that links evidence to the claim
Capkinoglu et al., 2020	11–12 years	- One small-group oral debate - One whole-class oral debate - *Additional student activities*: field trip or analyzing newspaper articles or experiencing informative presentations - The teacher provides explicit instruction on argumentation	*Data collection and comparison*: comparison of argumentation quality in small-group oral debates with the three different additional student activities *Criteria to assess argumentation quality*: occurrence of arguments including only a claim or a counterclaim, a claim with data, warrant, or backing, and with one weak or strong rebuttal, or multiple rebuttals

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debates (Capkinoglu et al., 2020), or whole-class oral debates (Osborne et al., 2004; Zohar & Nemet, 2002). In some studies (Atabey & Topçu, 2017; Grace, 2009; Tal & Kedmi, 2006), one or two parameters of the assessed argumentation differed from the argumentation practiced during the intervention (i.e., written instead of oral argumentation, and/or individual instead of collective argumentation), what implies a transfer capacity that deserves to be taken into consideration. Second, the criteria used in these studies to evaluate the quality of argumentation on SSIs were also different. Most of them were related only to the generic norms of argumentation, namely, the justification norm (when the criteria concern the occurrence of claims being justified or supported by evidence, data, warrant, or backing) and the others norm (when the criteria concern the occurrence of counterclaims, alternative arguments, or rebuttals). In contrast, in only one study (Morin et al., 2014), the criteria can be related to the three norms specific to SSIs. In one study (Tal & Kedmi, 2006), they were linked to both the generic and specific norms, but in an incomplete manner regarding the norms previously identified. The questioning norm is never expressed within a criterion.

Looking in detail at the developments of students' argumentation following the interventions, it clearly appears that they provide more justifications for their claims. They also tend to produce more counterclaims, rebuttals, or incorporate more alternatives, but changes in this respect are smaller and sometimes not statistically significant. Therefore, students seem to have greater ease in appropriating the justification norm than the others norm, which is in accordance with the idea that considering others in one's own argumentation is more cognitively demanding (Kuhn et al., 2016).

Since the analysis grids take little account of the norms specific to SSIs, we have limited information on whether students are able to appropriate them. Nevertheless, regarding the complexity norm, one study showed that students come to consider more aspects of the SSI they investigated during the intervention (Tal & Kedmi, 2006). This result is in line with a study showing that 12- and 13-year-old students are quite capable of considering several aspects of an SSI (Lee & Grace, 2012). However, this result should be taken with caution because another study (Barthes & Jeziorski, 2012) showed that students tend to focus spontaneously only on certain SSI aspects, even at the graduate level.

Concerning the uncertainties norm, one study (Morin et al., 2014) found that students were able to integrate uncertainties related to future risks in their argumentation on an SSI, but this was for graduate students only. Another study pointed to the great difficulty that high school students encounter in incorporating knowledge uncertainties into their argumentation in science (Lee et al., 2014), which can be explained by the fact that teachers do not get them used to consider and discussing uncertainties in the science classroom (Leden et al., 2017); they may immediately reduce uncertainty when it rises in science activities (Chen et al., 2019). In the context of SSIs, some students even exhibit a lack of tolerance for uncertainties (Lee et al., 2020). In addition, students generally have limited awareness of the uncertainties associated with scientific knowledge (Chen & Qiao, 2020).

Regarding the open-endedness norm, one study (Morin et al., 2014) showed that graduate students were able to include a diversity of stakeholders' viewpoints in their argumentation. However, this result should be treated with caution. Another study conducted with 15- to 16-year-old students found that most of them were not capable of integrating different discourses representing multiple perspectives into their discussion of an SSI (Lindahl et al., 2019). These students maintained strong boundaries between discourses, which may be encouraged by common teaching practices that tend to establish a strong classification between disciplinary discourses, particularly between discourses in science and other disciplines.

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3.1.2 | Effects depend on students' initial level and teacher's role during the debates

To better understand the effect of such interventions, or even to improve them, it is useful to consider students' background and their initial level regarding several academic and epistemic dimensions. Indeed, depending on their social and cultural backgrounds (e.g., parents' profession or students' involvement in associations), they may identify with the SSIs in different ways, and as a result, they may be more or less engaged in the argumentation process and develop more or less quality arguments (Evagorou & Osborne, 2013; Simonneaux & Simonneaux, 2005). The level of students' prior knowledge also has an impact on the quantity, quality, and diversity of the types of arguments they will produce on an SSI (Baytelman et al., 2020). Moreover, it has been shown that students' argumentation developed on SSIs is of better quality if they possess more elaborate epistemic beliefs (Baytelman et al., 2020), or a better understanding of several aspects of the nature of scientific knowledge (Khishfe et al., 2017).

The role of the teacher has also been identified as an important factor to facilitate argumentation discussion on SSIs, for instance by rephrasing students' arguments, encouraging them to answer each other's questions, or asking follow-up questions to prompt justification (Dawson & Venville, 2010). Further studies have been conducted concerning the factors associated with the teacher that promote quality argumentation on topics other than SSIs. In particular, it has been shown that the quality of students' argumentation is fostered when teachers do not seek to control the progress of the debate (i.e., correct students and impart knowledge during the debate), and instead provide scaffolding for students' argumentation activity (i.e., ask them to justify and further elaborate on what they are saying; Schwarz & Baker, 2017; Webb et al., 2009). The explanations given by the teacher at the beginning of an argumentation discussion concerning the task also play a role: Asking students to share their ideas and develop a communal understanding of the topic under discussion leads them to produce argumentation that considers better the ideas of others (González-Howard & McNeill, 2019). Furthermore, some authors have argued that the teacher should not ask students to debate an issue without ensuring that students have appropriated this issue, that is, that they understand why it is problematic and deserving of being debated (Orange, 2003; Schwarz & Baker, 2017, p. 185).

3.1.3 | Little or no effect to transfer skills to different contexts

The results presented above show a positive impact of debate-based interventions in developing the quality of students' argumentation about the SSIs addressed during these interventions. However, what about the transfer of students' argumentation skills to debate on new SSIs? In other words, does participating in debates about given SSIs help students to appropriate the norms of argumentation on SSIs and thereby to better argue on SSIs in general? In this regard, a positive result was found in Zohar and Nemet's (2002) study, but this result has not been replicated elsewhere and should be relativized because of the nature of the two contexts used to assess the transfer of argumentation skills: In one posttest, the students had to develop their argumentation on an SSI different from the one in the pretest, but involving the same scientific domain, namely, the one investigated during the intervention (i.e., genetics), while a second posttest concerned a dilemma of everyday life not corresponding to an SSI. In the study by Osborne et al. (2004), the quality of students' argumentation produced in a debate about a new SSI at the end of the intervention was better than the one produced in the debate at the

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beginning of the intervention on another SSI, but this change was not statistically significant, although the intervention consisted of eight argument-based lessons over the course of a year (note that only two lessons were on SSIs, and the others were on scientific issues).

Considering the norms of argumentation specific to SSIs, this result can be related to current knowledge regarding the appropriation of SSR skills: a short intervention (e.g., over 2 weeks) does not demonstrate statistically significant gains in these skills; a longer intervention (e.g., over a whole semester) seems to be necessary to produce significant effects (Zeidler et al., 2019).

Considering the generic norms of argumentation, the result of Osborne and colleagues' study was also consistent with the findings of numerous studies concerning students' argumentation in general: The effects of a single debate are very limited on the development of students' argumentation skills; significant effects could only be observed following sequences composed of a large number of debates (Crowell & Kuhn, 2014; Kuhn et al., 1997; Kuhn et al., 2013, 2016; Kuhn & Udell, 2003). For instance, over the course of 3 years, the frequency of students criticizing the opposing viewpoint increased slightly after a year of intervention and increased significantly only after 2 years of intervention (Crowell & Kuhn, 2014; Kuhn et al., 2016).

One way to explain these results is to stress that argumentation skills require a high intellectual level. Another explanation can be provided if we consider that argumentation is a social practice characterized by several norms. According to this perspective, it is in the practice of argumentation, in particular in a debate situation, that students can appropriate the norms of argumentation, whether they are generic or specific to SSIs. Students should have many opportunities to practice argumentation to internalize these norms and be able to apply them.

3.2 | A second teaching strategy: Reflective activities

Interventions based merely on participation in argumentation practice have a limitation. There is a risk that students will only appropriate those specific norms that they constructed in the context of classroom activities, that is, those shared with other students. This is suggested by a study that points to the tendency of students to reproduce other students' "argument stratagems" (Anderson et al., 2001). Therefore, it seems necessary to allow students to not only practice argumentation but also develop meta-cognitive knowledge about the norms of argumentation. In this sense, Grooms et al. (2018, p. 1283) argued that it is necessary "for classroom instruction to provide opportunities for students to not only learn from engaging in argumentation, but to also learn about argumentation."

In this regard, one teaching strategy that seems promising according to the literature is to provide students with reflective activities on argumentation, in which they are asked to discuss the norms of argumentation by evaluating their own argumentation productions. Within this frame, the teacher can introduce theoretical elements of argumentation at the point where it makes sense for the students. This way, they can guide the students toward the norms of argumentation.

Several studies have shown the positive impact of such reflective activities on students' argumentation on a variety of topics, from social to scientific (Felton, 2004; Iordanou, 2010; Iordanou & Constantinou, 2015; Iordanou & Rapanta, 2021; Kuhn et al., 2008; Shi, 2019). In Felton's (2004) study, reflective activities, combined with oral debate activities on a social topic (capital punishment), involved asking students aged 12–14 years to analyze their and opponents' arguments by identifying "reasons," "criticisms," and "defenses" on a worksheet that also

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included a short definition of each of these categories. The study shows that a series of five debates combined with reflective activities has a positive effect on the quality of students' argumentation on a transfer topic (abortion), which is not the case when debates are conducted without associated reflective activities.

The reflective activity in Iordanou's (2010) study was adapted from the one of Felton (2004): after a written debate, students aged 11–12 years had to fulfill two scaffold sheets asking them to identify the "main arguments" and "counterarguments" that they and their opponents had produced. The study showed that two sessions combining a debate and a reflective activity allow the development of students' argumentation skills and their transfer from a scientific topic (dinosaur extinction) to a social topic (home schooling), and vice versa.

Kuhn et al. (2008) examined the effects of a similar intervention involving three identical phases of thirteen 40-min sessions composed of written debates, each on a different social topic (the obligation to attend school, school expulsion, and teacher pay), and reflective activities based on the same scaffold sheets as mentioned above. This study showed, not only that students aged 11–12 years developed the quality of their argumentation, but also that this development is associated with a greater number of "meta-level statements" (e.g., "give us some reasons," "you need to give facts instead of opinion," "its the same argument except with some modifications"), indicating at least implicit understanding of generic norms of argumentation.

Iordanou and Constantinou (2015) extended this research by focusing on the use of evidence in argumentation. In their study, the intervention was composed of nineteen 1-hour sessions composed of a written debate on a scientific issue involving a social dimension (the causes of climate change) and a reflective activity asking students to reflect on the use of evidence in support of their own claims or against the opposing side's claims. The study conducted with students aged 15–16 years showed a positive impact of the intervention: in their argumentation, students used evidence more often, used more evidence to critique others' claims, and used more accurate evidence. Moreover, in their dialogues, meta-level talk about evidence became more frequent over the course of the intervention, indicating a growing awareness of the importance of evidence. As evidence is a type of justification, this result suggests that the intervention contributes to the appropriation of the justification norm.

Another study focused on evidence was performed by Shi (2019) with 11- to 12-year-old students. In this study, the intervention involved thirty 40-min class sessions composed of a written debate first on a social topic (the part-time job of teenagers over 16), then on two successive SSIs (the testing of new medical products on animals; the legalization of the sale of kidneys). During the debates, one group of students had to complete two scaffold sheets to identify and reflect on the opponents' main argument, and reflect on their own side's main argument. Another group of students participated in the debates without this reflective activity. With respect to the use of evidence congruent or incongruent with a claim, the gains were significantly better for the students experiencing the reflective activity. This study, therefore, highlights the specific contribution of reflective activities in fostering students' appropriation of the justification norm. This was confirmed by a recent study reported by Iordanou and Rapanta (2021) showing that an intervention combining debates with reflective activities was more efficient in the development of students' argumentation skills than an intervention involving only debates.

In light of these studies, it appears that reflective activities can promote the integration of generic norms of argumentation and the ability of students to remobilize them in new contexts of argumentation practice. However, as far as we know, no studies have evaluated the impact of reflective activities on the appropriation of the argumentation norms specific to SSIs.

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We assume that such meta-cognitive activities would help students become aware of the quality of their argumentation, allow them to identify and integrate not only the generic norms of argumentation but also those specific to SSIs, and thereby foster the appropriation of these two types of norms.

3.3 | Computer-mediated debates

A complementary way to increase the effects of an intervention aiming to develop the quality of students' argumentation on SSIs is to undertake debates in the classroom by using computers and a debate software program. As a matter of fact, several studies mentioned above (Iordanou, 2010; Iordanou & Constantinou, 2015; Kuhn et al., 2008, 2016; Morin et al., 2014; Shi, 2019) made use of computer-mediated debates, motivated by the multiple advantages they have over oral debates (Asterhan & Eisenmann, 2011; Clark et al., 2007; Clark & Sampson, 2008; Guiller et al., 2008; Kuhn et al., 2008). On the one hand, these advantages concern the social aspects of communication and, on the other hand, the cognitive aspects of argumentation production. Regarding the social aspects of communication, computer-mediated debates can partially overcome the psychosocial barriers associated with face-to-face communication, that is, difficulties in public speaking, the need to respond immediately, and competition in speaking. Several studies have shown that in computer mediated debates, students are less inhibited and more willing to express their viewpoints, they do not need to compete for the right to speak, and they can post contributions simultaneously, which often leads to increased and more equal participation (for a review on these aspects, see Asterhan & Eisenmann, 2011). There is a distinction to be made between asynchronous debates, in which students participate remotely at home, and synchronous debates, which are located in the classroom and in which students participate simultaneously. Synchronous classroom debates are likely to avoid some of the drawbacks of distributed, anonymous debate environments for educational purposes, such as flaming and lack of accountability for the content being debated. In the case of synchronous debates, teachers are physically present so that they can sustain engagement, monitor and support the functioning of the group, and provide individual assistance when needed (see Asterhan & Eisenmann, 2011).

Regarding the cognitive aspects of argumentation production, computer-mediated debates involve collective argumentation being developed in written form, which allows students to have more time to analyze in details others' arguments, look for information (e.g., on the Internet, in students' notebooks, or in specific knowledge bases), and this may be used to assess other's claims and justifications, and build their own arguments (Clark et al., 2007; Guiller et al., 2008; Lin et al., 2012). In addition, they have the advantage of providing an immediately available record of the arguments on which participants can reflect, unlike in real-time oral debates. Thereby, they offer support for the development of a meta-level awareness concerning the argumentation produced (Iordanou, 2010). It is possible to further stimulate this meta-level awareness through specific software scaffolding. For example, *Digalo* (Kochan, 2006) and *Agora-net* (Hoffmann & Lingle, 2015) present students' arguments on a map and ask them to choose the function of their contribution among a set of predefined functions (e.g., if it counters or supports another student's claim), or its structure among a set of predefined structures (e.g., modus ponens or modus tollens). These software programs promote students' reflection on argumentation (Schwarz & Baker, 2017). However, their shortcoming is that they limit the number of possible argumentation structures, in contrast to the richness of argumentation in

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usual unguided contexts (De Checchi, 2021, pp. 166–117; Walton, 1996). Other software is less constraining from this point of view (e.g., instant messaging). Whatever the degree of scaffolding during the debate, the written argumentation developed by the students is recorded and thus available to allow them to analyze their arguments after the debate has taken place (Kuhn et al., 2008). In other words, computer-mediated debates offer a very convenient way to perform reflective activities on the arguments produced by students. Therefore, they make it possible to combine the two strategies described above to develop their argumentation on SSIs.

4 | RATIONALE OF THE STUDY AND RESEARCH QUESTIONS

The above literature review on teaching strategies for developing students' argumentation on SSIs points to an existing gap in research. On the one hand, many studies have investigated the effects of oral and written debates on SSIs, on the other, several studies have examined the effects of the combination of debates with reflective activities about the generic norms of argumentation. However, to the best of our knowledge, no studies have been conducted on the effects on the quality of students' argumentation on SSIs by combining debates on SSIs with reflective activities about the argumentation norms specific to SSIs. The present study aimed to fill this research gap by examining the impact of this strategy on students' argumentation of SSIs. We selected computer-mediated debates because of their advantages with respect to the fostering of quality argumentation and the implementation of reflective activities. More precisely, we designed and tested a sequence composed of four teaching units spread over 2 years, each combining a computer-mediated debate on an SSI and a reflective activity. The computer-mediated debates involved students interacting and developing their arguments in writing. These debates were performed synchronously in the classroom. The four reflective activities followed a progression that allowed for the discussion of the generic norms of argumentation (i.e., justification, others, and questioning norms) as well as the norms specific to SSIs (i.e., complexity, uncertainties, and open-endedness norms). Central to this study was to investigate the evolution of students' written argumentation on SSIs during this teaching sequence. Given the diversity of students' profiles with respect to argumentation, one may wonder whether their argumentation evolves in different ways. To be able to understand these changes, it is important to determine the quality of students' argumentation that the synchronous computer-mediated debates made possible, that is, to assess the extent to which the norms of argumentation on SSIs, both generic and specific, are being met. Moreover, to assess the depth of learning associated with these changes, it is also worthwhile to determine whether there is a transfer to the context of individual written argumentation, and whether students become more aware of the norms specific to SSIs in this context. Consequently, we can frame a preliminary research question RQ1, before the central question RQ2, and two deepening questions RQ3 and RQ4 as follows:

- RQ1: What is the quality of students' argumentation on SSIs that a synchronously written debate affords?
- RQ2: How does the quality of students' argumentation on SSIs change over the course of a sequence combining several synchronous written debates and reflective activities addressing different norms of argumentation on SSIs?

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- RQ3: To what extent is students' appropriation of the norms of argumentation on SSIs during this sequence transferred to the context of individual writing?
- RQ4: How does students' awareness of the norms specific to SSIs evolve over the course of the sequence?

5 | METHOD

5.1 | Participants

The teaching sequence was tested in two classes, A and B, of two different high schools, one located in the center of a city of 275,000 inhabitants, and the other in a town of 8500 in the middle of a rural area. Both high schools welcome pupils from various socioeconomic backgrounds. The first two units of instruction were conducted in classes A and B when the students were in Grade 11 (16–17 years old) and the next two when the students were in Grade 12 (17–18 years old). The teachers described the overall academic level of the students in both classes as medium. Prior to the intervention, students had no specific training about the structure and process of argumentation, or about the debate software used in the sequence, that they were able to master within a short time. As class A had more than 30 students, the debates were organized with two subgroups each time, which was not the case in class B as its size was smaller. Class sizes changed from the first year to the second, and some students were absent from some of the debates on SSIs. Table 2 provides the number of students present at the different debates. A total of 64 students participated in the experiment, of which 34 were present in all four debates.

5.2 | Design of the teaching sequence

The teaching sequence was elaborated using a method of "design experiment" (Cobb et al., 2003; DiSessa & Cobb, 2004; Sandoval, 2013), that is, by means of a collaborative and iterative work involving a team of both researchers and teachers. Being "collaborative," this method allows for building a meaningful sequence for teachers that is not too far from their usual practices and is compatible with the constraints of the school environment. The method is also "iterative" in that it consists of several loops of implementation and assessment, enabling improvement of the teaching sequence. Prior to the present study, this sequence was the subject of two loops of experimentation over 2 years involving a total of 21 classes. With several adjustments, this sequence was then implemented in classes A and B. For class A, the team consisted of four researchers and three teachers of biology, history and geography, and philosophy. For class B, the team consisted of the same four researchers and three other teachers of physics and chemistry, history and geography, and philosophy. The teachers all had many years of teaching experience (>10 years). All of them were well aware of the objectives regarding the development of students' argumentation skills that are explicitly included in the official instructions of their discipline. For the purpose of this study, they took part in several working sessions, including two training sessions and four sessions devoted to the co-construction of the units of the teaching sequence. During the training sessions, key knowledge was introduced about argumentation, student learning of argumentation, and the norms of argumentation specific to SSIs. The philosophy teachers could share their expertise concerning the teaching of argumentation

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TABLE 2 The number of students participating in each synchronously written debate of the sequence

Year	Debate	Class and group	Number of students	Total number of students
Year 1	Debate 1	Class A, group 1	17	54
		Class A, group 2	17	
		Class B (whole class)	20	
	Debate 2	Class A, group 1	18	50
		Class A, group 2	15	
		Class B (whole class)	17	
Year 2	Debate 3	Class A, group 1	14	46
		Class A, group 2	14	
		Class B (whole class)	18	
	Debate 4	Class A, group 1	11	46
		Class A, group 2	12	
		Class B (whole class)	23	

that lies at the core of their discipline. These sessions were then used to discuss with teachers how best to intervene in debates to promote quality argumentation. All of them had the opportunity to implement computer-mediated debates in their classes in the year prior to the sequence being studied. During the co-construction of the teaching units, the teachers chose the SSIs to study with their students in their classes so as to fit with the curriculum of their respective discipline, selected the texts used as a starting point for the debates, and discussed with the researchers the details of the various activities of the sequence.

This sequence took place over 2 years and was composed of four teaching units (Table 3). Each teaching unit had three phases: a preparatory phase on contents (one to three sessions), a phase of debate on an SSI (one session), and a phase with a reflective activity (one session). Each of the teaching units focused on a different SSI. In the first year, since the teachers of the two classes were not from the same discipline, different SSIs were chosen by the teachers to fit their respective curricula: hydrocarbon exploration and glyphosate in Class A; GMO crops and armed drones in Class B. In the second year, the teachers of both classes were from the same discipline so that the same SSIs could be chosen: environmental performance and animal farming. The sequence was composed of a limited number of teaching units—and thus a limited number of debates, reflective activities, and SSIs addressed—so that it could be compatible with the actual constraints of the curriculum and could be replicated under ecological conditions outside the scope of this study.

In the preparatory phase, teachers were asked to introduce a set of contents on a topic related to the SSI being debated. The topic studied in this phase (e.g., scientific and technological advances for agriculture and their impact on the environment and health) was broader than the debated SSI (GMO crops). The goal was for students to acquire knowledge that could be called upon during the debate to ensure a minimum argumentation quality (Baytelman et al., 2020; Grooms et al., 2018; Sadler & Fowler, 2006). With this goal in mind, teachers were free to conduct the sessions in this phase based on their usual teaching practices and consistent with the national curriculum. This freedom was given to the teachers so that they could appropriate the sequence and that it could be reproduced in the future under ecological conditions

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TABLE 3 Detailed content of the implemented teaching sequence

Year and unit	Class	Preparatory phase topic being studied (Discipline of the teacher carrying out the unit)	Synchronously written debate debated SSI (Title of the paper taken as a starting point/Source)	Reflective activity features of argumentation being discussed in relation to the generic norms and the norms specific to SSIs (in italics)
Year 1 Unit 1	Class A	Plate tectonics and hydrocarbon research (Biology and Geology)	Hydrocarbon exploration (Total authorized to drill in French Guiana/ Les Echos, 2018)	• A claim needs to be justified to become an argument (justification-norm). • *The arguments on an SSI may concern different aspects (complexity-norm).*
	Class B	Scientific and technological advances for agriculture and their impact on the environment and health (Physics and Chemistry)	GMO crops (Bt GMOs are organic!/ Mediapart, 2019)	
Year 1 Unit 2	Class A	Agriculture to feed humanity: crop production agrosystem and glyphosate (Biology and Geology)	Use of glyphosate in crops (Emmanuel Macron renounces his promise to ban glyphosate in 2021/Le Monde, 2019)	• Taking into account what others say makes a debate more constructive (others-norm). • *Different viewpoints may be supported on an SSI (open-endedness-norm).*
	Class B	The French presence in the world (diplomatic, military, etc.) and its limits (History and Geography)	Armed drones (France enters the era of armed drones/Le Monde, 2019)	
Year 2 Unit 3	Classes A and B	Impact of globalization on the environment (History and Geography)	Environmental performance of countries (Environment: France is the second most efficient country in the world/Les Echos, 2018)	• Questioning one's own and others' ideas allows being more critical in evaluating and producing arguments (questioning-norm). • *Taking into account the uncertainties associated with an SSI allows being more critical in evaluating and producing arguments on SSIs (uncertainties-norm).*

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TABLE 3 (Continued)

Year and unit	Class	Preparatory phase topic being studied (Discipline of the teacher carrying out the unit)	Synchronously written debate debated SSI (Title of the paper taken as a starting point/Source)	Reflective activity features of argumentation being discussed in relation to the generic norms and the norms specific to SSIs (in italics)
Year 2 Unit 4	Classes A and B	Philosophical and ethical issues concerning technology in our societies (Philosophy)	Animal farming (The dark side of those who denounce porthole cows and animal husbandry/Huffington Post, 2019)	• A claim may be justified by values or a value system (justification-norm). • *Different viewpoints on an SSI may be supported due to different values or value systems (open-endedness-norm)*

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without the control of the researchers. Since the teachers were from different disciplines, each topic was approached from a different perspective, depending on the knowledge and epistemology specific to each discipline. It should be stressed that no explicit discussion on the structure and process of argumentation was carried out in this phase. In other words, this phase was intended to prepare students on the contents that could be used in the debate to follow, but not on how to argue with those contents.

The debates were computer-mediated and took place synchronously in the classrooms with all students present (either in half groups or with the whole class; Table 2). They were computer-mediated to benefit from the several advantages that this type of debate has over oral debates (Asterhan & Eisenmann, 2011; Clark et al., 2007; Clark & Sampson, 2008; Guiller et al., 2008; Kuhn et al., 2008). As stressed above, such debates can partly overcome the psychosocial barriers associated with face-to-face situations and promote the simultaneous participation of all students in a class. They also give students more time to analyze other people's arguments, look for information, and build their arguments. Finally, the software makes it very easy to keep a written record of the exchanges, which makes it simpler for teachers to prepare a reflective activity on the students' argumentation. With the software used in this study (developed with a team of computer scientists and interface designers in the frame of our research project entitled "AREN"), the starting point of the debate is not a predefined question but a text chosen by the teacher. Throughout the debate, this text remains on the left half of the software interface (Figure S1). The students' contributions appear on the right half of the same interface. To make a new contribution, students have first to select an extract of the text or an extract of another student's contribution. A pop-up window appears and students have to indicate their position with the help of a button (by choosing between "rather agree," "rather disagree," or "not understood"), reformulate the selected extract in their own words, and then write their argument(s) to support their position in a separate space. The new contribution appears on the right side of the text. When it is a reaction to another student's contribution, it appears after the latter with a slight indentation to reflect the concatenation (as shown in the example in Figure S1). When it is a reaction to the text, the new contribution appears below all other contributions without indentation. It follows that the structure of the successive contributions is not linear but characterized by multiple ramifications. Taking a text as a starting point allows, on the one hand, to show students the initial arguments on the SSI that can act as a model for quality argumentation, and on the other hand, to not impose a question to be debated and to leave it up to the students to frame questions that make sense to them, which can foster problematization (Orange, 2003; Schwarz & Baker, 2017, p. 185). In our study, all the texts used were from newspaper articles. During the first two iterations of the implementation of the sequence based on the use of this software, the results showed that the students started from several excerpts of the text to raise a multiplicity of questions (Pallarès et al., 2020). Furthermore, before the debate began, teachers instructed students to debate collaboratively to better understand the SSI. Such an instruction tends to promote quality argumentation (Asterhan & Schwarz, 2016; González-Howard & McNeill, 2019). During the debates, teacher interventions consisted solely of "scaffolding" students' argumentation by encouraging them to justify and further elaborate on their ideas (Schwarz & Baker, 2017, p. 190; Webb et al., 2009). The indicative duration of the debates was 1 h with some variation depending on the time taken by students to log into the software and to read and understand the text.

A reflective activity was performed in another session following each debate. The four reflective activities were designed in a progression to discuss the generic norms of argumentation and the specific norms of argumentation on SSIs: justifying a claim and the complexity of

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SSIs, taking into account others' ideas and the open-endedness of SSIs, questioning ideas and the uncertainties associated with SSIs, and the role of values and the open-endedness of SSIs (see the details in Table 3). During each reflective activity, the teacher began with a discussion with all the students to raise questions about an aspect of argumentation (e.g., "What makes a contribution in a debate relevant?"), highlighted an important point with them (e.g., the need to justify a claim for it to be an argument), and asked them to work in small groups on this point by analyzing some of their own arguments previously selected by the teacher and printed on sheets of paper (e.g., they had to determine whether the claims were justified and propose a criterion for a justified claim). In this activity, students were asked to work collaboratively, making their analyses of the arguments explicit, and comparing and discussing them. They interacted orally, that is, without using the software, and wrote their proposals on sheets of paper.

5.3 | Data collection

The study of the effects of the sequence is based on two types of data (Figure 1). The main data are the students' contributions during the debates. These were posted on the software and, therefore, could be collected automatically. These data allow us to study the quality of students' argumentation on SSIs in a "dialogal" situation (Bres et al., 2016), namely in a debate, and its evolution during the sequence. In addition, we administered a series of four tests throughout the sequence during each of the four teaching units, following the preparatory phase before the debate.

Each test consisted of three questions (Q1, Q2, and Q3) and students were asked to answer these on a piece of paper. The objective of Q1 was to study the possible impact of the sequence on students' argumentation in a "monologal" situation (Bres et al., 2016), namely in an individual writing. In this question, a statement about an SSI related to the topic of the debate was formulated (Table 4), and students were asked to express their degree of agreement or disagreement on a five-point Likert scale and argue to justify their answer. Q2 and Q3 were designed to assess the degree of students' awareness of the argumentation norms specific to SSIs, by checking, for each SSI, whether they explicitly refer to its complexity and associated uncertainties, and whether they acknowledge its open-ended nature: "Can anyone have another acceptable opinion on this topic, and why?" (Q2) and "Can anyone be certain about this topic, and why?" (Q3). Students were given an average of 30 min to answer Q1, Q2, and Q3.

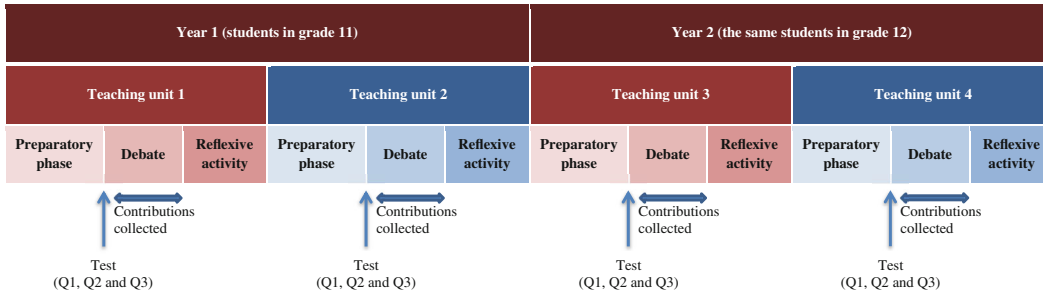

FIGURE 1 The stages of data collection during the sequence

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TABLE 4 The statements submitted to the students in Q1

		Statements submitted in Q1 Students were asked to take a position on the following statements and argue
Year 1 Unit 1	Class A	New hydrocarbon drilling should continue to ensure an efficient functioning of our society.
	Class B	GMO crops should be favored because they produce more and are less expensive.
Year 1 Unit 2	Class A	Phytosanitary products should still be used in agriculture to ensure sufficient productivity and to feed 9 billion people by 2050.
	Class B	Since we are not a country at war, we do not need to develop French weapons technology.
Year 2 Unit 3	Classes A and B	To protect the environment, pollution linked to globalization, in particular, to the free trade of goods, information sharing, and the free movement of people between countries, must be drastically reduced.
Year 2 Unit 4	Classes A and B	We should not put animal well-being on the same level as human well-being.

5.4 | Data analysis

The quality of students' argumentation developed in the frame of the computer-mediated debates has been evaluated in terms of the generic and specific norms of argumentation on SSIs. We first present the analysis method for the three generic norms—others, justification, and questioning—then for the three norms specific to SSIs—complexity, uncertainties, and open-endedness.

To determine how well students fulfilled the others norm in the debates, we analyzed each student contribution (i.e., each post made on the interface of the debate software) by identifying the argumentative moves it contains. Argumentative moves are defined in this study as statements that take into account the arguments of others, develop or criticize them (Section 2.1). In each contribution to the debate, there could be zero, one or more argumentative moves. The following argumentative moves were distinguished: development of a claim or its justification (Dev), rebuttal of a claim (ReC), rebuttal of the justification of a claim (ReJ), nuance of a claim or its justification (Nu), concession (Conc), and questioning of a claim or its justification (Quest; see details in Table 5). It should be noted that when a student develops a claim or justification expressed by another student, it is a claim or justification with which she/he agrees. According to several authors (Crowell & Kuhn, 2014; Kuhn et al., 2016; Kuhn & Udell, 2003), such an argumentative move can be considered less cognitively demanding than that criticizing other's claim and justification or qualifying one's own claim and justification. The rate of the different types of argumentative moves per contribution in each debate allowed us to measure the extent to which the others norm was met.

Regarding the justification norm, we considered each argumentative move produced by students and assessed whether it was justified or not. As stressed above (Section 2.2), in the context of a debate on an SSI, various types of justification are appropriate. In our analysis, the following were taken into account: empirical data, scientific knowledge, common sense knowledge,

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TABLE 5 The argumentative moves used to analyze students' contributions during the synchronously written debates

Argumentative move	Description	Translated statements produced by students in the frame of the synchronously written debates
Development of a claim or its justification (Dev)	Statement(s) completing or extending others' claims or its justification	*Debate on GMO crops* *Claim*: "Insect-resistant GMOs make it possible to reduce the overall use of insecticides." *Development of this claim*: "Yes, I agree that GMOs reduce the use of insecticides because some GMO plants produce a Bt protein resistant to insects, which can reduce the consumption of insecticides but not eliminate its use."
Rebuttal of a claim (ReC)	Statement(s) opposed to others' claim	*Debate on the environmental performance of countries* *Claim*: "Wealth is a major determinant of the success of environmental policies." *Rebuttal of this claim*: "The United States and Canada are extremely rich countries but that does not prevent them from not prioritizing the environment and the exit of the United States from the Paris Agreement on climate change is proof of this."
Rebuttal of the justification of a claim (ReJ)	Statement(s) opposed to the justification of others' claim	*Debate on animal farming* *Claim*: "[The] practice of [porthole cows] is nothing new." *Justification of this claim*: "It is part of the whole experimental arsenal of animal productions." *Rebuttal of the justification of this claim*: "I think we really need to stop conducting experiments on animals for the purpose of making more money, trying to find false solutions. The killing and suffering of animals must stop."
Nuance of a claim or its justification (Nu)	Statement(s) qualifying others' claim or its justification	*Debate on armed drones* *Claim*: "If someone decides to go to war against France, we have to be ready in terms of weapons." *Nuance of this claim*: "Okay, but so much money? Millions of Euros, that is a lot of money, is it not? We could spend less and use it instead for things that might be more useful at the moment ..."
Concession (Conc)	Statement(s) implying the full or partial acceptance of others' claim or its	*Debate on hydrocarbon exploration* *Claim*: "But, have you thought about the environment?"

(Continues)

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TABLE 5 (Continued)

Argumentative move	Description	Translated statements produced by students in the frame of the synchronously written debates
	justification, and qualifying our own claim or its justification	*Statement containing a concession of this claim*: "The environment remains a problem as with all the resources exploited in the world. However, resources are still exploited in the world and allow man to enrich themselves. It certainly degrades the environment but I do not see why Guyana should not benefit from the resources present on its territory as the other territories do."
Questioning of a claim or its justification (Quest)	Question(s) concerning a claim or its justification demanding clarification or suggesting a possible criticism	*Debate on the use of glyphosate in crops* *Claim*: "A gardener developed skin cancer because he used glyphosate every day." *Questioning of this claim*: "What percentage of the population gets diseases that are thought to be caused by the use of glyphosate?"

reference to a publication, reference to a law, compliance with values, or a value system. The extent to which the justification norm was satisfied in each debate could be measured by the rate of argumentative moves that were justified.

With respect to the questioning norm, the method was more straightforward. To assess how well students fulfilled this norm in each debate, we calculated the rate of the corresponding argumentative move (i.e., questioning) per contribution.

Regarding the complexity norm, we identified the aspects of the SSI that were addressed in each contribution. The eight following aspects of an SSI were distinguished: scientific, technical, environmental, sanitary, social, economic, political, and axiological. To measure the degree to which the complexity norm was satisfied in each debate, we determined the rate of occurrence of each aspect per contribution.

Three different categories were used concerning the uncertainty norm: domain of validity and qualifiers (DV-qual), uncertainties concerning knowledge (UncertK), and uncertainties concerning future evolutions (UncertE). A single but broader category was used with respect to the open-endedness norm. This category includes the consideration of viewpoints, values, system of values, and interests of stakeholders of the SSI (Stak). The rate of occurrence of each of these categories per contribution was calculated to measure the extent to which the uncertainty and open-endedness norms were met in each debate.

Detailed descriptions of the categories related to the three specific norms of argumentation on SSIs as well as examples are given in Table 6. Note that all these categories are not mutually exclusive so that multiple categories could be identified in the same contribution.

As for the assessment of the quality of argumentation produced by the students in monologal situations in their answers to Q1, we considered the number of justifications to determine the appropriation of the justification norm. This monologal situation however was not suited to determine students' appropriation of the others and the questioning norms.

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TABLE 6 Categories relative to the specific norms of argumentation on SSIs used to analyze students' contributions during the synchronously written debates, with examples of contributions

Specific norm	Category	Description	Translated statements produced by students in the frame of the synchronously written debates
Complexity	Possible aspects of an SSI: Scientific (Sci) Technical (Tech) Environmental (Env) Sanitary (Sani) Social (Soc) Economic (Eco) Political (Poli) Axiological (Axio)	Statement(s) falling under one or more of these aspects	*Debate on the use of glyphosate in crops* "I think that its use should at least be reduced; it should not be used intensively *[Technical]* and farmers should consider a transition to a more reasoned agriculture to preserve the environment *[Environmental]* even if its use saves time and money *[Economic]*. However, given the difficulty of the farming profession today, it would seem difficult to stop the use of pesticides such as glyphosate, although I do not think that this would necessarily lead to unemployment among our farmers *[Social]*."
Uncertainties	Domain of validity and qualifier (DV-qual)	Statement(s) mentioning the domain of validity of an idea and/or qualifying this idea	*Debate on hydrocarbon exploration* "We may, despite their word, have doubts about their honesty because there is no evidence to the claims that they minimize accidents and that this is not detrimental to the environment despite what Total says, *perhaps [qualifier]* blinded by the money it will bring them."
	Uncertainties concerning knowledge (UncertK)	Statement(s) mentioning the uncertainties concerning knowledge (due to its tentativeness or insufficient investigation)	*Debate on GMO crops* "I find that GMOs are potentially a good solution to avoid polluting the earth, but the problem is that we do not know what their repercussions are on man and the planet in the long term."
	Uncertainties concerning future evolutions (UncertE)	Statement(s) mentioning the uncertainties concerning future	*Debate on armed drones*

(Continues)

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TABLE 6 (Continued)

Specific norm	Category	Description	Translated statements produced by students in the frame of the synchronously written debates
		evolutions in the world (at the level of human societies, technologies, the environment, etc.)	"Many things can prevent the plans of the army and the government from being realized; for example, funding problems, a change of government, and so on. Nothing is certain."
Open-endedness	Viewpoints, values, system of values, and/or interests of the stakeholders (Stake)	Statement(s) mentioning viewpoints, values, system of values, and/or interests of stakeholders	*Debate on animal farming* "Animal products from small producers would obviously be much more expensive so that they get fair wages; this is not necessarily what consumers are looking for, as they are used to paying less and less."

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Regarding the three specific norms of argumentation on SSIs, their appropriation was analyzed according to the same categories as for the contributions during debates. Finally, students' awareness of these specific norms in their responses to Q2 and Q3 was studied using the categories presented in Table 7.

The set of analysis categories evolved and was refined over the three iterations of the research project. For each category, a subset of the data was coded by two researchers; the calculation of the inter-rater agreement made it possible to adjust the coding and ensure its reliability. The agreement rate was greater than 0.85 for all categories. Cohen's Kappa was very good for all categories (>0.6), with three exceptions: it was good for Just (0.54) and moderate for ReC (0.38) and ReJ (0.49)—two types of rebuttal that were sometimes difficult to distinguish, but were identified in a very satisfactory manner when taken together (0.68).

6 | FINDINGS

6.1 | Argumentation quality on SSIs afforded by the synchronously written debates (RQ1)

We present the overall results for classes A and B. In total, the students produced 1102 contributions over the four synchronous written debates. The average number of contributions per student per debate was 5.62. On average, each contribution contained 1.35 argumentative moves. Each debate was composed of a set of chains of contributions that develop in parallel and generally branch out. This branching can be explained by the fact that the software allows students to intervene freely by reacting to the idea of their choice that was expressed during the debate. We notice that these chains of contributions do not have a single, but multiple starting points, which correspond to different passages of the text freely chosen by the students. For example, in the debate on GMO crops, the students reacted to 15 different passages of the same text. In each of the branches, the students responded to each other by making contributions containing various argumentative moves, which reflect a clearly dialogical process. The following excerpt shows a sequence of three contributions that successively answer each other on the subject of hydrocarbon drilling (the coding is indicated in square brackets):

> Student A: This collaboration between Total and the French Guyana community completely disregards the environmental problems that these drillings will cause. It is surprising that the French Guyana community agrees with the major company Total, because we should not just think about the economic benefits [justified rebuttal of a former claim].
>
> Student B: I support this idea [unjustified concession] but Guyana, being a very weak country, preferred to bring in money because Total shares half of its profits with the Guyanese community, which would make the protection of its forests easier [justified nuance].
>
> Student A: Yes, of course, this money could be beneficial for the environment [justified concession]; but, it is not worthy if it is to the detriment of the seabed. It is better not to damage the ocean even if it would protect (which is not guaranteed)

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TABLE 7 Categories relative to the specific norms of argumentation on SSIs used to analyze students' answers to Q2 and Q3, with examples of answers

Specific norm	Category	Description	Translated excerpts of students' answers to Q2 and Q3
Complexity	Complexity of the SSI (Complex)	Answer with an explicit reference to various aspects of the SSI under consideration	*SSI related to hydrocarbon exploration* "Some may think that it is a way to get rich and make society evolve. Some may think that drilling for hydrocarbons can degrade areas of the planet and make them inaccessible."
Uncertainties	Uncertainties concerning knowledge (UncertK)	Answer with an explicit reference to the uncertainties concerning knowledge (due to its tentativeness or insufficient investigation)	*SSI related to phytosanitary products* "Studies on the subject can be contradictory. We have the example of glyphosate characterized as carcinogenic by ECHA and noncarcinogenic by WHO."
	Uncertainties concerning future evolutions (UncertE)	Statement(s) mentioning the uncertainties concerning future evolutions in the world (at the level of human societies, technologies, the environment, etc.)	*SSI related to globalization and pollution* "Globalization causes pollution, but it is not the only cause, and there is no way of knowing whether limiting trade would preserve the environment."
Open-endedness	Other acceptable viewpoints (Acc)	Answer admitting that another viewpoint is acceptable on the SSI under consideration.	*SSI related to weapons technology* "I have a definite opinion on this subject; however, everyone can have their own opinions because ..."

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> the Guyanese forests; it is better to do nothing than to destroy an ecosystem to protect another one... [justified nuance].

With some exceptions, several minutes elapsed between the two successive contributions. For example, in the debate on GMO crops, this time is 9.8 min on average (SD = 6.4). This means that the students took time to read what others had written, construct their own contributions, and justify their ideas. We observed a rate of 0.67 of justified argumentative moves. Some students also looked for additional information on the Internet, which they integrated into their contributions by mentioning their sources. For example, in the debate on glyphosate, one student wrote as follows:

> Student C: Indeed [unjustified concession] but, according to this article, pesticides would cause nearly 200,000 deaths per year. The State only thinks about its development and not about the society (https://www.agriculture-environnement.fr/2018/02/27/pesticides-causeraient-200000-morts-dans-monde-baliverne-18) [justified nuance].

The six argumentative moves of our analysis grid were all present in significant proportions in each debate, with an average rate per contribution ranging from 0.09 (for questioning) to 0.37 (for development). The students also frequently produced argumentative moves that can be considered more demanding from a cognitive point of view, such as the rebuttal of a justification or the nuance of a claim, whose rate per contribution was 0.15 and 0.23, respectively. Table 8 presents the details regarding the rate of each argumentative move in each debate.

Consider now the items related to SSIs. Regarding complexity, consideration of each of the eight possible aspects of an SSI distinguished in our analysis grid is meaningful in each of the debates (rate of 0.14–0.35 per contribution), as much its scientific and technical aspects as its social, economic, or political aspects. Differences appeared according to the debates, sometimes quite marked. Thus, the environmental aspect was very well represented (rate of 0.69 per contribution) in debate 3 (on the environmental performance of countries), and the axiological aspect (0.55) in debate 4 (on animal farming). Table 9 presents the details of the results.

The different aspects of an SSI were addressed in parallel chains of contributions, but they were also interconnected within the same chain, between successive contributions, and within the same contribution. These two types of connections between the aspects of an SSI are illustrated in the following exchange that occurred during the discussion on the environmental performance of countries:

> Student G: Globalization has, in my opinion, a multitude of beneficial effects on the world, despite the dangers it has on the environment in particular [Environmental]. Globalization allows different countries and individuals to be linked throughout the world [Political & Social] to maintain both commercial [Economic] and social relations [Social]. It also allows individuals to be freer, especially in their movement [Social].

> Student H: I disagree, because globalization also creates inequalities: the poorest countries rely on the richest countries to buy their products from them and if the latter no longer needed these products, the economy of the former would collapse [Political & Economic]. Moreover, many transnational firms relocate to be able to employ a workforce from a less advanced country, which will cost less [Economic & Social].

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TABLE 8 Argumentative moves produced by all students during the synchronously written debates

Category		Debate 1	Debate 2	Debate 3	Debate 4	Totals or means
Number of students (Classes A and B)		54	50	46	46	–
Contributions	Number	409	292	208	193	1102
	Per student and debate	7.57	5.84	4.52	4.20	5.62
Dev	Number	146	94	97	76	413
	Per contribution	0.36	0.32	0.47	0.39	0.37
	Rate with a justification	0.69	0.80	0.76	0.80	0.75
ReC	Number	71	41	12	28	152
	Per contribution	0.17	0.14	0.06	0.15	0.14
	Rate with a justification	0.83	0.78	1	0.93	0.85
ReJ	Number	61	55	14	37	167
	Per contribution	0.15	0.19	0.07	0.19	0.15
	Rate with a justification	0.79	0.93	0.93	0.95	0.88
Nu	Number	78	77	59	41	255
	Per contribution	0.19	0.26	0.28	0.21	0.23
	Rate with a justification	0.74	0.69	0.85	0.78	0.76
Conc	Number	54	55	27	24	160
	Per contribution	0.13	0.19	0.13	0.12	0.15
	Rate with a justification	0.33	0.20	0.41	0.33	0.30
Quest	Number	37	23	17	26	103
	Per contribution	0.09	0.08	0.08	0.13	0.09
	Rate with a justification	0.41	0.43	0.76	0.69	0.54
Sum of argumentative moves	Number	515	404	278	294	1491
	Per contribution	1.26	1.38	1.34	1.52	1.35
	Rate with a justification	0.65	0.65	0.71	0.70	0.67

Abbreviations: Conc, concession; Dev, development of a claim or its justification; Nu, nuance of a claim or its justification; Quest, questioning of a claim or its justification; ReC, rebuttal of a claim; ReJ, rebuttal of the justification of a claim.

In general, in each of their contributions, students do not limit themselves to considering only one aspect of the SSI but connect several aspects, with an average of 2.05 aspects per contribution.

The results for the three items related to uncertainties were found to be contrasted: there was a rate of 0.32 for domains of validity and qualifiers per contribution compared to only 0.03 for uncertainties concerning both knowledge and future evolutions. While the occurrence of domains of validity and qualifiers was quite constant in the four debates, the occurrence of uncertainties concerning knowledge and future evolutions appeared to be more dependent on the SSI being debated. For example, students underlined several types of uncertainties related to the knowledge about the impact of Bt GMOs or glyphosate on the environment.

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TABLE 9 SSI items in the contributions of all students during the synchronously written debates

Specific norm	Category		Debate 1	Debate 2	Debate 3	Debate 4	Totals or means
Complexity	Sci	Number	68	70	42	40	220
		Per contribution	0.17	0.24	0.20	0.21	0.20
	Tech	Number	136	133	34	88	391
		Per contribution	0.33	0.46	0.16	0.46	0.35
	Env	Number	37	37	144	10	228
		Per contribution	0.09	0.13	0.69	0.05	0.21
	Sani	Number	20	110	11	9	150
		Per contribution	0.05	0.38	0.05	0.05	0.14
	Soc	Number	71	56	47	102	276
		Per contribution	0.17	0.19	0.23	0.53	0.25
	Eco	Number	113	45	84	41	283
		Per contribution	0.28	0.15	0.40	0.21	0.26
	Poli	Number	107	82	110	19	318
		Per contribution	0.26	0.28	0.53	0.10	0.29
	Axio	Number	51	43	21	107	222
		Per contribution	0.12	0.15	0.10	0.55	0.20
	All aspects	Number	729	573	545	413	2260
		Per contribution	1.78	1.96	2.62	2.14	2.05
Uncertainties	DV-qual	Number	126	100	60	70	356
		Per contribution	0.31	0.34	0.29	0.36	0.32
	UncertK	Number	20	8	0	0	28
		Per contribution	0.05	0.03	0.00	0.00	0.03
	UncertE	Number	8	10	5	0	23
		Per contribution	0.02	0.03	0.02	0.00	0.03
Open-endedness	Stake	Number	2	2	1	4	9
		Per contribution	0.00	0.01	0.00	0.02	0.01

Abbreviations: Axio, axiological; DV-qual, the domain of validity and qualifier; Eco, economic; Env, environmental; Poli, political; Sani, sanitary; Sci, scientific; Soc, social; Stake, viewpoints, values, system of values, and/or interests of the stakeholders; Tech, technical; UncertE, uncertainties concerning future evolutions; UncertK, uncertainties concerning knowledge.

However, they did not mention any uncertainties related to the knowledge about animal husbandry techniques.

Concerning the open-endedness of the SSI, the stakeholders item (i.e., viewpoints, values, value systems, and/or interests of the stakeholders) appeared negligible in the contributions of the four debates (rate of 0.01 per contribution). The students rarely mentioned the views of the different stakeholders. Although the ideas put forward by the students were rich, especially in terms of the multiplicity of the SSI aspects, they generally did not link these ideas to different stakeholders and their respective interests and values.

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6.2 | Changes in the quality of argumentation on SSIs in the synchronously written debates (RQ2)

6.2.1 | Global changes

If we compare the data of the four synchronous written debates, multiple variations can be observed (Table 8). The number of contributions per student per debate progressively decreased from 7.57 in Debate 1 to 4.20 in Debate 4, while the number of argumentative moves per contribution progressively increased from 1.26 in Debate 1 to 1.52 in Debate 4. Regarding the argumentative moves, none of them followed a monotonic evolution: for example, the rate of development in the four debates first decreased, then increased, and decreased again. Moreover, the changes from one debate to another were sometimes opposite depending on the argumentative move; for example, between Debates 1 and 2, the rate of rebuttals of a justification decreased while the rate of nuances increased. These changes should all be viewed with caution, as the sets of students who participated in the different debates were not identical. Only 34 of the 64 students participated in all the four debates. Moreover, these four debates focus on very different SSIs. Therefore, the lack of positive and monotonic change in the quality of argumentation could be explained by the dependency on the group of students present and/or the SSI being debated.

To overcome these dependencies and identify possible effects of the sequence on the quality of argumentation, we targeted the analysis on the 34 students who participated in all units of the sequence, and compared the data from Debate 1 with those from Debate 4 (Table 10). This choice is also justified by the results of the studies presented in the literature review (Section 3.1.3), which point out that changes in the quality of students' argumentation in transfer situations are not significant with one debate, but generally only with a large number of debates. The decrease in the number of contributions per student per debate was confirmed (−0.45). There was also an increase in the proportion of justified contributions (+0.21), although this increase was not significant. In contrast, the number of argumentative moves per contribution was relatively constant. The variations of the different argumentative moves also were minor and all nonsignificant.

Regarding the SSI items, the number of aspects of the SSI considered per contribution increased (+0.28), as does the rate of domains of validity and qualifiers (+0.47), but these changes were not significant. The rates of uncertainties concerning knowledge and future evolutions, and the rate of references to stakeholders decreased, but the values involved were extremely low for both debates and did not allow us to conclude on their evolution (Table 11).

6.2.2 | Changes depending on students' initial level

On comparing the quality of the contributions from one student to another, important differences appeared for certain items, particularly for a major indicator of the quality of argumentation during debate 1, namely the proportion of justified argumentative moves (mean during debate 1: 0.65; standard deviation: 0.24). Therefore, three initial profiles could be distinguished: 11 students with "low" initial level, for whom the rate of justified argumentative moves in debate 1 was lower than 0.6 (mean rate: 0.43), 9 students with "medium" initial level, for whom this rate was between 0.6 and 0.8 (mean rate: 0.71), and 14 students with "high" initial level, for whom it was higher than 0.8 (mean rate: 0.94). The evolution of argumentation quality was

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TABLE 10 Argumentative moves produced during debates 1 and 4 by the 34 students who participated in the entire teaching sequence

Category		Debate 1	Debate 4	Rate of change	*p*-value
Number of students (Classes A and B)		34	34	0.00	–
Contributions	Number	271	149	−0.45*	0.003
	Per student and debate	7.97	4.38		
Dev (per contribution)	All 34 students	0.36	0.40	0.13	0.28
	With low initial level	0.38	0.44	0.16	0.94
	With medium initial level	0.32	0.38	0.19	0.76
	With high initial level	0.37	0.38	0.01	0.20
ReC (per contribution)	All 34 students	0.17	0.14	−0.17	0.33
	With low initial level	0.15	0.10	−0.33	0.59
	With medium initial level	0.13	0.12	−0.07	0.84
	With high initial level	0.27	0.21	−0.23	0.13
ReJ (per contribution)	All 34 students	0.17	0.16	−0.03	0.41
	With low initial level	0.13	0.10	−0.20	0.89
	With medium initial level	0.15	0.21	0.44	>0.05
	With high initial level	0.27	0.19	−0.31	0.19
Nu (per contribution)	All 34 students	0.21	0.23	0.10	0.71
	With low initial level	0.17	0.17	0.00	–
	With medium initial level	0.27	0.26	−0.02	1.00
	With high initial level	0.22	0.29	0.32	>0.05
Conc (per contribution)	All 34 students	0.15	0.12	−0.18	0.71
	With low initial level	0.10	0.0	−0.17	0.60
	With medium initial level	0.20	0.12	−0.41	0.43
	With high initial level	0.15	0.17	0.09	0.40
Quest (per contribution)	All 34 students	0.10	0.15	0.43	0.16
	With low initial level	0.12	0.08	−0.29	0.31
	With medium initial level	0.138	0.143	0.03	0.76
	With high initial level	0.02	0.23	12.52*	<0.05
Sum of argumentative moves (per contribution)	All 34 students	1.16	1.21	0.04	0.77
	With low initial level	1.05	0.98	−0.06	0.76
	With medium initial level	1.20	1.24	0.03	0.84
	With high initial level	1.31	1.46	0.12	0.47
Moves with a justification (rate)	All 34 students	0.65	0.79	0.21	0.28
	With low initial level	0.43	0.79	0.86*	0.003
	With medium initial level	0.71	0.75	0.06	0.81
	With high initial level	0.94	0.81	−0.13	>0.05

Note: The *p*-value was calculated by means of a Student's *t*-test, or estimated as >0.05 or <0.05 by means of a Wilcoxon test when the normality assumption was not satisfied. *means significant ($p < 0.05$).

Abbreviations: Conc, concession; Dev, development of a claim or its justification; Nu, nuance of a claim or its justification; Quest, questioning of a claim or its justification; ReC, rebuttal of a claim; ReJ, rebuttal of the justification of a claim.

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studied for each of these profiles. The analysis of all the items in debates 1 and 4 (Tables 9 and 10) lead to identify two salient changes, which are statistically significant. The first one concerns students with a low initial level: the rate of their justified argumentative moves increased drastically (final mean rate: 0.79; increase: +0.86) and became equivalent to that of students with a high initial level (final mean rate: 0.81). The second salient change concern students with a high initial level: the rate of their questioning per contribution increased also drastically (final mean rate: 0.23; increase: +12.52).

6.3 | Changes in the quality of argumentation on SSIs in the individual writing (RQ3)

Of the 34 students who participated in all four synchronous written debates, eight students were absent on one or more of the four tests. Therefore, we analyzed the test data (i.e., answers to Q1, Q2, and Q3) only for the 26 students who both participated in all four debates and completed all four tests. Table 12 displays the results for Q1. It can be seen that the quality of students' argumentation in terms of the number of justifications increased monotonically over the four tests. However, this increase was not significant. On comparing the data for the students of the three previous profiles, the average of their initial level in terms of the number of justifications in writing (Test 1) was consistent with their initial level in terms of the proportion of justified argumentative moves in the debate (Debate 1): 4.55 justifications on average for the students of "low" profile, 5.5 for the students of "medium" profile, and 5.91 for the students of "high" profile. The evolution of this indicator between Tests 1 and 4 was slightly negative for the students in "low" profile (−0.06), but positive for the students in "medium" profile (+0.12) and "high" profile (+0.27). However, these changes were not significant.

For the items relating to the complexity, uncertainties, and open-endedness of the SSI, there was either a decrease or a nonmonotonic evolution, especially in Test 4. A qualitative analysis of the students' answers revealed that the claim submitted in this test ("We should not put animal well-being on the same level as human well-being") appealed more to the students' moral values and made them take stronger positions than in the other tests. As an example, here is an excerpt from a student's argument against the claim submitted:

> Student I: Treating animals as objects or as less than nothing is violence, and we should ask ourselves if we would want to do the same to humans.

6.4 | Changes in the awareness of the specific norms of argumentation on SSIs (RQ4)

The results for Q2 and Q3 (Table 13) also do not show a positive and monotonic change in awareness of the complexity of an SSI and its associated uncertainties. The proportion of students who explicitly referred to the multiple aspects of the SSI or its associated uncertainties varied greatly depending on the SSI considered. Further, awareness of its open-endedness (i.e., recognition of alternative acceptable viewpoints) gradually increased, except for Test 4, which strongly involved moral values (making acceptance of alternative viewpoints more difficult). Moreover, the average rate of awareness of the open-ended nature of an SSI was markedly higher than those concerning complexity and uncertainties. This reflects the fact that

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TABLE 11 SSI items in the contributions made during debates 1 and 4 by the 34 students who participated in the entire teaching sequence

Specific norm	Category		Debate 1	Debate 4	Rate of change	*p*-value
Complexity	All aspects (per contribution)	All 34 students	1.70	2.17	0.28	0.32
		With low initial level	1.30	1.78	0.37	0.23
		With medium initial level	1.76	2.10	0.19	0.73
		With high initial level	2.41	2.73	0.13	0.25
Uncertainties	DV-qual (per contribution)	All 34 students	0.23	0.34	0.47	0.41
		With low initial level	0.14	0.31	1.25	0.20
		With medium initial level	0.287	0.286	−0.005	0.84
		With high initial level	0.32	0.42	0.29	>0.05
	UncertK (per contribution)	All 34 students	0.03	0.00	−1*	<0.05
		With low initial level	0.02	0.00	−1	Not sign
		With medium initial level	0.04	0.00	−1	Not sign
		With high initial level	0.05	0.00	−1	Not sign
	UncertE (per contribution)	All 34 students	0.03	0.00	−1	Not sign
		With low initial level	0.01	0.00	−1	Not sign
		With medium initial level	0.07	0.00	−1	Not sign
		With high initial level	0.00	0.00	0.00	Not sign
Open-endedness	Stake (per contribution)	All 34 students	0.022	0.020	−0.09	>0.05
		With low initial level	0.02	0.00	−1	Not sign
		With medium initial level	0.01	0.00	−1	Not sign
		With high initial level	0.05	0.06	0.23	Not sign

Note: The *p*-value was calculated by means of a Student's *t*-test, or estimated as >0.05 or <0.05 by means of a Wilcoxon test when the normality assumption was not satisfied ("not sign" is mentioned for cases where the number of data was insufficient to calculate the *p*-value); *means significant ($p < 0.05$).

Abbreviations: DV-qual, domain of validity and qualifier; Stake, viewpoints, values, system of values, and/or interests of the stakeholders; UncertK, uncertainties concerning knowledge; UncertE, uncertainties concerning future evolutions.

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TABLE 12 Monologal argumentation produced in response to Q1 by the 26 students who participated in the entire teaching sequence and answered all the four tests

Category		Test 1	Test 2	Test 3	Test 4	Rate of change Test 1 to Test 4	*p*-value
Justifications	Number (per answer)	5.38	5.81	6.04	6.08	0.13	0.33
Complexity	All aspects (per answer)	3.31	3.31	2.77	2.23	−0.33*	0.004
Uncertainties	DV-qual (per answer)	0.85	0.73	0.73	0.46	−0.45*	0.02
	UncertK (per answer)	0.12	0.04	0.04	0.00	−1	0.25
	UncertE (per answer)	0.08	0.23	0.04	0.00	−1	0.48
Open-endedness	Stake (per answer)	0.00	0.04	0.00	0.08	–	0.48

Abbreviations: DV-qual, domain of validity and qualifier; Stake, viewpoints, values, system of values, and/or interests of the stakeholders; UncertE, uncertainties concerning future evolutions; UncertK, uncertainties concerning knowledge.
Note: The *p*-value was calculated by means of a Student's *t*-test for justifications and complexity, and by means of a McNemar test for DV-qual, UncertK, UncertE, and Stake; *means significant ($p < 0.05$).

TABLE 13 SSI items in the answers to Q2 and Q3 provided by the 26 students who participated in the entire teaching sequence and answered the four tests

Specific norm	Category	Test 1	Test 2	Test 3	Test 4	Rate of change Test 1 to Test 4	*p*-value
Complexity	Complex (rate)	0.31	0.50	0.19	0.08	−0.75*	0.05
Uncertainties	DV-qual (rate)	0.15	0.12	0.00	0.04	−0.67	0.37
	UncertK (rate)	0.15	0.08	0.15	0.04	−0.75	0.37
	UncertE (rate)	0.12	0.12	0.12	0.00	−1	0.25
Open-endedness	Acc (rate)	0.62	0.77	0.85	0.42	−0.31	0.23

Note: The *p*-value was calculated by means of a McNemar test; *means significant ($p < 0.05$).
Abbreviations: Acc, other acceptable viewpoints; DV-qual, domain of validity and qualifier; UncertE, uncertainties concerning future evolutions; UncertK, uncertainties concerning knowledge.

many students accepted that multiple views of an SSI are acceptable without justifying it with the idea that the SSI is complex and/or involves uncertainties. For example, one student's response to Q2 related to the question of the use of glyphosate in crops was as follows:

> Student J: Everyone can have their own point of view, but studies have been conducted, and they prove the dangers pesticides pose to soil.

7 | DISCUSSION

7.1 | What is the quality of students' argumentation on SSIs that a synchronously written debate affords? (RQ1)

This study aimed to investigate the evolution of students' written argumentation on SSIs during a sequence combining several synchronous written debates on SSIs and reflective activities on the argumentation produced by the students during these debates. To be able to understand the

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possible changes, we first characterized the quality of the argumentation that synchronously written debates afford. The results show that students, from the very first debate, collectively produce a rich and quality argumentation about SSIs: Each student makes numerous contributions to the debate, the argumentative moves produced are diversified, there is a high rate of justified argumentative moves, and all relevant aspects of the SSI are addressed. The diversity of argumentative moves and the high rate of justified moves mean that students are satisfying, to a large extent, two of the generic norms of argumentation, namely, the others and justification norms. Similarly, the fact that students take into account all important aspects of the SSI implies that the complexity norm is also respected. By contrast, we observe that the questioning move is present in a lower proportion. The associated generic norm is therefore less satisfied. Similarly, the low rates of uncertainties and stakeholders of the SSIs considered in students' contributions mean that the uncertainties and open-endedness norms are also not well met in the debates.

How can these results be explained? The high number of contributions per student and the diversity of argumentative moves produced from the first debate can be explained, to some extent, by the interest that SSIs can arouse insofar as they are authentic and current societal issues, generally related to students' lived experiences (Karisan & Zeidler, 2017; Sadler et al., 2007). Another explanation for the richness of these exchanges lies in the debate environment, which is computer-mediated and thus allows all students to participate simultaneously, more freely, and with less inhibition (Asterhan & Eisenmann, 2011). A third explanation can be provided: Within the framework of the software used, each debate was based on a short text (i.e., an excerpt from a press article), thus avoiding imposing on the students a question to be debated, and instead allowing them to collectively bring out their own questions. Such a setting seems to help students problematize and make sense of the content being debated (Orange, 2003; Schwarz & Baker, 2017, p. 185).

To some extent, the high rate of justified argumentative moves can be explained by the average initial level of students. Recall that they are in Grades 11 and 12 and, for this reason, may already have acquired some argumentation skills on other occasions during their schooling. The preparatory phase introducing a set of contents on the topic associated with the SSI is probably a complementary explanation, as a minimum level of knowledge is required to be able to justify a claim. As shown in a previous study, the quality of students' argumentation on an SSI depends on their prior knowledge (Baytelman et al., 2020). Another possible explanation is that computer-mediated debates provide time for students to seek information and produce their contributions (Clark et al., 2007; Guiller et al., 2008). An online environment can thus allow students to better justify their claims.

The fact that students, from the first debate, develop an argumentation on the SSI that takes account of its complexity can also be explained in several ways. First, the preparatory phase provides students with an opportunity to become familiar with different SSI aspects. Second, the text that is used as a starting point for the debate may itself already address several SSI aspects. Finally, the computer-mediated debate setup enables students to make a variety of contributions in response to each claim made in the debate, so that the multiple aspects related to a given claim can be addressed in parallel branches of argumentation.

In view of all these explanations, multiple parameters need to be considered for a debate on an SSI to allow students to develop a quality argumentation. Although these multiple parameters were considered in the device of this study, it remains that three norms of argumentation on SSIs were hardly respected during the first debate: the questioning, uncertainties, and open-endedness norms. These norms do not seem to be easily accessible to students.

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Despite this limitation, the results of this study show that synchronously written debates on SSIs, under certain conditions (such as setting up a preparatory phase and using a short text as a starting point) can provide a learning environment that is in itself sufficient to prompt students to develop argumentation governed by the others, justification, and complexity norms. Therefore, providing students with the opportunity to participate in such debates can help acculturate them to the practice of collective production of quality is written argumentation on SSIs.

7.2 | How does the quality of students' argumentation on SSIs change over the course of the sequence? (RQ2)

We assessed the degree of this acculturation afforded by a sequence combining several synchronous written debates on SSIs and reflective activities. We examined the way in which the argumentation of the students, who participated in the four teaching units and thus in the four debates of the sequence, evolved. Overall, the results show positive changes, even if they are limited, regarding the appropriation of some generic and specific norms of argumentation on SSIs: In the last debate of the sequence, students tended to produce more justified argumentative moves (justification norm), more questioning (questioning norm), take better account of the different aspects of the SSI being debated (complexity norm), and include more often the domain of validity of the ideas at stake or qualifiers (uncertainties norm) in their argumentation.

The most striking changes were observed when different initial levels of students' argumentation quality were considered. In their contributions to the first debate, three profiles could be distinguished regarding the fulfillment of the justification norm (i.e., the rate of justified argumentative moves): students with a low, medium, or high initial level. We examined the changes in the quality of argumentation for these three student profiles, and two salient changes, which were statistically significant, emerged: Students whose initial level was low tended to justify their arguments more frequently, approximately as much as students with a high initial level; and students with a high initial level tended to question the claims and arguments more often, while preserving their rate of justified argumentative moves.

This result suggests a possible progression in students' appropriation of the generic norms of argumentation on SSIs, which had not been previously identified, to the best of our knowledge. According to this progression, students first learn to justify their argumentative moves more frequently, and then to question the ideas stated in the debate more often. In other words, they would first appropriate the justification norm, which is a basic norm of argumentation (Kuhn et al., 2013; Weinstock et al., 2004), and then the questioning norm, which relates to critical thinking (Nussbaum, 2021) and thus corresponds to a more advanced level of thinking. It appears all the more important to get students capable of raising questions during class debates since questioning leads overall to higher quality argumentation that can benefit all students. According to a study conducted with middle school students (Chin & Osborne, 2010), questions raised by some students serve as triggers that stimulate concessions, challenges, and counter-challenges and lead to the construction of more elaborate justifications and changes in viewpoints.

How can these changes be explained? Those concerning the justification of argumentative moves and the number of aspects of the SSI considered can both be explained by the contribution of synchronously written debates and reflective activities. As stressed above (Section 7.1),

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the argumentation quality regarding these two points is high from the first debate. In this regard, the successive debates in the sequence can act as a model, with norms that should be followed for the students who participate (Anderson et al., 2001). For example, justifying an argumentative move and enriching it by taking into account more aspects of the SSI may appear useful to students in strengthening their argumentation. However, there is no evidence that during the debates students become aware of the value of these two norms and of the fact that they should follow them. In this respect, reflective activities on the argumentation produced by the students can play an important role. In fact, justification and complexity norms were explicitly discussed during the reflective activities of the implemented sequence. Therefore, the students were able to become aware of the importance of each of these two norms for the quality of their argumentation on SSIs. By participating in new debates, and following these reflective activities, they had the opportunity to operationalize this "meta-level awareness" (Iordanou, 2010; Kuhn et al., 2008). From this point of view, the combination of debates on SSIs and reflective activities seems relevant in promoting the quality of students' argumentation on SSIs.

The situation is different for the evolution related to the questioning norm. The rate of contributions involving questioning in the first debate was not high. Therefore, this debate could not display this argumentative move as a norm to be satisfied. However, this norm was discussed in one of the reflective activities. The fact that a statistically significant change was observed for students with an initially high level of argumentation quality tends to show that the reflective activity on the questioning norm had a positive impact on the argumentation produced by the students afterward.

It should be stressed that the positive evolutions remain statistically nonsignificant with respect to the whole group of students of the study. Therefore, they should be interpreted with caution. A sequence with a greater number of debates and reflective activities should be implemented and studied to confirm the trend of an overall improvement in the quality of argumentation. Recall that the sequence included four debates and four associated reflective activities, while previous studies have shown statistically significant effects on students' argumentation when the interventions included considerably more debate sessions, for example, 16 sessions (Kuhn & Udell, 2003) or even 36 sessions (Crowell & Kuhn, 2014). Furthermore, the students in these earlier studies were at the middle school level, whereas the students in the present study were at the high school level and thus possibly have less room for improvement regarding the quality of their argumentation.

Moreover, no clear trend emerges concerning the others norm insofar as the rates of the various argumentative moves per contribution (that indicate the degree to which other students' ideas are taken into consideration) do not all evolve in the same way: some positively, others negatively. However, from the first debate, students produce on average more than one argumentative move per contribution (if we consider all types of argumentative moves). In other words, from the beginning of the sequence, their contributions take into account the ideas of others. Accordingly, there is no reason to expect a strong evolution in this respect.

Finally, regarding two categories related to the uncertainties and open-endedness norms, a lack of positive evolution is observed: The occurrence of uncertainties associated with knowledge and future evolutions and the reference to the different stakeholders of the SSIs remained negligible in students' contributions throughout the sequence.

An explanation for these results lies in the fact that the uncertainties and the multiple viewpoints associated with different stakeholders of the SSIs were not considered in the first debate, so the argumentation developed there could not be a model to follow. Nevertheless, various

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points related to the uncertainties and open-endedness norms were discussed in the frame of the reflective activities. One of them concerned the notion of uncertainty: The students had to distinguish different types of possible uncertainties and identify their occurrence in a selection of arguments they produced. It seems that this reflective activity had only a limited impact. During the final debate, students tended to mention the domain of validity of knowledge and/or to use qualifiers more often, testifying to a more nuanced or cautious argumentation. However, they did not come to integrate uncertainties about knowledge or future evolutions associated with the SSIs into their argumentation. This may be because students are rarely invited to discuss the limitations of scientific knowledge being taught in class (Leden et al., 2017; Lee et al., 2014), and are therefore not used to include uncertainties in their argumentation. Common science teaching practices tend to present scientific knowledge as truth that is stable and certain, what leads some students to develop a lack of tolerance for uncertainties (Lee et al., 2020). In this regard, some students may be reluctant to consider uncertainties in their argumentation on SSIs. Another possible reason may result from students' limited awareness of uncertainties associated with scientific knowledge (Chen & Qiao, 2020).

Regarding the open-endedness norm, two related ideas were discussed in the reflective activities: the idea that different viewpoints may be supported on an SSI, and the idea that these viewpoints are relative to different values or value systems. Since the students were asked to discuss these two ideas by analyzing their own argumentation, they were not prompted to bring the various stakeholders of the SSIs into the discussion. Yet the categories used to assess whether students met the open-endedness norm in the debates involved explicit mention of stakeholders. To some extent, then, there is a gap between the ideas discussed in the reflective activities and these categories. This provides a possible explanation for the lack of measured change regarding the satisfaction of this norm.

7.3 | To what extent is students' appropriation of the norms of argumentation on SSIs during this sequence transferred to the context of individual writing? (RQ3)

To assess the depth of students' appropriation of the norms of argumentation on SSIs, we examined how the quality of their argumentation evolves in the context of individual writings on a new SSI. The study shows that students tend to provide more justifications for their argumentation in their individual writings, which echoes the positive change in the rate of justified argumentative moves in the debates and suggests the existence of a transfer. According to this result, the teaching sequence would therefore have allowed for an in-depth appropriation of the justification norm.

In contrast, the number of SSI aspects that students consider does not increase in their individual writings. It even decreases in the last writing, which can nevertheless be explained by the topic (i.e., animal well-being) on which the students developed more morally charged viewpoints. This suggests that the complexity norm governing the argumentation developed collectively during the debates is not fully internalized and transferred to the context of monologal argumentation. It is possible that in the context of a debate, the exploration of the complexity of an SSI corresponds to an emergent collective phenomenon, which does not require the students to be fully aware of the complexity norm and/or be able to satisfy it alone in an individual writing.

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Furthermore, in the individual writings, there was also no positive evolution in the consideration of uncertainties and stakeholders. This result is not surprising as these two elements are not well considered during the debates.

7.4 | How does students' awareness of the norms specific to SSIs evolve over the course of the sequence? (RQ4)

In this study, a supplementary means was used to assess the depth of appropriation of the three argumentation norms specific to SSIs. Considering students' responses to two questions of a written test (i.e., Q2 and Q3), we assessed their awareness of these norms. The results reveal that their level of awareness of the complexity norm remains limited over the course of the sequence, supporting the idea that students have only partially integrated this norm.

The results also show that students' awareness of the uncertainties associated with the SSIs remained very low. Thus, most students do not seem to recognize that these uncertainties are an important element to consider in relation to the SSIs. This may explain why the uncertainties norm remains low in both their collective and individual argumentation.

Finally, regarding the open-endedness norm, a large proportion of students recognized that there was another acceptable viewpoint on the SSI being discussed than their own. However, this result should be viewed with caution. This is because the meaning that students assign to the idea of multiple acceptable viewpoints is not necessarily the same as it is for researchers. From an epistemological perspective, this idea of open-endedness of the SSI can be related to its complexity and its associated uncertainties. However, these relations were rarely expressed by the students. Instead, they very often referred to everyone's freedom of thought, which may evoke the epistemic beliefs associated with "multiplism" (Kuhn et al., 2000). Thus, students' cognitive pathways were in contrast with the researchers' reasoning. They tended to first consider an initial form of open-endedness of the SSI, admitting several acceptable opinions by virtue of a general principle according to which everyone is entitled to their opinion, and then to consider that this open-endedness is related to the complexity of the SSI and by uncertainties. By acknowledging that the open-endedness of the SSI is related to its complexity, students give more attention to the rationality of individuals who have a different opinion, and view the SSI from a different perspective.

7.5 | Educational implications

Merely engaging students in synchronously written debates about SSIs does not appear to be enough to allow them to appropriate the norms of argumentation about SSIs, unless the number of debates is large (Osborne et al., 2004). This is difficult to achieve in practice due to time constraints usually imposed by the curriculum. This study shows that an effective strategy for fostering appropriation of these norms with a limited number of debates is to set up computer-mediated debates and combine them with reflective activities. This strategy can be considered effective insofar as it allows students with different initial levels of argumentation to progress. For these reasons, it deserves to be disseminated and become part of teaching practices. Thus, several parameters of the teaching strategy need to be considered, including the setting up of a preparatory phase to introduce contents related to the SSI to be debated and the use of a short text as a debate starting point.

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Moreover, this study provided information about students' learning that teachers should consider, showing that when such a strategy is implemented, there is a tendency for high school students to first learn to justify their argumentative moves more often, and then to question the ideas formulated during the debates. Moreover, it brings to light their difficulties in considering the uncertainties and the multiple possible viewpoints of the different SSI stakeholders. These two points, therefore, need to be studied in greater depth with the students.

One of the challenges is to overcome students' lack of tolerance for uncertainties, in particular by making them aware that uncertainties are inherent to knowledge and that taking them into account is a guide for knowledge development (Allchin, 2012; Chen & Techawitthayachinda, 2021). Regarding the different SSI stakeholders, taking them into account in the argumentation implies not only knowing them, but also being able to coordinate the possible viewpoints of these stakeholders, their interests, and their values. Two complementary avenues could be explored to improve the teaching strategy implemented in this study. The first is to select texts for computer-mediated debates that mention stakeholders of the SSI, so that students are encouraged to discuss the viewpoints and arguments explicitly related to certain stakeholders. The second is to devote a reflective activity to the stakeholders of a certain SSI, with the objective that students become aware of the existence of these stakeholders, their viewpoints, and arguments in relation to their interests and values. To tackle these challenges, further studies are required.

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