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Relationship Between Nature of Science and Argumentation: a Follow-Up Study

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Abstract

The purpose of the study was to investigate the relationship between high school students' understandings of aspects about nature of science (NOS) and their argumentation skills, particularly whether informed conceptions of NOS contribute to better argumentation skills. Participants, a total of 125 Grade 10 students, responded to an open-ended questionnaire, *Controversial Socioscientific Issues Questionnaire (CSI)*, that involved two scenarios addressing socioscientific issues (SSI) about genetically modified food and water fluoridation. Each of the two scenarios was accompanied by two sets of questions that address argumentation and NOS. Stepwise regression analyses were performed on data from the participants' responses with three NOS aspects (subjective, tentative, and empirical) as independent variables and the argumentation components (argument, counterargument, and rebuttal) as dependent variables (each at a time). The results demonstrated positive correlation between argumentation and NOS. Moreover, the results showed that the tentative, empirical, and subjective aspects are significant predictors of the argumentation components with some variations depending on the context (whether genetically modified food or water fluoridation). These results provide concrete evidence illustrating the associations between argumentation and NOS knowledge within two SSI (water fluoridation and genetically modified food).

Keywords Argumentation · High school students · Nature of science · Scientific literacy

Introduction

Science and technology dominate many of the world's pressing issues; therefore, the goal of the scientific community is to prepare scientifically and technologically literate citizens (American Association for the Advancement of Science [AAAS],

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1989; National Research Council [NRC], 1996; NGSS Lead States, 2013). Helping people understand the nature of science (NOS), science as a way of knowing, is a central component of this disciplinary literacy (Holbrook & Rannikmae, 2007). One of the dimensions of the public understanding of science and argumentation deals with the democratic aspect of many societies, where the understanding of NOS is necessary for informed argument and decision-making about complex science-based social dilemmas (Cavagnetto, 2010; Ewing & Sadler, 2020; Lederman & Lederman, 2019). The issues of and knowledge gaps among NOS understandings, argumentation skills, and socioscientific issues (SSI) are the focus of the present study. There is a need to further address our understanding of these relationships. Thus, the purpose of the present study was to investigate the relationship between high school students' understandings about NOS aspects and their argumentation skills, particularly whether informed conceptions of NOS contribute to better argumentation skills among high school students addressing specific SSI.

Nature of Science

Nature of Science (NOS) refers to the epistemology of science, as a way of knowing and constructing scientific knowledge (Pritchard, 2016) and the values and beliefs inherent to this knowledge and its development (Lederman, 2007). Epistemology contrasts with ontology, which is the study of reality and the different entities and categories that comprise that reality (Slevitch, 2011).

There exist different approaches towards conceptualizing or defining NOS; for instance, the consensus view (Lederman, 2007), the family resemblance approach where NOS is conceived as a system (Irzik & Nola, 2014), the whole science approach (Allchin, 2011), and the features of science that advocates for discussion and inquiry (Matthews, 2012). However, many researchers and educators agree on certain common aspects of NOS that characterize the development of scientific knowledge (Lederman, 2007), are relevant to K-12 students, and can be reasonably taught to students. These aspects address the beliefs about the development and construction of scientific knowledge, which means these aspects are epistemological and do not relate to the ontological categories (Chi, 2008). Lederman (2007) described these aspects as follows: (1) scientific knowledge is empirically derived from observations, (2) scientific knowledge is tentative that is subject to change, (3) scientific knowledge is subjective in that it considers the scientist's background and experience, (4) scientific knowledge is socially and culturally embedded, (5) scientific knowledge involves creativity and imagination, (6) there are distinctions between observations and inferences, and (7) there are distinctions between theories and laws. Three aspects of NOS (tentative, empirical, and subjective) have been shown to relate to argumentation in the context of SSI (Khishfe, 2012) and thus were examined in the present study. Scientific knowledge is defined as tentative with the understanding that it is not absolute, and it is subject to change with the available evidence or reinterpretation of existing data. Scientific knowledge is defined as empirical with the understanding that it is derived from real-world observations and is therefore dependent on evidence. Scientific knowledge is defined as subjective with the understanding that it is affected by scientists' backgrounds, experiences, theoretical frameworks, and biases.

Argumentation

Kuhn (2010) proposed "*science as argument*" where science was described as being a social activity and argumentation is at its heart in that the social aspect of science is communicating and persuading. Therefore, scientific thinking can be viewed as a social activity. And argumentation revives this social aspect of science. Aligning with this definition, argumentation nowadays is becoming a crucial topic in the scientific community especially that developing argumentation skills is considered a major goal in science education (NRC, 2012).

An argument has been defined as an assertion with its accompanying justification (Erduran et al., 2004). Engaging students in the process of argumentation would lead them to a cognitive process of comparison and contrast (Osborne, 2010). This process gives students a chance to justify their claims and generate counterarguments and rebuttals, which in turn would pave the way for students to construct and reconstruct their own knowledge (Berland & McNeill, 2010). Three argumentation components (argument, counterargument, and rebuttal) were examined in the present study. An argument is a claim that shows one's position; a counterargument is an argument that opposes the initial argument; and a rebuttal is a claim that opposes the counterargument.

At the same time, argumentation is a type of informal reasoning where learners make inferences from uncertain principles (Teig & Scherer, 2016) as they deal with the context of SSI. Argumentation is also considered a central part of decision-making (Amgoud & Prade, 2009) when dealing with SSI (Karpudewan & Roth, 2018). SSI are ill-structured social science-based problems with multiple perspectives and interpretations. Since there would be more than one position on a certain SSI and each is supported by appropriate justification, this makes SSI a good medium for argumentation. SSI have been identified as a basis to anchor students' understandings and applications in a practical everyday context. These issues offer unique opportunities to engage students in thinking and reasoning processes and to mirror the discourse practices used in real life. Thus, students can develop their arguments based on concrete everyday life experiences where they engage in SSI issues as active contributors to society in relation to issues and problems that affect their lives (Sadler, 2009) and are meaningful to them.

Nussbaum et al. (2012) looked at the difference in students' arguments in different contexts as the two faces of an argument. They considered that scientific contexts are more theoretical, while the socioscientific contexts are more practical. However, they insisted that the socioscientific contexts should contain a scientific dimension in order to serve the goal of enhancing scientific literacy.

Some studies indicated that a relation exists between argumentation and NOS (e.g. Kutluca & Aydin, 2017; McDonald, 2010). Additionally, at the 2015 NARST international conference, a group of researchers and scholars presented their perspectives on research in the field of argumentation and the key challenges facing it. One of the key challenges was epistemology and classroom culture (Henderson et al., 2018). This epistemology entails shifting from "What we know?" to "How we know?" and having students think of scientific knowledge as a social enterprise that is open to critique and debates rather than being rigid and absolute. That feeds into the heart of our topic in the present study, which is the relationship between students' conceptions of NOS and their argumentation skills in the context of SSI.

Relationship Between NOS and Argumentation

A review and synthesis of studies of NOS and argumentation revealed four themes: (1) studies that related epistemological understandings and argumentation with no intervention (Lee & Chan, 2017; Mason & Scirica, 2006; Weinstock et al., 2006; Wu & Tsai, 2011); (2) studies that related NOS and argumentation with no intervention (Khishfe, 2012; Khishfe et al., 2017; Sadler et al., 2004); (3) studies that related NOS and argumentation based on an intervention involving explicit instruction of NOS and argumentation (Kenyon & Reiser, 2006; Khishfe, 2014, 2021; Kutluca & Aydin, 2017; McDonald, 2010; Ogunniyi, 2006; Sandoval & Milwood, 2008; Walker & Zeidler, 2007); and (4) studies that related NOS and argumentation based on an intervention that did not involve explicit instruction of NOS and argumentation (Bell & Linn, 2000; Kelly & Takao, 2002). Therefore, the present study involved the findings from the first two themes as no intervention or treatment was involved. Following, we discuss findings from these two themes.

Epistemological Understandings and Argumentation

The relationship between epistemological understandings and argumentation has been the central focus of previous studies, where some researchers have used the constructs of NOS and epistemological understandings interchangeably (McDonald, 2010). However, Khishfe (2012) noted that NOS is an element in the epistemological understandings that revolves around beliefs about the nature of knowledge and its construction and the nature of knowing. The latter involves learners' ideas about how they construct these ideas, and how these ideas influence their thinking and reasoning (Hofer, 2001).

Mason and Scirica (2006) studied how the epistemological understandings of 62 Grade 8 students collected with a 15-item instrument contribute to their argumentation skills in two socioscientific contexts: genetically modified food and global warming. The students were introduced to two scenarios about these topics and they were asked to formulate arguments, counterarguments, and rebuttals providing justifications. After controlling for topic knowledge and topic interest, the findings revealed that epistemological understandings contributed to the development of arguments, counterarguments, and rebuttals for both topics.

Wu and Tsai (2011) examined how 68 Grade 10 students' epistemological understandings and their cognitive structures can predict their reasoning skills on the nuclear power usage. Epistemological understandings were assessed using a 26-item Likert questionnaire and informal reasoning was assessed by an open-ended questionnaire. Results showed that students' beliefs about the justification of scientific knowledge (an aspect of the nature of knowing science) were significantly correlated with their reasoning quality. Furthermore, the extent and richness of students' cognitive structures and their usage of the information processing mode were positively correlated with their reasoning quality. A series of regression analyses showed that students' use of the information processing mode (comparing) was the most significant factor for predicting reasoning quality, while their beliefs regarding the justification of scientific knowledge were the other important predictor.

Weinstock et al. (2006) investigated the relationship between 193 Grade 7, 9, and 11 students' epistemological understandings and their informal reasoning skills with a focus on the identification of fallacies. They investigated whether epistemological understandings can predict informal reasoning fallacies, which are violations of the norms of argumentation and thus are crucial in developing argumentation skills. The students' epistemological understandings were assessed by 15-paired statements with contrasting views about a topic of five judgment domains. Findings revealed that the epistemological level predicted only the identification of one type of fallacy that might be described as epistemological in nature. This finding appears to indicate that the ability to evaluate different types of informal argumentation is dependent on the epistemological level of students.

However, Lee and Chan's (2017) examination of 146 Grade 7, 9, 10, and 11 students' epistemological understandings and their ability to identify different informal fallacies (appeal to popularity, appeal to ignorance, and personal attack) revealed different results. Data were collected using a 14-item Epistemic Beliefs Questionnaire and scenario tasks for informal fallacies. Findings of a regression model revealed that only grade levels, but not epistemological understandings, predicted fallacy identification (appeal to authority) when all variables were considered.

NOS and Argumentation

A more recent and emerging line of research aimed to investigate the relationship between argumentation and NOS in an attempt to help citizens engage in decision-making (Fang et al., 2019) and develop desirable understandings of NOS. Khishfe (2012) investigated the relationship between 219 Grade 11 students' understandings of three NOS aspects (subjective, tentative, and empirical) and their argumentation skills (argument, counterargument, and rebuttal) with respect to two SSI: genetically modified food and water fluoridation. A mixed method approach with quantitative (Pearson's correlations) and qualitative analysis was used without explicit instruction about NOS or argumentation. Results revealed strong correlations between the counterargument and the three NOS aspects as compared to the argument and rebuttal. Later, Khishfe et al. (2017) investigated 74 Grade 11 students' understandings of the same three NOS aspects and their argumentation skills in the context of four SSI (global warming, genetically modified food, acid rain, and human cloning). Again, there was no explicit NOS and argumentation instruction. The quantitative results (Pearson's correlations) revealed no significant correlations between students' argumentation components and NOS aspects.

Sadler et al. (2004) investigated the ways 84 high school students understand the tentative, empirical, and social aspects of NOS and how they use them to evaluate a controversial SSI about global warming. The students read contradictory reports about global warming and responded to an open-ended questionnaire related to NOS and socioscientific decision-making. Students' understandings about the tentative aspect of NOS were addressed by providing them with conflicting viewpoints related to the causes of global warming and asking them to evaluate the production of different conclusions. The social embeddedness of the scientific knowledge was assessed by asking the students to discuss the economic, personal, and social influences on global warming. Students' understandings about the empirical basis of scientific knowledge were sought out by asking them about the utility of information in different positions. The authors suggested that the understanding of several aspects of NOS influences the way in which students understand, evaluate, and discuss contradictory evidence about SSI. They concluded that conflicting conceptions about global warming aroused students' understanding of NOS and encouraged them to become more knowledgeable about the ways researchers evaluate contradictory proofs.

Summary and Research Focus of NOS and Argumentation

The limited studies addressing the relationship between students' NOS understandings and their argumentation skills have emphasized correlational studies and revealed ambiguous results. The present study will go beyond these limitations to explore whether NOS aspects can predict argumentation components by using stepwise regression analyses. Knowing how NOS and argumentation influence each other would be useful as these findings will have consequences on both the teaching of NOS and the teaching of argumentation, both of which are components of scientific literacy. Particularly, the study would test one of the arguments given for teaching students about NOS, which would be to influence their argumentation skills related to SSI (Driver et al., 1996). The importance of this study lies in providing quantitative results and deeper insight and indicating more precisely the relationship existing between students' conceptions about the three NOS aspects (subjective, tentative, and empirical) and students' argumentation skills (arguments, counterarguments, and rebuttals) in the context of two SSI. It is important to use two different SSI to study the consistency of the findings over different contexts. The research questions that guided the present study were:

1. How do Grade 10 students' conceptions of NOS contribute to the quality of their argumentation skills in the context of genetically modified food?
2. How do Grade 10 students' conceptions of NOS contribute to the quality of their argumentation skills in the context of water fluoridation?

Methodology

A quantitative approach was used in the present study where two socioscientific contexts (genetically modified food and water fluoridation) were used to study three targeted aspects of NOS (empirical, subjective, and tentative aspects) and how they relate to three aspects of argumentation (arguments, counterarguments, and rebuttals).

Context and Participants

The study was conducted in three schools, where the language of science instruction was English, selected from different geographical areas in Beirut (Lebanon). Participants were Grade 10 students ($n = 125$) from these schools: fifty students (25 females and 25 males) from school 1, 40 students (21 females and 19 males) from school 2, and 35 students (17 females and 18 males) from school 3. The average age of students was 15 years and their socioeconomic status varied between low and medium range, as evidenced from the income-based fees charged at the selected schools, which are acceptable in comparison with other private schools. The participants in all three schools have not experienced any explicit instruction about NOS or argumentation. Moreover, participants have not directly engaged in the science content related to genetically modified food or water fluoridation.

Ethical approval was received from the University's Human Research Protection Program (HRPP). The author informed the school administrators, parents, and students about the purpose of the study and received their permission.

Data Sources and Instruments

A quantitative methods approach was used in the present study where the quantitative analyses were in the form of stepwise regression analyses in the *Statistical Package for the Social Sciences* (SPSS). As such, the socioscientific contexts (genetically modified food and water fluoridation) were used to study three targeted aspects of NOS (empirical, subjective, and tentative) as three variables and how they relate to argumentation skills as three variables (arguments, counterarguments, and rebuttals).

Data using a questionnaire and interview were collected on the participants' understandings and argumentations skills in two socioscientific contexts (genetically modified food and water fluoridation) regarding three targeted aspects of NOS (empirical, subjective, and tentative aspects) and how they relate to argumentation skills (arguments, counterarguments, and rebuttals). The rationale underlying the use of NOS aspects (subjective, tentative, and empirical) as the independent variables and the argumentation components (argument, counterargument, and rebuttal) as the dependent variables is based on the developmental sequence of epistemological understandings extending from childhood to adolescence to early adulthood where individuals move from absolutists (unquestionable knowledge) to multiplists (idiosyncratic knowledge) to evalutivists (shared norms of knowing). This developmental sequence has been considered a significant predictor of argumentation skills—that is the development of arguments, counterarguments, and rebuttals and the reported relationships between learners' overall epistemological beliefs and the different argumentation skills and epistemological understanding as a significant predictor of all three components of argumentation skills in relation to different SSI.

Questionnaire

An open-ended questionnaire (Appendix), *Controversial Socioscientific Issues Questionnaire (CSI)*, was used in this study. It involved two scenarios addressing SSI about genetically modified food and water fluoridation. Each scenario was accompanied by two sets of questions that address argumentation and NOS. First, participants were required to generate an argument, a counterargument, and a rebuttal, and to justify them. Counterarguments represented arguments held by another person, who disagreed with their position. Rebuttals are presentations that represented the participant's response to the counterargument. Second, participants were asked questions to elicit their views about the tentative, empirical, and subjective aspects of NOS. These NOS aspects have been selected in previous research for their close alignment with SSI (Khishfe, 2021). The following items illustrate the general nature of the questionnaire:

> (c) Another scientist, Professor Ponso, disagrees with your decision. How could he explain his position to illustrate the reasons supporting it and convince you?
> (f) Do you think the knowledge about genetically modified food might change in the future? Explain why or why not.

Item (c) asked about Professor Ponso's position and his reasons, which addressed the participant's counterargument. While item (f) asked whether scientific knowledge might change in the future, which addressed the participant's understanding about the tentative and empirical aspects of NOS.

The psychometrics of the questionnaire were established in a previous study (Khishfe, 2012). The content validity was explored by the input of experts (two science educators, three biologists, two ethics professors, and three high school biology teachers). Minor changes and edits were undertaken in the questionnaire based on expert feedback. Moreover, the clarity of the questionnaire was pilot-tested with 20 Grade 10 participants from another school and followed up by interviewing six students. The results of the pilot study showed the suitability of the questionnaire for the intended group of participants in fulfilling the purpose of the study. At the same time, the test–retest reliability was found to be 0.87 when the questionnaire was administered to a group of 40 high school students and then the questionnaire was administered again to the same group with a two-week time interval between testings.

Interviews

Individual semi-structured interviews were administered after the completion of the questionnaire in order to validate the questionnaire with this group of participants. The interviews were conducted with a random sample of 20% of the participants ($n=25$). Ten students were randomly selected and interviewed from school 1, eight from school 2, and seven students from school 3. During the interviews, students were provided their questionnaires and they were asked to explain and clarify their responses as well as give additional examples. Additional probing and elaborating questions were used to enrich their responses. The interviews were consistent across the three schools and lasted between 35 and 50 min.

Data Analysis

The section on data analysis is divided into three parts: (a) describing the preliminary coding of the students' NOS and argumentation response (Tables 1 and 2); (b) reporting the validity and reliability results of the 25-student subsample of interview and questionnaires; and (c) describing the stepwise analysis of the coded questionnaire responses.

The preliminary data analysis involved participants' argumentation and participants' conceptions of NOS. First, the researcher and another science education researcher coded the argumentation and NOS responses according to a 3-category scoring rubric. The three argumentation components (argument, counterargument, and rebuttal) were addressed. The responses relating to participants' argumentation components were categorized into naïve (1 point), intermediary (2 points), or informed (3 points). The ordinal categorization of each component was done in accordance with an established rubric (Khishfe, 2021; examples provided about genetically modified food in Table 1): (a) a naïve category was given when the participant's response did not exhibit a claim or the exhibited claim was not aligned with any piece of evidence; (b) an intermediary category was given when the participant's response exhibited a claim that related to one piece of evidence and/or there was no valid reasoning to connect between the evidence and the claim; and (c) an informed category was given when the participant's response showed a claim that related to more than one piece of evidence and there was valid reasoning to connect between the evidence and the claim.

The NOS aspects (subjective, tentative, and empirical) considered the responses relating to participants' conceptions were categorized into naïve (1 point), intermediary (2 points), or informed (3 points). The categorization of these NOS aspects was done in accordance with the rubric used in previous studies (Khishfe, 2008, 2012; examples provided about genetically modified food in Table 2): (a) a naïve category was assigned when the participant's response did not reflect what is accepted by science educators about the conceptions of that particular aspect of NOS; (b) an intermediary category was assigned when the participant's response involved multiple co-existing conceptions contradicted each other; and (c) an informed category

Table 1 Examples of participants' responses related to argumentation skills

	Argument	Counterargument	Rebuttal
Naive	We should produce genetically modified rice (S10, Questionnaire)	Professor Ponso would tell me that he is right (S16, Questionnaire)	I would say that I will not change my decision (S59, Questionnaire)
Intermediary	Genetically modified rice needs to be produced because it helps to prevent blindness by improving vitamin A intake (S35, Questionnaire)	Professor Ponso should say that this modified rice helps to reduce blindness among children (S78, Questionnaire)	My response is that this would help save the sight of children to a large extent (S7, Questionnaire)
Informed	GM rice needs to be produced as this will address vit. A deficiency so helps to prevent blindness. And there are no studies that have shown any dangers related to genetically modified food (S99, Questionnaire)	The professor would respond that rice should not be produced because of the danger of contamination plus a balanced diet is a better solution (S114, Questionnaire)	If the professor told me that we should not produce it because a healthy diet is better then I would tell him that not all poor families can afford a healthy diet and the research has not shown danger with genetically modified food (S41, Interview)

Table 2 Examples of participants' responses related to NOS aspects

	Subjective	Tentative	Empirical
Naive	It is not possible that scientists reached different conclusions when looking at the same data about genetically modified rice (S36, Questionnaire)	The knowledge about genetically modified food would not change in the future (S100, Questionnaire)	The knowledge about genetically modified food should not change (S28, Questionnaire)
Intermediary	Scientists can reach different conclusions because they have different perspectives …the reason scientists reached different conclusions since they were looking at different data (S86, Interview)	The knowledge about genetically modified food will change in the sense of adding new data to the knowledge (S43, Questionnaire)	The knowledge would change with new evidence… after the knowledge is established it will not change with new studies (S118, Interview)
Informed	Scientists reach different conclusions because they look at data from different angles due to different backgrounds (S124, Questionnaire)	I think the knowledge about genetically modified rice would change as we get new data so scientists would reconsider their knowledge (S64, Interview)	The change in the knowledge about genetically modified rice is based on the new data from research (S22, Questionnaire)

was assigned when the participant's response reflected what is accepted by science educators about the conceptions of that particular aspect of NOS.

It is important to note that the different categories given to the three different variables related to argumentation (argument, counterargument, and rebuttal) were based on participants' responses to the three different items (b, c, and d) that followed each of the two scenarios. As for the different categories given to the three different variables related to NOS (subjective, tentative, and empirical), they were based on participants' responses to the three different items (e, f, and g) that followed each of the two scenarios.

To simplify matters and to address the purposes of the present study, all the variables (argument, counterargument, rebuttal, subjective, tentative, empirical) were changed from being ordinal variables (three categories) into binary variables (two categories). This was done by grouping the naïve and intermediary categories into a single category referred to as uninformed. That resulted in two categories (uninformed and informed) for the different variables, where a value of 0 was given for the uninformed category and a value of 1 was given for the informed category.

It is important to note that the 25 interviews and their corresponding questionnaires were independently analyzed to categorize participants' argumentation components and conceptions of the emphasized NOS aspects. The 25 pair-wise comparisons of the participants' interviews and corresponding questionnaire responses for the two scenarios revealed no discrepancies. This finding added confirmation of the face validity of the open-ended questionnaire for this particular sample (Lederman & O'Malley, 1990). The inter-rater reliability was found to be about 86%. All differences in the coding were settled through discussions and consultations of the divergent codes to reach a consensus.

The research questions explored how students' conceptions of NOS contribute to the quality of their argumentation skills in the context of the two SSI. Stepwise multiple regression analyses in the SPSS were performed to address the two research questions. Stepwise regression analysis is a step-by-step iterative build-up of a regression model that involves adding or removing predictor variables in order to find a set of independent variables that significantly influence the dependent variable. Then, three stepwise regression analyses were performed for each of the two scenarios. The three NOS aspects (subjective, tentative, and empirical) were used as the independent variables and each component of argumentation (argument, counterargument, and rebuttal) was used as the dependent variable in the three stepwise regression analyses performed. The same procedure was repeated for the second scenario.

Results

The following reports the results related to the two scenarios. The report about the genetically modified food scenario presents the descriptive results, the correlations, and the regression results that address the three stepwise regression analyses of the argumentation and NOS responses corresponding to the first research question. Similarly, the report for the second scenario about water fluoridation presents the descriptive results, the correlations, and the regression results that address the three stepwise regression analyses of the argumentation and NOS responses corresponding to the second research question.

Scenario About Genetically Modified Food

Descriptive Results

Results show that less than 18% of participants generated informed arguments, counterarguments, and rebuttals involving claims that related to more than one piece of evidence with valid reasoning to connect the evidence and the claim for Scenario I (Table 3). The majority of participants constructed arguments with no claims, claims not aligned with evidence, claims that related to one piece of evidence, and/or there was no valid reasoning to connect the evidence and the claim. Analysis of the NOS results indicated that about one-quarter of participants provided informed conceptions of the subjective aspect of NOS (Table 3), while less than 14% exhibited informed conceptions of the tentative and empirical aspects for Scenario I. The majority of participants held naïve and intermediary conceptions of the NOS aspects.

Table 4 presents the descriptive statistics of the different variables related to the scenario about genetically modified food. The means for the different variables related to argumentation components and NOS aspects are presented along with the standard deviations after the variables were changed from being ordinal variables (three categories) into binary variables (two categories).

Correlations and Regression Results

The correlations examined the associations among the argumentation and NOS variables for the genetically modified food scenario (Table 5). The three argumentation variables (argument, counterargument, and rebuttal) are significantly correlated ($p < 0.01$) with the empirical aspect of NOS. The argument and rebuttal variables are significantly correlated ($p < 0.01$) with the tentative aspect of NOS and the rebuttal variable is significantly correlated ($p < 0.01$) with the subjective aspect of NOS.

The stepwise regression analyses related to the scenario about genetically modified food revealed that the tentative aspect of NOS significantly predicted the argument and the empirical aspect of NOS significantly predicted the counterargument, while the tentative and subjective aspects significantly predicted the rebuttal. Table 6 presents the model summary from the three stepwise regression analyses with the descriptive details of these models.

The first stepwise regression analysis with the NOS aspects (subjective, tentative, and empirical) as the independent variables and argument as the dependent variable resulted in one model showing that the tentative aspect of NOS significantly predicted it accounting for 13% of the variance ($p < 0.001$).

The second stepwise regression analysis with the NOS aspects (subjective, tentative, and empirical) as the independent variables and counterargument as the

Table 3 Descriptive results for the argumentation components and NOS aspects for the two scenarios

		Argument	Counterargument	Rebuttal	Subjective	Tentative	Empirical
Scenario							
Genetically modified food							
	3 (informed)	17% (21)	18% (22)	4% (5)	27% (34)	9% (11)	14% (18)
	2 (intermediary)	49% (61)	37% (47)	43% (54)	42% (52)	51% (64)	27% (34)
	1 (naïve)	34% (43)	45% (56)	53% (66)	31% (39)	40% (50)	59% (73)
Water fluoridation							
	3 (informed)	15% (19)	11% (14)	6% (8)	23% (28)	6% (8)	10% (12)
	2 (intermediary)	54% (68)	46% (57)	46% (57)	38% (48)	39% (49)	23% (29)
	1 (naïve)	31% (38)	43% (54)	48% (60)	39% (49)	55% (68)	67% (84)

Table 4 Descriptive statistics for the argumentation components and NOS aspects for the two scenarios

	Variable	Mean	Standard deviation
Scenario			
Genetically modified food			
	Argument	0.17	0.38
	Counterargument	0.18	0.38
	Rebuttal	0.04	0.20
	Subjective	0.28	0.45
	Tentative	0.10	0.28
	Empirical	0.14	0.34
Water fluoridation			
	Argument	0.14	0.34
	Counterargument	0.10	0.31
	Rebuttal	0.06	0.25
	Subjective	0.21	0.41
	Tentative	0.04	0.20
	Empirical	0.08	0.27

Table 5 Correlations between the examined variables of argumentation and NOS for the two scenarios ($N = 125$)

	Variable	Subjective	Tentative	Empirical
Scenario				
Genetically modified food				
	Argument	0.53	0.36**	0.30**
	Counterargument	0.04	0.14	0.29**
	Rebuttal	0.24**	0.28**	0.20**
Water fluoridation				
	Argument	0.08	0.16	0.06
	Counterargument	0.21*	0.20*	0.19*
	Rebuttal	0.11	0.45**	0.28**

*Correlation is significant at the 0.05 level ($p < 0.05$)

**Correlation is significant at the 0.01 level ($p < 0.01$)

dependent variable resulted in one model. The model revealed that the empirical aspect of NOS significantly predicted it with the empirical accounting for 8% of the variance ($p < 0.001$).

The third stepwise regression analysis with the NOS aspects (subjective, tentative, and empirical) as the independent variables and rebuttal as the dependent variable resulted in two models. The models revealed that the tentative and subjective aspects of NOS significantly predicted it with the tentative accounting for 8% of the variance ($p < 0.01$) and the subjective accounting for an additional 3% of the variance ($p < 0.01$).

Table 6 The model summary with the descriptive details from the three stepwise regression analyses for the two scenarios

Scenario	Dependent variable	Predictor variable	*B*	*SE B*	*β*	*F*
Genetically modified food						
	Argument	Tentative	0.46	0.11	0.36	18.55***
		Subjective	−0.03			
		Empirical	0.12			
		R^2		0.13		
	Counterargument	Empirical	0.31	0.09	0.29	11.22***
		Subjective	0.01			
		Tentative	−0.09			
		R^2		0.08		
	Rebuttal (model 1)	Tentative	0.22	0.07	0.28	10.06**
		Subjective	0.18			
		Empirical	0.04			
		R^2		0.08		
	Rebuttal (model 2)	Tentative	0.18	0.07	0.23	7.37**
		Subjective	0.09	0.05	0.18	
		Empirical	0.05			
		R^2		0.11		
Water fluoridation						
	Argument	None				
	Counterargument	Subjective	0.16	0.07	0.21	5.84*
		Tentative	0.16			
		Empirical	0.15			
		R^2		0.05		
	Rebuttal	Tentative	0.56	0.10	0.45	30.72***
		Subjective	0.02			
		Empirical	0.06			
		R^2		0.20		

B unstandardized regression coefficient, *SE* standard error, *β* standardized regression coefficient

*Significant at the 0.05 level ($p < 0.05$)

**Significant at the 0.01 level ($p < 0.01$)

***Significant at the 0.001 level ($p < 0.001$)

Scenario About Water Fluoridation

Descriptive Results

Results show that less than 15% of participants generated informed arguments, counterarguments, and rebuttals involving claims that related to more than one piece of evidence with valid reasoning to connect between the evidence and the claim for Scenario II (Table 3). The majority of participants constructed arguments with no claims, claims not aligned with evidence, claims that related to one piece of evidence, and/or there was no valid reasoning to connect between the evidence and the claim. Analysis of the NOS results indicated that less than one-quarter of participants showed informed conceptions of the subjective aspect of NOS (Table 3) while a minority of participants exhibited informed conceptions of the tentative and empirical aspects for Scenario II. The majority of participants held naïve conceptions of the NOS aspects.

Table 4 presents the descriptive statistics of the different variables related to the scenario about water fluoridation. The means for the different variables related to argumentation components and NOS aspects are presented along with the standard deviations after the variables were changed from being ordinal variables (three categories) into binary variables (two categories).

Correlations and Regression Results

The correlations examined the associations among the argumentation and NOS variables for the water fluoridation scenario (Table 5). The counterargument variable is significantly correlated ($p < 0.05$) with the three NOS aspects (subjective, tentative, and empirical). The rebuttal variable is significantly correlated ($p < 0.01$) with the tentative and empirical aspects of NOS.

The stepwise regression analyses related to the scenario about water fluoridation revealed that none of the three NOS aspects significantly predicted the argument, while the subjective aspect of NOS significantly predicted the counterargument, and the tentative aspect significantly predicted the rebuttal. Table 6 presents the model summary from the three stepwise regression analyses with the descriptive details of these models.

The first stepwise regression analysis considered the NOS aspects (subjective, tentative, and empirical) as the independent variables and the argument as the dependent variable. This analysis revealed that none of the three NOS aspects significantly predicted the argument.

The second stepwise regression analysis considered the NOS aspects (subjective, tentative, and empirical) as the independent variables and counterargument as the dependent variable. This analysis revealed in one model that the subjective aspect of NOS significantly predicted it accounting for 5% of the variance ($p < 0.05$).

The third stepwise regression analysis considered the NOS aspects (subjective, tentative, and empirical) as the independent variables and rebuttal as the dependent variable. This analysis revealed in one model that the tentative aspect of NOS significantly predicted it accounting for 20% of the variance ($p < 0.001$).

Discussion

The results revealed that students struggled to provide informed valid arguments, counterarguments, and rebuttals and demonstrated naïve understandings of NOS, which could be attributed to the fact that neither explicit argumentation nor NOS instruction was provided in the design of the study or part of the participants' prior classroom instruction. The primary focus of this study was to highlight the correlation among NOS and argumentation aspects. The study provided supportive, but varied, empirical evidence of the connectedness between argumentation and NOS knowledge in the two SSI (water fluoridation and genetically modified food).

The first research question asked if the NOS aspects could contribute significantly to the quality of students' argumentation skills in the context of genetically modified food. Results from the stepwise regression analyses showed that the tentative aspect of NOS is a significant predictor of the argument, and the empirical aspect is a significant predictor of the counterargument. Moreover, the results showed that the tentative and subjective are significant predictors of the rebuttal. The second research question asked if the NOS aspects could contribute significantly to the quality of students' argumentation skills in the context of water fluoridation. Results from the stepwise regression analyses showed that the subjective aspect of NOS is a significant predictor of the counterargument, and that the tentative aspect of NOS is a significant predictor of the rebuttal.

The finding related to the empirical aspect of NOS being a significant predictor of the counterargument is not surprising since understanding the empirical aspect of NOS would require the learner to relate scientific conclusions to justifications based on data and evidence. Similarly, solid counterarguments should be based on abundant and strong evidence. Accordingly, a change in the understanding of the empirical aspect of NOS would explain the change in the counterargument of participants. Furthermore, the finding that the tentative aspect of NOS being a significant predictor of the argument and rebuttal can be expected. Developing informed conceptions about the tentative aspect of NOS requires learners to understand that science can undergo change. Hence, when learners exhibit developed understandings of the tentative aspect of NOS, they might exhibit cognitive flexibility and be less resistant to change. Eventually, they will be more capable of providing arguments and rebuttals. As for the finding that the subjective aspect is a significant predictor of the counterargument, it can be explained by relating to the different perspectives involved in a counterargument. The subjective aspect entails understanding that scientists can look at the same data yet reach different conclusions. That relates to participants' ability to generate counterarguments, which are claims different than what learners believe in.

The finding that the subjective, tentative, and empirical aspects are significant predictors of argumentation indicates that changes in students' understandings of the subjective, tentative, and empirical aspects of NOS would probably lead to changes in their argumentation. This entails that integrating NOS instruction into the science classroom would most likely enhance the learning of argumentation. This finding would support one of the arguments for teaching NOS where the understanding of NOS is necessary for informed argumentation and decision-making related to SSI (Driver et al., 1996).

The other finding of the study is related to the correlation and regression differences between the two scenarios. This can be attributed to the notion that students exhibit different conceptions of NOS (Khishfe, 2017; Hofer, 2006) and different argumentation in relation to different topics or contexts. This inconsistency in students' NOS conceptions and argumentation across different contexts might explain the different results obtained with the two different scenarios. At the same time, specific contextual factors like students' prior content knowledge about the SSI discussed or students' personal relevance with the SSI (Khishfe, 2012) might have contributed to the differences between the two socioscientific contexts (genetically modified food and water fluoridation) demonstrated in this study. Students' content knowledge could influence their argumentation and the justification of their positions (Sadler & Fowler, 2006). Means and Voss (1996) had claimed that the number and types of reasons related to students' argumentations are significantly related to their content knowledge. However, the lack of evaluation of such contextual factors prevents us from asserting the effect of these factors on the linkage between argumentation and NOS. A subsequent study exploring the effect of such contextual factors (e.g. content knowledge) might enhance the understanding of the relationship between NOS and argumentation.

These findings are aligned with those of Mason and Scirica (2006) who found that the overall epistemological understanding significantly contributed to the quality of participants' argument, counterargument, and rebuttal in the context of both global warming and genetically modified food. However, they took epistemological understanding as one entity. While NOS (part or subset of epistemological understanding) in the present study was taken as different aspects (namely subjective, tentative, and empirical). Similarly, Wu and Tsai (2011) found that participants' scientific epistemological beliefs were linked to their ability to provide rebuttals indicating developed and advanced argumentation skills. Along the same lines, Khishfe (2012) demonstrated a significant correlation between the ability of high school students to form counterarguments and their understandings of the subjective, tentative, and empirical aspects of NOS.

However, no correlation between argumentation and NOS among high school students was documented by Walker and Zeidler (2007) who found that participants were not able to exhibit their NOS views in their argumentation even when there was explicit instruction about both ideas. Furthermore, there were several insufficiencies within the students' arguments, and they were not able to provide evidence-based reasoning in their decision-making processes. Similarly, no significant correlations between argumentation components and NOS views (tentative, empirical, and subjective) were found by Khishfe et al. (2017) in the context of four SSI (global warming, genetically modified food, acid rain, and human cloning) when there was no explicit instruction of NOS and of argumentation.

Implications and Future Research

A clear outcome of this study is related to linking informed conceptions of NOS to high-quality argumentation in the context of SSI. Future studies designed with the aim of understanding the relationship between NOS and argumentation might investigate that relationship in different contexts to address varying prior content knowledge among participants in relation to other topics and thereby identify the effect of contextual factors, as previous knowledge and personal relevance, on the relationship between NOS and argumentation. Future research studies can also address this relationship between NOS understandings and argumentation skills in different scientific contexts (Jin et al., 2021). Additionally, extensive studies are needed to further explore the connectedness between NOS and argumentation with different participants (e.g. preservice science teachers, elementary students).

A significant implication of this study is related to the finding that the empirical, tentative, and subjective aspects of NOS are significant predictors of argumentation components. In that sense, this would provide a case for the teaching of NOS and highlights the importance of developing students' understandings of these aspects of NOS, which would enhance students' argumentation skills, a critical objective in science education. In order to do that, teachers need to create norms in their classrooms that foster explicit instruction of NOS (Bilican et al., 2021) to develop students' understandings of the empirical, tentative, and subjective aspects of NOS, in order to promote argumentation skills among students. Towards that goal, the findings of this study highlight the need to develop teacher education programs for preservice science teachers in order to help them to incorporate NOS ideas and argumentation skills in their lesson plans as well as to guide them on how to implement them in the science classroom.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10763-022-10307-0.

Declarations

Ethical Approval and Consent to Participate The study reported in this paper had the American University of Beirut-Institutional Review Board (AUB-IRB) approval (FAS.RK.02). Informed consent was obtained from all student participants included in the study.

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