



# Investigation of Preservice Science Teachers' Nature of Science Understanding and Decision Making on Socioscientific Issue through the Fractal Model

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## Abstract

The paper reports a qualitative study to reveal how preservice science teachers' decision making (DM) processes on socioscientific issue (SSI) in a referendum case compare between unsophisticated (Group U) and sophisticated (Group S) views in terms of nature of science (NOS) understandings. Firstly, pre-study was conducted with focus group interviews with pre-service science teachers. With the findings, one-on-one semi-structured in-depth interviews of the main study for DM on SSI, the artificial meat was developed. In the main study, 12 participants' responses were analyzed, and a new DM model named the Fractal Model of DM which reflects real-life situation DM process, especially referendum case, was constructed. In DM, NOS lens usages of five NOS aspects about creativity and imagination, observation and inference, empirical-basis, subjectivity, and social and cultural embeddedness and 23 other lens usages such as animal rights (morality), economic, and risk factor were detected and explained through the fractal model. Findings showed that there is a hidden and complex effect of NOS understandings about tentativeness of scientific knowledge on DM. With multiple lens usage, each participant had multi-perspective considerations in DM. While Group S used NOS lenses mainly parallel with their NOS understandings, Group U used them in a more complicated way.

## 1 Introduction

Today, socioscientific issues (SSIs) are part of science curricula worldwide (e.g., Kultusministerkonferenz [KMK] 2005; Department for Education [DFE] 2014; Ministry of National Education [MNE], 2018). Socioscientific issues (SSIs) are controversial issues which contain scientific and social aspects and include moral or ethical reasoning (Sadler, 2004a, 2004b; Zeidler & Sadler, 2008; Zeidler et al., 2005). It is argued that in a democratic society, citizens should take responsibility and make decisions about SSIs as the

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results affect all of us (DeBoer, 2011; Hofstein et al., 2011; Roth & Lee, 2004; Zoller, 1982). Therefore, understanding people's decision making (DM) on SSI is very important and can be a survival issue for humankind like today's COVID-19 pandemic.

According to Driver et al. (1996), for informed DM on SSIs, understanding the nature of science (NOS) is necessary for everyone, and this is the "democratic argument" of why we teach NOS as science teachers (Lederman, 2006). In brief, NOS can be referred to as the epistemology of science (Lederman, 2006), and it is seen as a critical component of scientific literacy (National of Science Teachers Association [NSTA] 2020), which is the ultimate goal of many science curricula (United Nations Educational, Scientific and Cultural Organization [UNESCO], 1999; Donnelly et al., 1994; Ministry of National Education [MNE], 2006, 2018).

Thus, NOS, DM, and SSIs are three naturally bound concepts which help us survive in today's world, which consists of many problems of the constitution of science-technology-society-environment that can affect our life dramatically. In the present study, how DM process about SSI occurs under NOS influence was studied by focusing on a referendum simulation. Referendums are real life DM situations in which citizens take responsibility at least with their votes; therefore, they reflect one of the best cases to understand why we try to teach NOS to "all students" as science teachers.

## 2 NOS Effect

The famous physicist Feynman (1955, p.13) states that "Scientific knowledge is an enabling power to do either good or bad—but it does not carry instructions on how to use it." However, the researchers of the present study are the ones of those people including teachers, educators, and researchers who believe that understanding NOS can illuminate the pathways of the usage of scientific knowledge.

NOS covers the philosophy, sociology, psychology, and history of science, and science educators use the term NOS to describe the intersection of issues among these disciplines, which have the potential to affect science teaching and learning (McComas et al., 1998). Despite the ongoing discussions, NOS is the epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development (Lederman, 1992). Moreover, although there are some disagreements among philosophers, historians, and science educators, a general agreement was established in seven aspects of NOS, which are (1) the tentative nature of scientific knowledge, (2) the empirical nature of scientific knowledge, (3) the subjective nature of scientific knowledge, (4) the involvement of creativity and imagination to scientific knowledge, (5) the social and cultural embeddedness of scientific knowledge, (6) the distinction between observations and inferences, and (7) the functions of and relationships between scientific theories (Lederman, 2006).

Driver et al. (1996) provided five arguments regarding the importance of NOS: understanding NOS helps individuals make sense of science and manage technology in daily life (utilitarian), participate in decision-making processes on socioscientific issues (democratic), appreciate the value of science as a part of contemporary culture (cultural), understands the norms of the scientific community that embody moral commitments that are of general value to society (moral), and have better science understanding (science learning).

Each of these five arguments is directly related with and sheds light on many important points in modern human life. Therefore, in the literature, there are many studies that focus on the improvement of the understandings about NOS (e.g., Abd-El-Khalick & Lederman,

2000; Dhingra, 2003; Lederman & Druger, 1985; Moss, 2001; Zeidler & Lederman, 1989). Moreover, the second argument of Driver et al. (1996), “democratic argument,” has a special characteristic as it is about DM. Individuals have to make decisions continuously in every part of their lives, generally in order to solve the problems varying from the very simple one to the very complicated one which might be affected by many factors (Rue & Byars, 2003). However, the number of studies focused directly on NOS effect on DM is very limited, and they serve mixed results for some cases (e.g., Bell & Lederman, 2003; Khishfe, 2012).

It is believed that as our understanding about the interaction between NOS and DM improves, at least the citizens will be close to being more responsible in their decisions, which affects their lives, and they will be close to making decisions which reflect their true choices, which is vital for all people as decisions affect our lives. Thus, it can be said that while scientific knowledge is the constitutive component of the decision, NOS is the critical component of scientific knowledge; therefore, NOS understandings have the potential to affect the usage of scientific knowledge in decision making.

### 3 Decision Making and Science Education

Decision can simply be defined as selecting one of the alternatives; however, the decision itself is not a big part of DM—it is just a bit of it (Daft, 2003, p.272). In fact, DM is a process of making reasoned choices among alternatives based upon judgments consistent with the values of the decision maker (Heath et al., 1987), and educators classified it as a life skill (Zoller, 1990; Ministry of National Education [MNE], 2018).

The importance of DM for citizens' lives and the relationship between scientific literacy and DM were firstly highlighted by the report of Royal Society (1985), whose author is W. F. Bodmer. After that, other organizations related with education, such as the American Association for the Advancement of Science [AAAS] (1989) National Research Council [NRC] (1996), and Organisation for Economic Cooperation and Development [OECD] (1999), emphasized that one component of being a scientifically literate person is making knowledge-based decisions.

Zoller (1982) criticized the weakness of the traditional curricula in equipping students with sufficient experiences needed to make them capable decision makers. Furthermore, by premeditating the “first-hand experience,” he offered a DM-oriented science and technology curriculum in which students are exposed to open-ended problems within their natural setting and provided with real DM situations, and they have opportunities to get involved in scientific-technological action. In addition, Holbrook and Rannikmae (2009) proposed redefining the relationship between “science” and “education” by emphasizing the importance of citizens' participation in DM for the goodness of society. They brought to the forefront NOS influence on DM in societal issues and offered a shift in teaching approaches from “science through education” to “education through science.”

### 4 Decision Making Models in Education

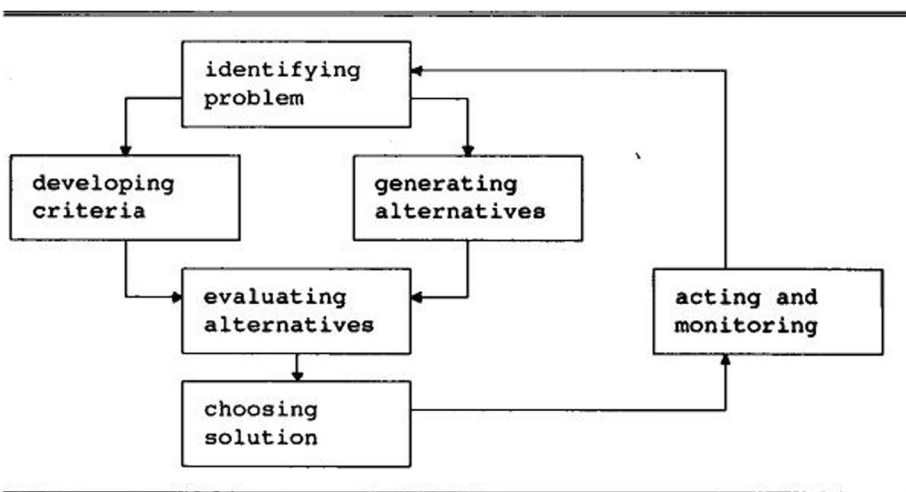
Considering professional decision makers, DM was explained by normative models, which were developed through DM theories by philosophers and economists and then were adopted by psychologists (Coombs et al., 1970; Edwards, 1954). Among other

disciplines, the appearance of normative DM models in education is relatively new, and in science education research areas, there is a shift from direct adoption of the model from a different discipline to the reformulation of the steps of models for specific use in science education research. For example, Kortland (1996), in his article “An STS Case Study about Students’ Decision Making on the Waste Issue,” brings Carroll and Johnson’s model (Fig. 1) to the forefront to discuss the Dutch junior secondary education students’ existing and developing DM ability.

However, to stimulate quality group discussions, Ratcliffe (1997) developed her well-known quality-focused six-step DM structure (options, criteria, information, survey, choice, and review) by selecting and improving the related steps of the models of Janis and Mann (1977), Hirokawa and Scheerhorn (1986), and Beyth-Marom et al. (1991). Moreover, a value-focused DM framework, offered by McDaniels et al. (1999) and Acar et al. (2010), was applied frequently in learning and teaching socioscientific DM (Fang et al., 2019). This framework includes five steps: (1) to characterize what matters to stakeholders, (2) to create alternatives, (3) to employ information to identify the impacts of the alternatives, (4) to identify the tradeoffs, and (5) to summarize the agreements, disagreements, and underlying reasons for different perspectives.

Recently, in order to analyze 24 articles (from 1995 to 2015) which directly focus on socioscientific DM and which have a clear definition of DM, Fang et al. (2019) have proposed a socioscientific DM framework based on the models of Svenson (1992), Ratcliffe (1997), and Betsch and Haberstroh (2005). This framework has three phases: (1) formulation of the DM space occurs, (2) a suitable DM strategy is posited, and (3) the post-selectional phase where metacognition plays a role and reflecting on the decision-making process occurs.

As a result, DM models have been widely used in learning and teaching SSIs (Fang et al., 2019), but these models adopted from other disciplines were found inappropriate for concrete tasks and too difficult for complex, real-world situations like SSIs



**Fig. 1** A normative model for the DM process offered by Carroll and Johnson (Carroll & Johnson, 1990; cited in Kortland 1996, p. 675)

(Aikenhead, 1989; Ratcliffe, 1997). In fact, in the literature, there was no DM model explaining the individuals' real-life DM process about SSI.

## 5 Criticism of Studies about NOS Effect on DM about SSI

Although separately, DM, SSI, and NOS literature are based on the studies over many decades, the intersection of these three literatures is relatively new and limited. In fact, there are six studies focusing directly on NOS effect on DM about SSI as follows:

- (1) Bell (1999), Bell, and Lederman (2003) attempted to explicate the role of NOS in DM on science and technology-based issues and identify factors and reasoning associated with these types of decisions. They focused on four SSIs: fetal tissue implantation, global warming, diet and cancer, and cigarette smoking and cancer. Their sample was well-educated adults, and they separated 18 volunteers from universities into two groups (Group A: consistent with current conceptions of NOS; Group B: inconsistent with current conceptions of NOS). Then, profiles of each group's DM were constructed based on participants' responses to the DM questionnaire and follow-up interviews. Finally, the two groups' decisions, decision influencing factors, and DM strategies were compared.
- (2) Zeidler et al. (2002) investigated the relationships between students' conceptions of NOS and their reactions to the evidence challenging their beliefs about SSIs. Firstly, Zeidler et al. evaluated 248 participants' (147 from high school physics and biology classes and 101 from university pre-service elementary science methods classes) NOS conceptions and collected their beliefs about animal rights through questionnaires. Then, by purposefully selecting 82 participants to obtain pairs with different levels of variation (low/high) based on an ordinal scale for their belief convictions, they conducted a qualitative study with semi-structured interviews about animal rights using one of the two reports with "exactly the same content" but different titles ('Report Supports Animal Testing for Medical Research' or 'Report Supports Computer Modelling for Medical Research'). In this way, they collected the students' confidence level about the findings.
- (3) Walker and Zeidler (2003) aimed to identify the relationship between students' NOS understandings and their decisions on SSI. They assessed 50 students' concern levels about three controversial issues (global warming, water fluoridation, and genetically modified foods) and decided to focus on genetically modified foods. They purposefully selected 36 students from 9 to 12th grade at a suburban vocational education school and separated them into two groups (20 participants for the pilot study and 16 for the actual study). They administered the Nature of Scientific Knowledge Scale (NSKS) to students, and each group had introductory discussions about NOS with a semi-structured interview through the Views on the Nature of Science Questionnaire (VNOS). Then, the students watched a video about the controversy of genetically modified foods and were provided with a series of online activities and follow-up interviews.
- (4) Sadler et al. (2004) aimed to explore student conceptualizations of NOS and their interpretations and evaluations of conflicting evidences of SSI. Eighty-four high school biology students read contradictory reports about global warming and answered a five-item open-ended questionnaire constructed to elicit students' NOS understandings and

- factors influencing socioscientific DM. To triangulate data from the written responses, 30 students were also interviewed.
- (5) Liu et al. (2010) aimed to explore the interaction between scientific epistemological views (SEVs) and the reasoning process in socioscientific DM. They collected data from 177 college students (60% science and 40% non-science majors) in three public universities with SEV instrument and 5 weeks later with a DM questionnaire. DM instrument contained an informative text with different perspectives about the battle against exotic species *Mikania micrantha* and a set of open-ended questions.
  - (6) Khishfe (2012) investigated the influence of explicit NOS instruction on high school students' DM. She designed a quasi-experimental research with 90 9th graders in a public school by forming 4 groups (two treatments and two comparisons as regular/honor students). All groups received a 4-week unit which consisted of instruction and activities about genetic engineering and how to formulate arguments and make decisions related to this controversial issue. Only the treatment groups additionally received explicit instruction about the application of NOS aspects in formulating arguments and DM. At the beginning of the treatment, Khishfe conducted a NOS questionnaire first and then the scenario about genetically modified food to all groups to collect participants' written responses. Four weeks later, at the end of the treatment, she conducted the same questionnaires in the same order with all participants for the same reason. To establish the validity of the questionnaire and the scenario, she randomly selected 5 individuals from all groups after each application and gave them an opportunity to clarify their responses verbally with an interview.

All these six previous studies served valuable information to the literature, and their findings can be summarized that although epistemology involvement in DM was detected (generally with multi-perspective reasoning), no, or indirect, or very limited NOS effect on DM about SSI was reported. Moreover, when the previous studies are investigated, four main criticisms arise: (i) not using a DM model, (ii) selecting SSI without focus group interviews to understand the participants' true interest level and prior knowledge about SSI, (iii) assessing NOS through issues different from SSI studied, and (iv) collecting mainly written responses.

Firstly, none of the studies above were constructed on a DM process model; therefore, the researchers strictly focused on the "decision" itself, which is only one of the several steps of DM, and they did not adequately cover "decision making" as a process. Secondly, they missed to consider personal relevance to selected SSI as the participants' true interest level and prior knowledge about used SSI was not determined through a focus group. Students' personal interests in a particular SSI were seldom reported, and issues about how to select an appropriate SSI were in the dark (Fang et al., 2019). However, DM process is affected by people's readiness to make a decision, priorities among existing problems, and ways of collecting information (Bettman et al., 1991; Svenson, 1996). Moreover, in line with Fraenkel and Wallen's (2006) methodological approach, for a proper analysis, selected SSI should be clearly understandable, interesting, and familiar to participants, and participants' prior knowledge should be similar in that SSI. Thirdly, NOS was mainly assessed through issues different from the SSIs focused on. Khishfe (2012) used the same SSI in her study to assess the understandings about NOS, but it was only for one aspect of NOS, the tentativeness of scientific knowledge. Therefore, it seems that the previous studies ignored the possibility of NOS differences in different scientific disciplines. However, Lederman (2006) mentioned that different

scientific disciplines may have different definitions of NOS. Finally, data analyses conducted were mainly based on the written responses. Actually, some interviews were made in some of the previous studies (e.g., Bell & Lederman, 2003; Khishfe, 2012), but only after the questionnaires for clarification purposes. Although questionnaires are generally preferred by researchers for their advantages they provide in terms of time and effort spent on data analysis, one-to-one interviews, especially in-depth interviews, are much more efficient in collecting detailed information, and they serve many more advantages mainly with regard to the validity and quality of the study (Boyce & Neale, 2006).

## 6 Research Question

The aim of this study is to determine the influence of the nature of science (NOS) understandings on decision making (DM) about a socioscientific issue (SSI). To achieve this aim, DM patterns of two groups of pre-service science teachers, (i) Group U which consists of the members who had unsophisticated NOS understandings and (ii) Group S which consists of the members who had sophisticated NOS understandings, were compared through the Fractal Model of DM in the light of the main research question: How are DM processes about an SSI operated by Group U and Group S participants in a referendum case?

## 7 Method

This study is a qualitative research grounded theory study which focuses on a referendum simulation as it was a real-life DM and it responds to four criticisms of the previous studies. Firstly, in the present study, DM was considered as a process, and a new DM model, “The Fractal Model of Decision Making” was constructed directly through the participants’ responses in referendum simulation about SSI. Secondly, in the beginning, Focus Group interviews were conducted to select an appropriate SSI. Thirdly, NOS understandings were analyzed specifically through the selected SSI—artificial meat. Finally, as spoken language is more productive than written one as a medium for expressing ideas (Horowitz & Berkowitz, 1964), all data were collected through verbal expressions with semi-structured in-depth interviews.

## 8 Research Design

NOS effect on DM about an SSI was still left to be much unexplored with its dynamics as none of the previous studies (e.g., Bell, 1999; Khishfe, 2012) considered DM as a process. Moreover, this study was the first to cover a referendum situation about an SSI, and in the literature, there were no defined structures to explain the way of thinking about an SSI of ordinary referendum participants. Therefore, gathering sophisticated data directly from the participants was necessary to develop an understanding about the issue. Because it is the research strategy to enable systematic discovery of theory from the data (Glaser & Strauss, 1967), grounded theory was used, and its main emphasis is on the knowledge gained during the investigation (Hunter et al., 2005). In the present grounded theory study, parallel with Cutcliffe’s (2000) viewpoint, a literature review was made before data gathering and

analyzing to complete lack of information in the research area and to have a more rational perspective. With the suggestion of Baş and Akturan (2008), purposeful sampling was used, and direct involvement in all data gathering process was preferred (Nakip, 2003). To have more representative results for the real situation, more than one data gathering technique were used (Backman & Kyngas, 1999). At first, focus group interviews were conducted to understand potential participants' basic social process, basic social psychological process, and main concerns related with the studied issue (Charmaz, 2006; Glaser, 1978) in order to compare and contrast the potential participants' subjectivity to understand their readiness which affects DM (Bettman et al., 1991).

The focus group sample was selected among the potential participants of the main study, and it reflected the theoretical sample mentioned in the grounded theory study (Cutcliffe, 2000). Appropriate with the spirit of the grounded theory study, both the focus group and the in-depth interview questions were semi-structured, and even after the pilot studies (which are for focus group interviews questions and for the questions in one-to-one interviews of the main study including the questions about separating participants through their NOS understandings), they evolved from one application to the other (Hancock et al., 2009). In grounded theory, the analysis begins as soon as the first bit of data is collected (Corbin & Strauss, 1990, p.6). In fact, in the present study, the constant comparative method (Glaser & Strauss, 1967) was conducted with the comparison of data with data, data with codes, and codes with codes during not only data collection but also after all data were collected. All three codings of grounded theory (open coding, axial coding, and selective coding) represented by Corbin and Strauss (1990) were made through the collected data. Moreover, expert opinions were vitally important in the present study, and they directly shaped the process of the grounded theory in each time. More specifically, in the present study, the discussions with experts (mainly with three professors on science education at a university) helped the researchers develop new insights and increased theoretical sensitivity for the sake of grounded theory, just like Corbin and Strauss (1990) emphasized.

## 8.1 Sample

At first, a pre-study was conducted with focus group interviews with 13 second-year female pre-service science teachers aged between 21 and 23 at one of the biggest universities in Turkey in the spring semester to develop a data gathering tool with an appropriate SSI selection for the in-depth interviews in the main study. One year later, in-depth interviews were conducted with 16 (according to NOS understandings, 12 were selected for further analysis) third-year female pre-service science teachers aged between 21 and 24 at the same university. Of the 13 participants in the pre-study, 7 participated in the main study, too. The sampling was purposive to express a range of different levels of sophistication in terms of NOS with similar backgrounds.

## 8.2 Data Analyses

Qualitative content analysis was used to identify the focus group characteristics, to separate the participants into groups according to their NOS understandings, to construct a DM model for the referendum situation, and finally for the main study itself to understand NOS effect on DM about SSI. To achieve dependability, a second coder established codes through more than 15% of the data selected randomly. With the formula of Miles and Huberman (1994) intercoder, reliability was calculated as 92%. After that, the themes that



were constructed differently were discussed by two coders, and an agreement was settled through them.

### 8.3 The Pre-study with Focus Group Interviews

Focus group interviews were used to identify the type of SSI potential participants were interested in most and to understand their interest level, methods of collecting information, and discussion styles about SSIs. These interviews were conducted with two inner groups, one with 6 members and the other one with 7. Approximately 2 h of interviews were made with each group in different sessions. To start a discussion, semi-structured questions such as “Which SSIs do you find most emergent? Why?” were asked to whole focus group at once.

### 8.4 The Artificial Meat as an SSI

In the light of the focus group interviews, the artificial meat was selected as a focused SSI for the main study. This issue consists of unstructured problems in uncertainty conditions as scientists are still working on it. It is directly related with the food technologies and nourishment and also can easily be connected to healthiness, which were the two interest areas the focus group liked to discuss most and thus is familiar with. It has come to the agenda in the last decade, which is the focus group's interested time period for SSIs. There are some taboos about the consumption of meat products in Turkey, mainly because of the reflections of the dominant religion. Therefore, the artificial meat is a controversial issue from the perspective of Turkish people and people with similar interests and concerns about meat products.

### 8.5 Data Gathering Tool for the Main Study

Besides all the process of pre-study conducted with focus group interviews, the development of the data gathering tool for the main study took 6 months, including its own pilot studies. After the selection of the artificial meat as the SSI to make a decision in the referendum simulation, wide research was done about it on the Internet as it was the basic information source of the focus group. Then, the information from the Internet was classified, simplified, and rearranged according to the focus group's general characteristics. Detailed descriptions of data gathering tool and procedures can be found Adal (2019).

One-to-one semi-structured in-depth interview technique was used in the main study. A five-part information instrument was constructed: “News about the Artificial Meat,” “The Production Procedure of the Artificial Meat,” “Opinions of the Scientists Who Work on the Artificial Meat,” “Opinions from Worldwide about the Artificial Meat,” and “Opinions of Turkish People about the Artificial Meat.” Moreover, 82 semi-structured questions (including 22 questions such as to assess the participants' NOS understandings and 3 questions to understand the participants' opinions about referendum and committee) were prepared to operate the “referendum” simulation. Mainly, in the interviews, semi-structured questions such as “What do you think about this opinion/this news?” were asked after the participant read a new piece of information in order to reveal participants' NOS and other lenses usages. There were also some follow-up questions such as “Which information makes you more satisfied? Why?” The interviews included two ballots: the first one was to collect

initial responses just after the participants read the news about the artificial meat which contains almost no useful information to decide whether the artificial meat should be sold in Turkish markets, and the second one was just after all information about the artificial meat was provided. The interviews of the main study took approximately two and a half hours.

## 8.6 Participants' NOS Understandings

Six NOS aspects, stated by Lederman (2006), were focused on: The Tentative Nature of Scientific Knowledge (NOS1), The Creative and Imaginative Nature of Scientific Knowledge (NOS2), Observation and Inference in Science (NOS3), The Empirical Nature of Scientific Knowledge (NOS4), The Theory-Laden Nature (subjectivity) of Scientific Knowledge (NOS5), and The Social and Cultural Embeddedness of Scientific Knowledge (NOS6). Moreover, although NOS aspect "The Distinction Between Scientific Law and Theories (NOS7)" was considered during the lens analyses of the main study, it could not be placed on participants' NOS understandings' section of the data gathering tool as the collected Internet-based information (related with news, production procedure, opinions, etc.) did not let to do that.

In the interviews, between the informing parts "The Production Procedure of the Artificial Meat" and "Opinions of the Scientists Who Work on the Artificial Meat," there was a group of questions which directly focused on examining the participants' NOS understanding specifically through the artificial meat. For example, the question "What is Mark Post (the scientist who work on the artificial meat in the news) trying to solve by doing artificial meat studies?" and then the question "If there were a Turkish scientist working on this issue, what do you think she/he was trying to find a solution to?" were used to determine mainly participants' NOS2, NOS5, and NOS6 understandings.

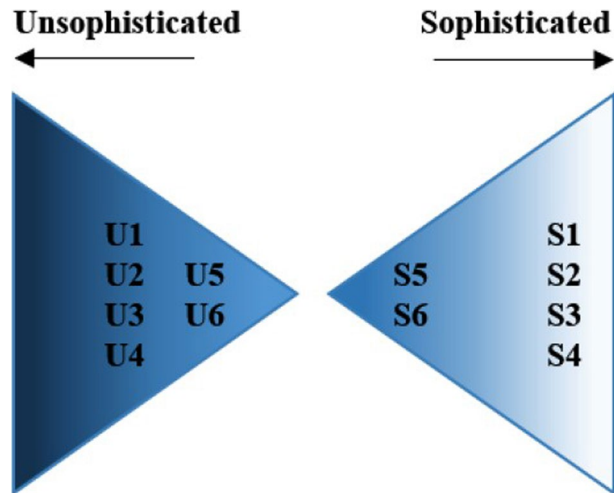
More specifically, in the data gathering tool, there was more than one question which was constructed to specifically measure the participants' understandings about only one NOS aspect. Moreover, there were questions like the ones above which focused on more than one NOS aspect. In other words, in the interviews, multiple questions were used to understand the participants' understanding of each NOS aspect. In this way, the internal validity of this section was established.

With the content analysis of all responses through the codes based on Lederman's (2006) statements, 12 of 16 participants were found appropriate to be placed into the groups (six for Group U and six for Group S) according to the similarities in their NOS understandings. The gaps between two groups in understandings of the aspects NOS1, NOS3, NOS5, and NOS6 were large. However, the gap between two groups in understandings of the aspect NOS2 was relatively small. Moreover, the participants' understandings were very close in NOS4. There were also some variations within each group. As seen in Fig. 2, none of the participants placed into Group U expressed totally unsophisticated NOS understandings mainly because of their sophisticated understandings about NOS4 and NOS2. However, the participants placed into Group S generally expressed understandings very close to be totally sophisticated.

## 8.7 DM Model Constructed for the Present Study

In the referendum, time flow in thinking was different from what the normative models present because the referendum had offered a ready solution to the comprehended

**Fig. 2** The positions of the members of Group U and Group S according to their general level of NOS understandings



problem(s) about the issue and, in fact, an already selected alternative to its participants, in this case, “the artificial meat.” The referendum ended with voting “YES” or “NO” for a solution, and its participant felt no need to “develop” real alternatives to a particular problem. In the referendum, being ordinary citizens, the participants had no special education about DM process, and they even did not have enough experiences with DM process as businessmen or politicians do. In this way, the participants did not feel any additional need to organize and check their thinking in DM process.

The analysis of the main study showed that different from what the professional decision makers are expected to do, in the referendum simulation, the participants did not follow one-by-one linear DM steps in the normative models such as in that of Ratcliffe (1997). Instead, the participants thought through some main questions:

- (i) For which reason is the artificial meat produced?/Why will we use the artificial meat?/What will artificial meat cause?—*in this study, it is labeled as thinking region about “goals.”*
- (ii) What should/must the qualification of the artificial meat be?—*in this study, it is labeled as thinking region about “criteria.”*
- (iii) What can be compared with artificial meat?—*in this study, it is labeled as thinking region about “alternatives.”*

The thinking regions, “goals,” “criteria,” and “alternatives,” were so dominant in DM process in the referendum simulation that they were even clearly observable in the very early responses; for example, just after the participants read the news about the artificial meat while they were answering simple questions such as “Have you heard about this news?” or “Do you have any information about this issue?” Table 1, Table 2, and Table 3 show respectively how “goals,” “criteria,” and “alternatives” aroused in these early responses to artificial meat.

For more detail, below there are three representative quotations which show the direct responses to one of the initial questions “what attracted your attention to this news most?”.

**Table 1** Quotation examples for thinking region about “goals” of the artificial meat just after reading the news of the artificial meat

Sbj	Quotation
U2	I think they all done to make money
U6	After all, not all people can directly eat meat. In this way, maybe it will be cheaper. People need protein in the end, and they need to take protein somehow
S2	There are a lot of hungry people in the world. They can't eat meat, but in this way, they may feel the taste of meat at least
S6	I may think of it like they will be able to increase the nutritional value of it, but now I feel like they prepared the news just to say, “we made it, we achieved this, it's here!”

**Table 2** Quotation examples for thinking region about “criteria” of the artificial meat just after reading the news of the artificial meat

Sbj	Quotation
U1	It has to be used carefully, it has to be made, developed carefully. [...] They have tried it, too
U5	Beet syrup, saffron, what is in it, what is used attracted my attention. I want to know what is in the thing I eat and how they added the flavor
S1	If it is produced in hygienic conditions, it might be beneficial because otherwise, we don't know how hygienic the other produced things
S5	But they have done this with a budget of over €250.000. I mean, was that really necessary? I mean, when doing science, its cost should also be taken into consideration after all

**Table 3** Quotation examples for thinking region about “alternatives” of artificial meat just after reading the news of the artificial meat

Sbj	Quotation
U3	The logic behind is most probably about not cutting animals. Therefore, I felt that it might be produced from herbs. By using plants, they might have tried to make it similar to meat
U4	If they spent this much money on agriculture and animal husbandry, we would overcome a lot of things in natural ways
S3	For example, since we wouldn't be able to obtain that protein structure or other values that we obtain from the normal meat or since we would get something with a different organic structure, this time something in our own body might change
S4	I've just had my climate change course a minute ago. There, for example, they are continuously talking about the fact that red meat should be consumed less. When we have something artificial, this will increase, so you know, this seems like a bad possibility although it is artificial

With these quotations, it can be clearly understood that some participants started to talk about the issue through highlighting “goals,” while some others started through “criteria” or “alternatives” of the artificial meat.

S5: In fact, I considered why they needed to make something like this the most. (Thinking region "goals": question the hidden aim)

U4: [What I thought about] the most is that spending that amount of money but getting this amount of meatballs. (Thinking region "criteria": cost)

U1: I didn't like it, actually. When these kinds of things become common, they will reach us too, and we can eat healthy meat or meat which is produced in this kind of laboratory environment. (Thinking region "alternatives": Normal meat)

Moreover, it was frequently observed that a participant responded to similar questions by starting to talk about "goals," "criteria," or "alternatives" about the artificial meat. Furthermore, a participant generally used more than one thinking region quickly while responding. As a representative for this issue, the following example which shows responses to the questions of "Do you think the advances about the artificial meat are positive or negative? Why?":

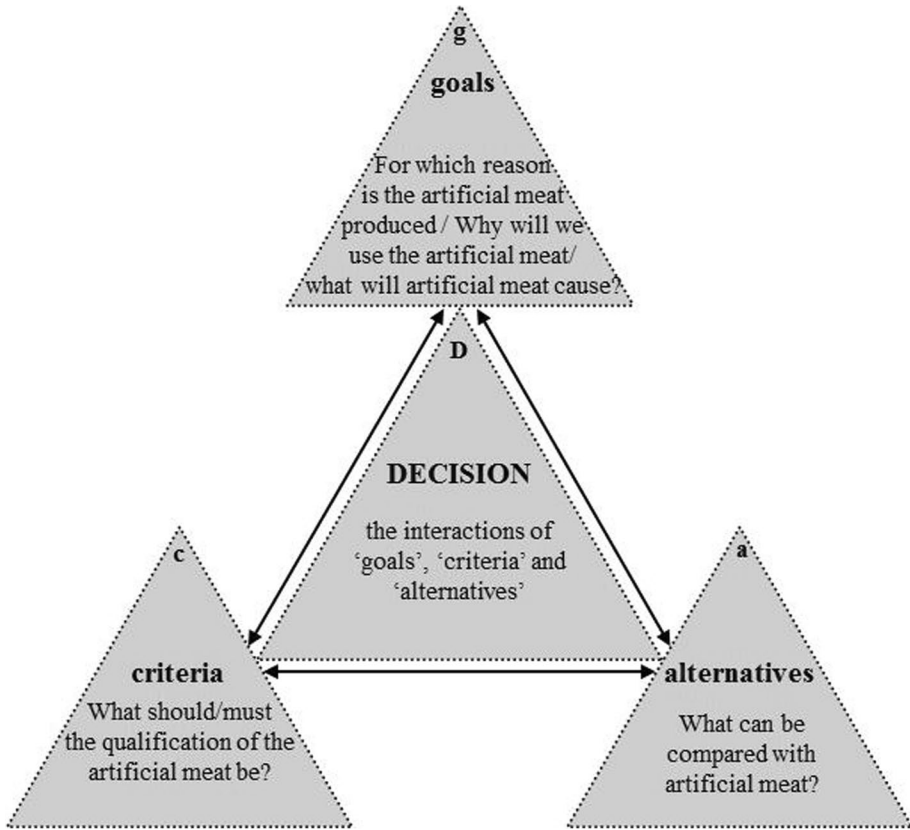
U3: You know now animals are produced in farms (*alternatives: Animal husbandry*). So this [the artificial meat] might be beneficial to prevent that (*goals: to protect the animals under bad conditions in animal husbandry/ to prevent the animals from being killed for food*). But spending a lot of money is the other side of the issue (*criteria: Cost*).

Therefore, it was understood that with an overall look, in participants' thinking systems, the thinking regions come to exist simultaneously. Moreover, during the referendum simulation, the participants expressed double way relationships among "goals," "criteria," and "alternatives." Furthermore, the participants frequently tried to make a decision about the artificial meat, such as whether they would use it or not, even before it was directly asked to them. Thus, there was an additional thinking region, which was labeled as a "decision." However, different from all other three thinking regions, "decision" was the thinking region which cannot exist by itself but seems to exist through the interactions of "goals," "criteria," and "alternatives" and therefore is continuously fed from them. For example, with the quotation of U1, it is understood that one side of the decision is constructed through the interactions between "goals" and "criteria".

U1: It [the artificial meat] has to be used carefully; it has to be made, developed carefully (*criteria: Production procedure*). It is something nice, but where is it going to be used? That's the question. What use does it have? Is it going to be given to people (*goals: Question to hidden aim*)? It shouldn't, I think (*decision*). They have tested it, too (*criteria: Being experimented*). But it shouldn't spread (*decision*), people may try it, taste it (*goal: to satisfy scientific curiosity/to develop science*), but that's it. It shouldn't increase, spread the world, reach us (*decision*).

The following quotation of U6 is a good example to represent more complex interactions among thinking regions as here 'decision' is constructed by the interactions among "goals," "criteria," and "alternatives."

U6: As a result, not everybody can eat meat (*alternatives: Normal meat*) directly. In this way, maybe it [the artificial meat] will become cheaper (*criteria: Price*), people need protein in the end, and they need to obtain this protein in one way or another. I mean, it would be easier [to reach protein] (*goals: to decrease the price of meat and provide meat for poor people*). The body takes that protein in a way, but how beneficial is that?



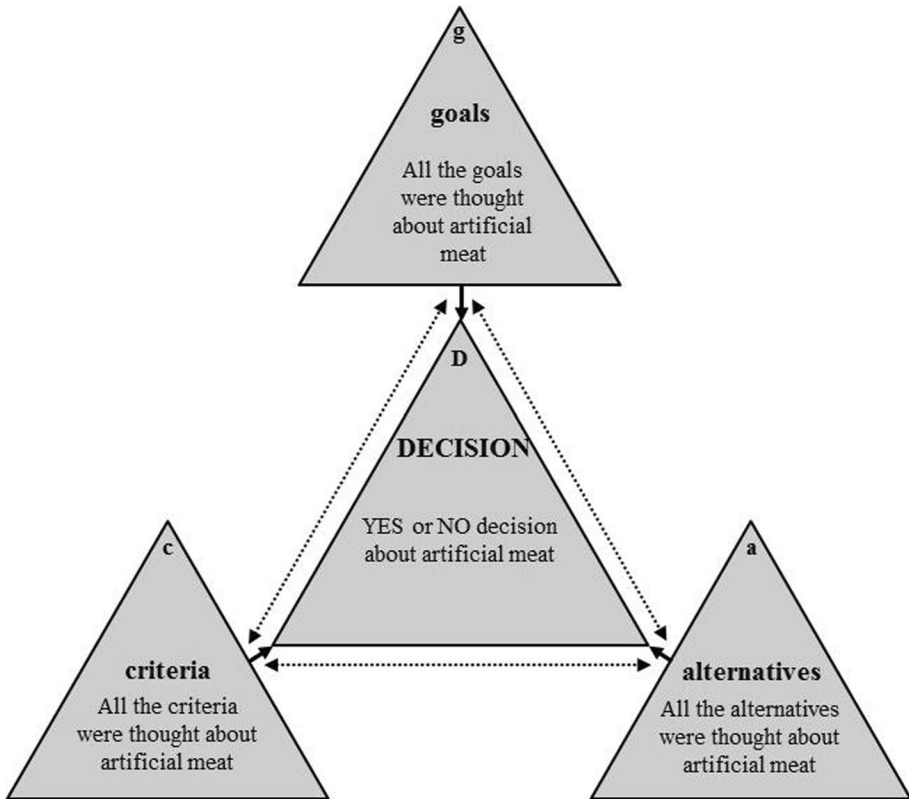
**Fig. 3** The Fractal Model of DM: the mechanism of DM process

Does it give any harm (*criteria: Healthiness*)? We cannot know this. You know, it cannot be as healthy as normal natural meat (*decision*).

Therefore, through the findings of the main study, the Fractal Model of DM in Fig. 3 and Fig. 4, which respectively show the mechanism of DM process and the final structure of DM process after the decision is made, was constructed in order to conceptualize the participants real thinking system in a referendum situation.

The Fractal Model of DM reflects 4 main distinctive properties when compared with the other DM models (e.g., Carroll & Johnson, 1990; Fang et al., 2019; Ratcliffe, 1997) in the literature:

1. The Fractal Model of DM about referendum required thinking regions about “goals,” “criteria,” “alternatives,” and “decision” which replaced the steps of the normative models in the literature. Appropriate with the nature of DM in a referendum case, thinking regions appeared simultaneously in the model, which is different from the linear steps following each other one-by-one in other models.
2. The Fractal Model of DM for the referendum illustrates the double way relationships among “goals,” “criteria,” and “alternatives” and the “decision” determined by these



**Fig. 4** The Fractal Model of DM: the final structure of the model after the decision is made

relationships. In this way, it also puts forward the spirit of the natural thinking process which is described in the literature as following, and therefore, it makes it possible to make interpretations going beyond the previously formed structure where DM steps follow each other. In the literature, it was stated that “If you want to pass across a brook running through the mountains, you hop from one stone to another or you zigzag. This passing across the brook is similar to thinking—it is mixed or disorganized but goal-oriented” (Adair, 2000, p.35).

3. “The Fractal Model of Decision Making” is the first model in DM literature which includes fractal geometry to represent ordinary people’s thinking systematic. The Fractal Model of DM is a moving (with lines getting clear and blurred again) fractal (the whole and its pieces exhibit similar patterns). The fractal geometry is the continuation of the theory of chaos and is used to explain the situation where the inputs become outputs, just like in DM. Therefore, the fractal model is suitable to be used in more complex issues, especially when it is necessary to make a series of decisions, as it can provide an ontological change in the steps of the DM process. With the fractal model, it is possible to see the previous decision itself, for example, as a problem or criterion of a new DM process. Thus, this fractal model includes the explanations of Adair (2000) which are “A problem is a kind of solution or the subtle version of the solution which is embedded

in the problem (p.33) and “The decision creates the problem” (p.35). Therefore, when a decision is made through this model, this decision can be incorporated into a new DM process easily. In this way, it also serves as an additional help to check for the effectiveness of the decision. According to Robbins and Coulter (2012), the implementation of the decision and, therefore, the effectiveness of the decision are inherent in the DM process and in order to get good results, it has to be examined.

4. The Fractal Model of DM about the referendum reflects the etymological meaning of the word used in Turkish and the one in the language of this study, English.

The word “karar” (decision) is transferred to Turkish from the Arabic language, and the word “karar,” which is derived from the root “kr” means staying, being stable, consistent, final opinion or option. What is implied here is general orderliness, and in our case, we can interpret this as solving the problem (whether the artificial meat should be sold in markets or not) and ending the chaos.

As for the word “decision” in English, it is seen that this word is related to the words cutting, scissors, separating in Latin. What is implied here is distinguishing between two different things, and this can be considered as transitioning from a problematic or chaotic situation to orderliness in our specific case. As a result, the “decision” which has taken shape through the interactions among “goals,” “criteria,” and “alternatives” leaves its components and becomes an entity that can be seen on its own (and can be integrated with other problems). Moreover, “goals,” “criteria,” and “alternatives” take their final forms, their interactions among each other become blurred, and their boundaries become clear. Moreover, at this stage, The Fractal Model of DM is coherent with Lederman’s (2006) NOS approach. However, there are more than one approach towards NOS (e.g., Erduran & Dagher, 2014). The efficiency of this model in other NOS approaches has not been tested yet.

## 9 Results

In this section, the data of the main study were analyzed through the Fractal Model of DM to understand the NOS effects on the DM process about an SSI were reported.

### 9.1 Thinking Regions in DM

In the interviews, 17 “goals” were mentioned:

- Deal with starvation and scarcity.
- Protect the animals under bad conditions in animal husbandry/prevent the animals from being killed for food.
- Satisfy the scientific curiosity/develop science.
- Produce healthier and more quality meat.
- Deal with the global warming.
- Make profit.
- Taste and consume the meat of exotic or endangered animals.
- Provide fresh meat for the astronauts in space.
- Decrease the price of meat and provide meat for poor people.
- Provide everyone with quality, cheap and healthy meat.



- Question the hidden aim.
- Provide economic development/open up new employment opportunities.
- Meet the people's increasing meat needs with an increase in population.
- Become a step of another scientific study like transplantation.
- Develop war technologies.
- Reduce nutritional value in order to deal with obesity.
- Vary the way of nutrition.

In the interviews, 16 “criteria” were mentioned. All participants mentioned healthiness, ingredients, and nutritive value; flavor; effects on animals; cost; production procedure; and being experimented, and all of them appeared in “decision.” The other “criteria” were price, being natural, texture/viscosity/color consistency, economic effects, legality, environmental effects, variation in usage area, effects on society, and religious approval.

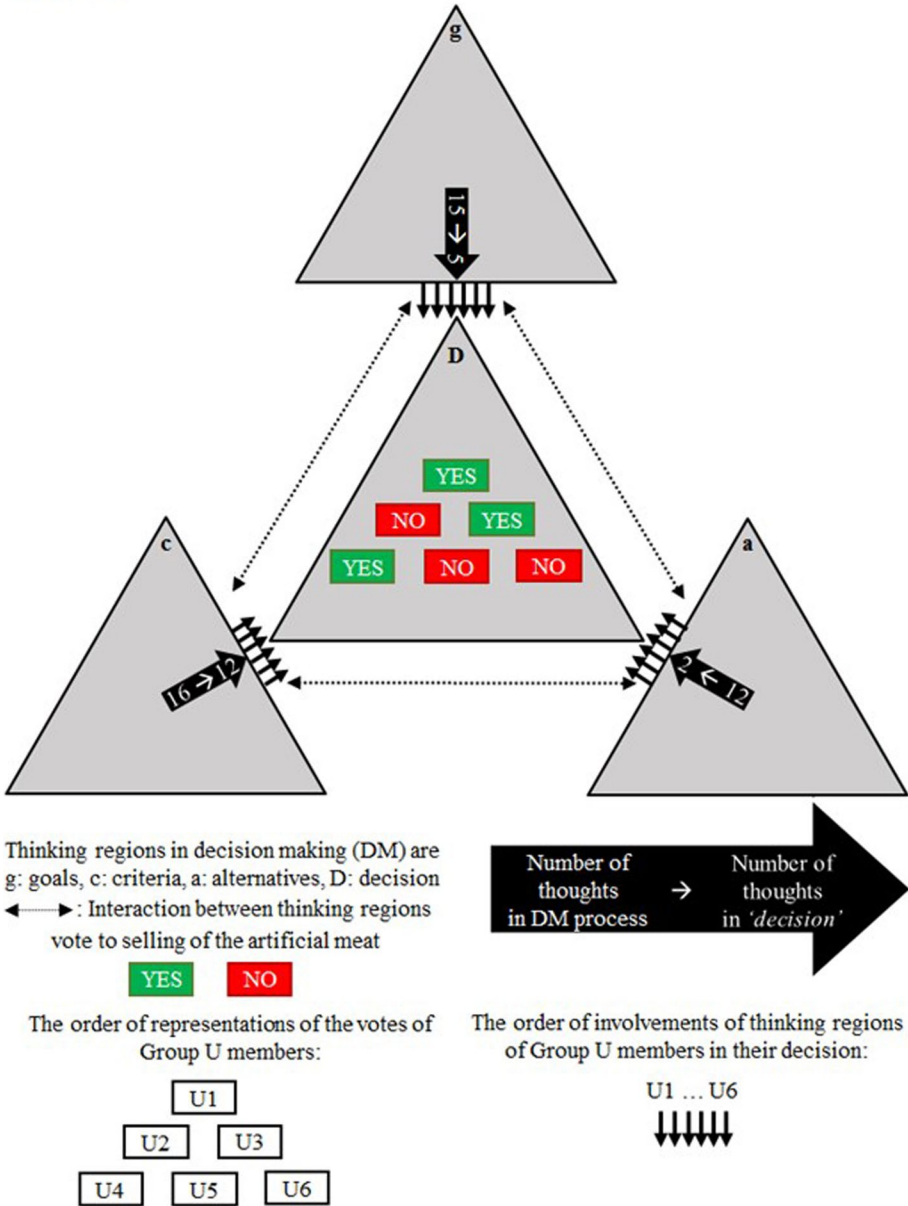
The participants mentioned 12 “alternatives.” It was understood that at the beginning of the interview, the participants thought about the “alternatives” to understand what the artificial meat is. However, as the DM process proceeded, they started to evaluate the effectiveness of the artificial meat by comparing it with its “alternatives” such as normal meat, genetically modified (GM) foods, plant-based meat-like product, and synthetic meat which were thought by all participants. Moreover, animal husbandry was a very common “alternative” in DM process, and it appeared in decision with very high frequencies like normal meat did. Other “alternatives” in DM process were fast foods/processed food, artificial tissues, and organs; supporting green housing and agriculture, dealing with the reasons for starvation and scarcity, balancing income distribution, changing the nutritional habits; and environmental protection works.

In the present study, the “decision” revolved around the question “Should the artificial meat be sold in Turkish markets or not?” As seen in Fig. 5 and Fig. 6, respectively, for Group U and for Group S, the “decision” was made by many connections among thinking regions: “goals,” “criteria,” and “alternatives.” However, for both groups, there were particular decreases especially in the numbers of “goals” and “alternatives” which are directly observable while shaping the “decision” when they are compared with the numbers of thoughts in DM. More specifically, for example, according to the wider arrow inside “goals” in Fig. 5, members of Group U mentioned a total 15 goals in DM process, and only 5 of these were directly observable in their “decision.” Moreover, with the short thin six black arrows from “goals” to “decision” in Fig. 5, it is understood that all members of Group U stated “goals” in their “decision.” When the wider arrow inside “goals” in Fig. 6 is examined, it is understood that Group S stated 16 “goals” in DM and mentioned only 6 of these in their “decision.” Furthermore, there are four short thin black arrows from thinking regions “goals” to “decision” in Fig. 6, and the lack of two of these arrows shows that two members of Group S (based on the locations, they are S2 and S4) did not mention any goals in their decision.

## 9.2 NOS Lens Usages in DM

With the analysis and in the light of the studies by Lederman (2006) and Khishfe (2012), a total of 10 codes were reached related with sophisticated and unsophisticated NOS lens usage for five aspects (in Table 4 with their representative quotations in given thinking regions). In the present study, “NOS understandings” and “NOS lens usages in DM” are different terms; one refers to participant’s existing perceptions about NOS aspects, and the

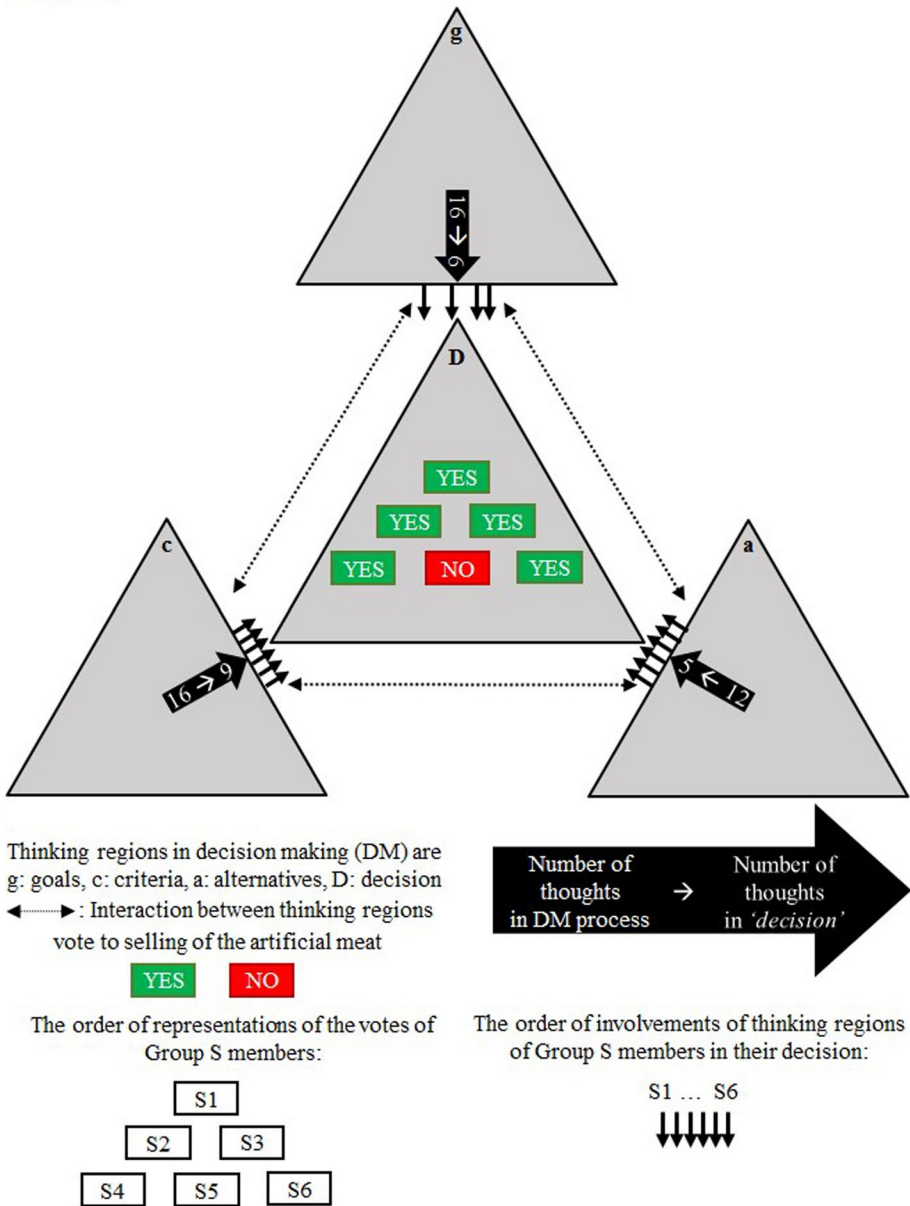
**GROUP U**



**Fig. 5** The overall demonstrations of Group U for the connections between “goals-decision,” “criteria-decision,” and “alternatives-decision” in DM

other refers to how these NOS understandings were activated in DM process. Therefore, mathematically, it is possible to reach findings such as that a sophisticated participant can adopt an unsophisticated NOS lens usage in DM or vice versa.

**GROUPS**



**Fig. 6** The overall demonstrations of Group S for the connections between “goals-decision,” “criteria-decision,” and “alternatives-decision” in DM

Firstly, no direct findings about NOS1 lens usages were reached, although there was a very wide gap between NOS1 understandings of Group U and Group S. Secondly, there were no strict differences between the general understandings about NOS2 of the groups; however, during the DM process about the artificial meat, Group S used sNOS2 lens

**Table 4** NOS lens usage codes in DM process related with the artificial meat and its alternatives with the representative quotations in stated thinking regions

NOS lens	Codes for sophisticated NOS lens usage with the representative quotations	Codes for unsophisticated NOS lens usage with the representative quotations
Creativity and imagination (NOS2)	<p>To appreciate the scientists' creativity and imagination in doing science (sNOS2)</p> <p>S6: <i>This is an expected, consistent opinion even from scientists' point of view. Scientists are open to innovation. [...] Many people might not be able to think of it. Maybe, even me not accepting it is because of the fact that I cannot imagine it. That's why scientists have dreamt about it, and dwelled on what kind of an environment it could happen or worked on his/her imagination to see what form it could take. (sNOS2 → Goal: to taste and consume the meat of exotic or endangered animals)</i></p>	<p>To find the scientists' creativity and imagination odd/ To see using creativity and imagination in science as moving away from doing science (uNOS2)</p> <p>U4: <i>[the opinion I fall for] Group 4. [...] Well, because they don't have an opinion conflicting with me, like saying, out of the blue, we should eat pandas [...] These ones [Group 4] look into it in every aspect rather than running after craziness [like Group 3] just because they are scientists... (uNOS2 → Goal: to taste and consume the meat of exotic or endangered animals)</i></p>
Observation and inference (NOS3)	<p>To highlight the inferences which are strictly aligned with the data or observations/ To mean that the data have different interpretations as the observations and inferences are different kinds of scientific knowledge (sNOS3)</p> <p>S6: <i>(While evaluating Type 2 vegetarians' inferences which are not strictly aligned with data or observation) How much should that fluid [the fluid taken from pregnant cattle] be? Would that do any harm on the offspring? They talk about it without knowing its dose. They are prejudiced about it being completely harmful. (sNOS3 → Criteria: Effects to animals)</i></p>	<p>To highlight the inferences which are not aligned with the data or observations/ To mean that the data have only one interpretation as if the inferences were the sum of observations (sNOS3)</p> <p>U2: <i>(While evaluating Type 2 vegetarians' inferences which are not strictly aligned with data or observation) For one thing, some things are obtained from animals, and we do not approve the use of fluids taken from those extremely beautiful pregnant cattle [they said]. It is true that you spoil their natural pregnancy period [...] And neither do we exactly know what the content of this production is [they said]. That's what exactly I'm trying to say. We do not know what exactly everything is, and what is in it. In fact, we consume something we do not know... Well, it has many things... damages.. that's what exactly I have been trying to say right from the start. (uNOS3 → Goal: to protect the animals under bad conditions in animal husbandry/ prevent the animals from being killed for food → Criteria: Healthiness/ Ingredients and nutritive value, Production procedure)</i></p>

Table 4 (continued)

NOS lens	Codes for sophisticated NOS lens usage with the representative quotations	Codes for unsophisticated NOS lens usage with the representative quotations
Empirical-basis (NOS4)	<p>To tend to look for scientific knowledge, which is resulted from scientific process and inquiry (sNOS4)</p> <p><i>S1: This [TUBITAK] not only reflects a scientific point of view but it also reflects the perspectives of animal rights advocates The researcher: How did you understand that it [TUBITAK] justifies a scientific point of view?</i></p> <p><i>S1: Because some research studies have been looked into, and they have gone over some data. (sNOS4 → Goal: To deal with starvation and scarcity, To protect the animals under bad conditions in animal husbandry/ prevent the animals from being killed for food)</i></p>	<p>To feel insufficient need to look for scientific knowledge, which is resulted from scientific process and inquiry (uNOS4)</p> <p><i>U1: I voted yes. It has many benefits, but I do not know how this will affect my health in the long-term. That's why this would be a bit of a question for me. [...] When I look into this process, the genetics have not been altered or so, and I considered that it would not have an adverse effect on our health. (uNOS4 → Decision: YES should be sold)</i></p>
Subjectivity (NOS5)	<p>To consider that the scientist express different and personal perspectives because of the differences in their characters, personal qualities, experiences, and working background (sNOS5)</p> <p><i>S1: A scientist might not be able to see something on his/her own. S/he might only be doing certain tests, but another scientist can come along and have a different point of view.... S/he can say let's have this and that. Let them have a look at it, you know, in this respect, it might have a drawback. You know, when the more the scientists are, the more point of views there will be. Research might also intensify as they won't all be doing research on the same things. (sNOS5 → Criteria: Healthiness)</i></p>	<p>To load a standard and strict character, personal quality and behavior on the scientists/ To expect objectivity from the scientists/ To give over credibility to the scientists by ignoring the differences in the working area (uNOS5)</p> <p><i>U6: Scientists are not of the same opinion on GMO either because they do not know its outcomes. But in general, people are against it. The case of not being of the same opinion is a result of everyone thinking differently. For one thing, it could have detriments, but it might not be harmful according to that person. If s/he doesn't have much of a scientific approach or not objective about it, s/he might think that way. However, a scientist should be objective. (uNOS5 → Alternative: GMO foods → Criteria: Healthiness)</i></p>

Table 4 (continued)

NOS lens	Codes for sophisticated NOS lens usage with the representative quotations	Codes for unsophisticated NOS lens usage with the representative quotations
Social and cultural embeddedness (NOS6)	<p>To consider the interaction between science and society (sNOS6)</p> <p>S5: <i>In fact, I wondered more why they needed to do something like this. Because you see, these things, things like GMO products, are generally produced to decrease the cost after all. But they have done this with a budget of over €250,000. I mean, was that really necessary? I mean, when doing science, its cost should also be taken into consideration after all. Because we cannot separate science financially or politically from anything, but it sounded different. Actually, some of it was spared for the research process. (sNOS6 → Goal: To decrease the price of meat and provide meat for poor people → Criteria: Production procedure, Cost → Alternative: GM foods)</i></p>	<p>To ignore the interaction between science and the society/ To see the scientists be isolated from the society which they are in (uNOS6)</p> <p>U4: <i>(The evaluation of Group 3 scientists' opinions) What do I think about now when I say this [I find producing different animals' meat unnecessary], the environment I live in affects me, my personal belief affects me, my religious belief affects me. But a scientist should have a more objective approach. (uNOS6 → Goal: To taste and consume the meat of exotic or endangered animals)</i></p>

generally by agreeing that in almost all scientific process steps, there is a need for creativeness and imaginativeness, while Group U generally used uNOS2 lens by thinking that a scientist should not use creativeness and imaginativeness in some steps especially in inferring from the data. As for both groups, NOS2 lens usages were observed in only "goals" of DM with a very specific issue, it was concluded that the effectiveness of NOS2 lens in ruling DM is very low.

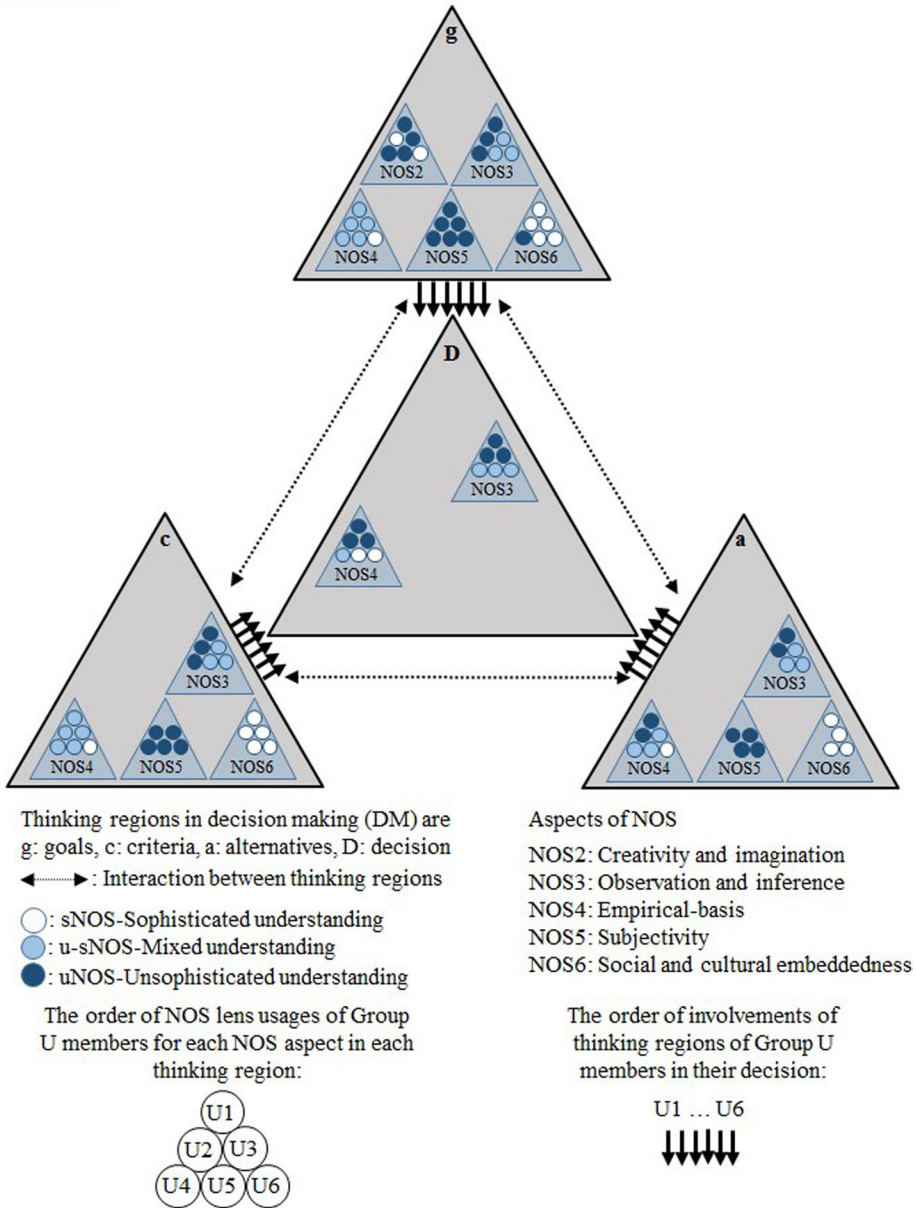
Thirdly, while Group S used sNOS3 lens in the whole DM process, half of Group U used only uNOS3 lens, and the other half tended to use u-sNOS3 mixed lens. This situation was not unexpected as Group U has such kind of heterogeneity in their NOS3 understandings. NOS3 lens directly and heavily affected the DM processes depending on the users' NOS3 understandings. The quotation of U2 in Table 4 is representative for uNOS3 lens usage on the "goals" and "criteria" of the DM process as it clearly shows how excited U2 was when she considered the "Second Type Vegetarians" (who are against the artificial meat, unlike the First Type Vegetarians who are for the artificial meat) unscientific opinions, and she rapidly made inferences related with the issue by using these opinions without needing any scientific data or observations. However, all members of Group S heavily searched the dependence on scientific data or observation in the opinions they met.

Moreover, Group U tended to reflect some relatively more unsophisticated approaches about NOS4 than Group S did, although there were no differences in NOS4 understandings among the participants. In fact, Group U had u-sNOS4 mixed lens usages as they used both uNOS4 and sNOS4 lens in DM. However, Group S frequently used sNOS4 lens in line with their NOS4 understandings in DM apart from "decision." Furthermore, the frequencies of NOS5 lens usages were far lower than those of NOS3 and NOS4 for both groups, and a direct usage of NOS5 lens was not observed in "decision" either. Group U used unsophisticated, and Group S used sophisticated NOS5. At first sight, these findings look similar to that of most of the previous studies. However, after a deeper analysis which showed that Group U gave over credibility to the scientists who work on the artificial meat and they thought that these scientists can decide on the healthiness of the artificial meat like a doctor can, it was understood that "subjectivity" lens may behave as contact lenses on eyes instead of lenses used in eyeglasses. Therefore, "subjectivity" lenses were on the participants' eyes in all DM processes. Finally, although Group U had unsophisticated understandings about NOS6, they could generally consider the interaction between science and society by wearing sNOS6 lens. Similar to Group S, Group U gave proper place to the conditions of Turkey in their DM process, which already includes directly Turkish context. For example, U3's following quotation selected from her response to the question "what can be the disadvantages of the artificial meat?", which was asked at the beginning of the interview only after she read the news about the artificial meat, is representative for how the members of Group U put forth the criterion flavor by talking about this criterion through a cultural basis.

U3: It might be the taste, it's something cultural in the end, and eating that kind of stuff might affect the taste. We start taking pills in cartoons, you see, and we feel satisfied with it. In fact, the taste is also an important sense for humans. This could affect it. There is nothing else I can think of. (sNOS6 Criteria: Flavor)

Indeed, almost all members of Group U made considerations through Turkish food culture, and they approached the criterion flavor through a cultural emphasis. Only U4 had unsophisticated NOS6 lens usage in a specific issue, and the quotation of U4 can be seen in Table 4.

**GROUP U**



**Fig. 7** The overall demonstrations of Group U for the usage of NOS lenses in DM

Moreover, the overall group demonstrations of usages of NOS lenses in DM are stated in Fig. 7 for Group U and Fig. 8 for Group S, and with these figures, it can easily be concluded that only NOS3 and NOS4 lenses were directly active in “decision.”

At this point, it is important to emphasize that the findings of the present study showed that in DM process, NOS lens usages about one aspect can be different from NOS



understandings on that aspect. For example, with Table 5, it is easy to see that U5 did sophisticated NOS6 lens usages in DM process except from during her final decision even though she has unsophisticated understandings about NOS6. Furthermore, it is also understood that NOS6 aspect cannot be visible in the decision of U5."

### 9.3 Other Lens Usages in DM

Except from NOS, some other epistemologies or subgroups of some epistemologies such as religious or personal experience affect DM. In the present study, the term "lenses" was found more suitable as these epistemologies or subgroup of some epistemologies act just as "lenses" on the eyes, which make the issues clearer according to their related perspectives. Moreover, 23 other lenses which affect the DM process were detected (Table 6).

To demonstrate the differences in other lens usages between Group U and Group S better, the following Figs. 9 and 10 were prepared, and with these demonstrations, it is easy to recognize the overall conclusions such as that Group S used other lenses less in each thinking region of DM by comparing the existence of the small triangles in the related thinking region.

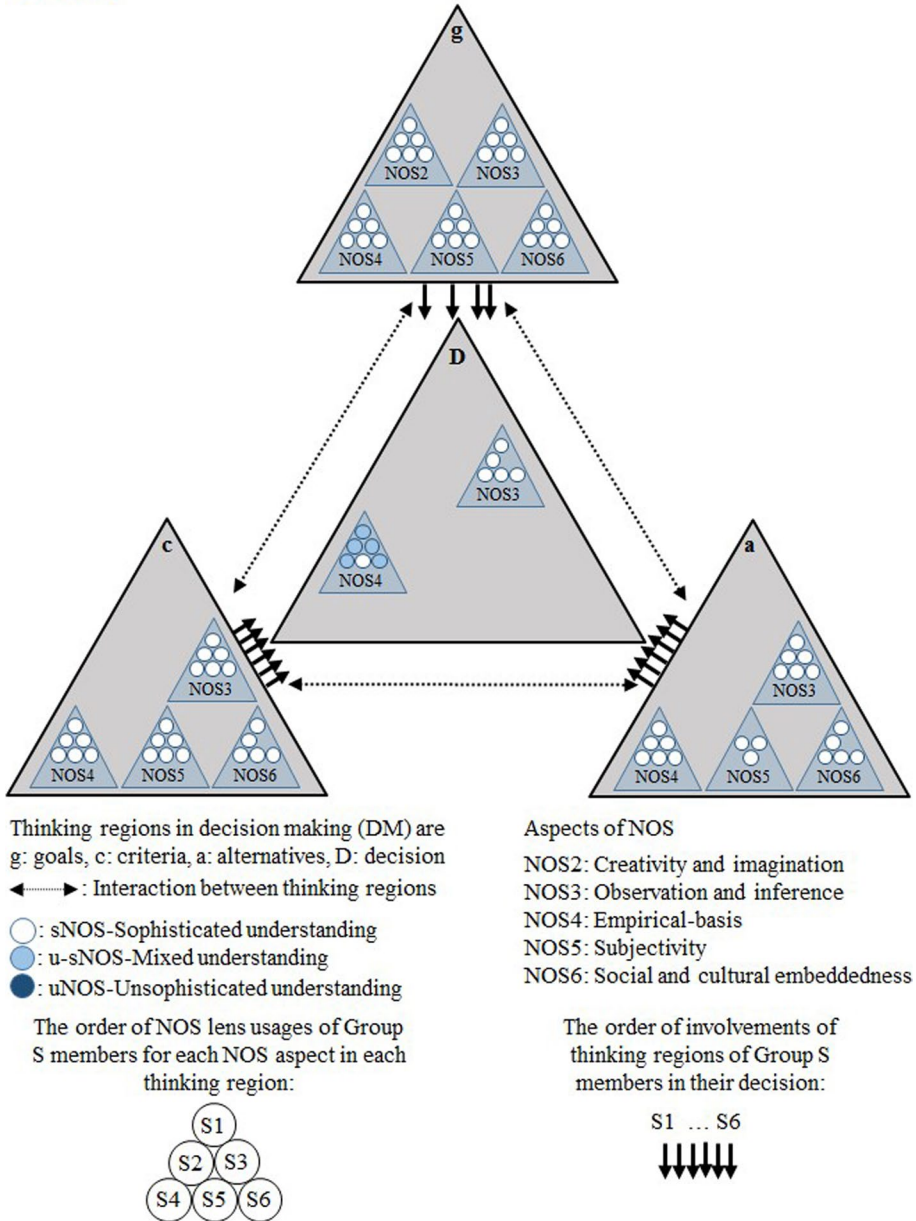
## 10 Discussion

The present study is the first study to focus on the impact of NOS on DM about SSI in a referendum situation, and it tries to answer, depending on their NOS understandings, how people's real DM process about an SSI is. Previous normative models (e.g., Carroll & Johnson, 1990; Ratcliffe, 1997) about DM were not appropriate to reflect the DM in referendum situation because of their linear structure. Therefore, with the findings of the present study, the Fractal Model of DM—reflecting the participants' DM process in a referendum about SSI—was constructed. The Fractal Model of DM states that in the referendum case, the participants thought through three thinking regions, which are "goals," "criteria," and "alternatives." Moreover fourth thinking region "decision" cannot exist by itself but seems to exist through the interactions of "goals," "criteria," and "alternatives." These thinking regions appear simultaneously in the model, which is different from the linear steps in other models, which follow each other one by one.

With the analysis through the Fractal Model of DM, in the present study, it was understood that the focused "goals" and interaction between "goals" and "decision" were different between Group U and Group S in referendum situation about the selling of the artificial meat. Group U focused more on the "goals": "to question the hidden aim" and "to provide everyone with quality, cheap and healthy meat" than Group S did. Although according to Group U, scientific knowledge is absolute and certain, they did not stop questioning the usage of this knowledge, and correlatively, they considered social benefit much more. Moreover, Group S was interested in human prosperity as they focused more on the "goals": "to provide economic development/ to open up new employment opportunities" and "to meet people's increasing needs for meat with the increase in population." Furthermore, two members of Group S did not mention the "goals" in their decisions. Thus, the linkage between the "goals" and the "decision" of Group S was not as strong as that of Group U.

Kortland (1996) stated that the range of the criteria mentioned by 8th grade level students was limited. However, the sample of the present study consisted of pre-service

**GROUP S**



**Fig. 8** The overall demonstrations of Group S for the usage of NOS lenses in DM

science teachers; therefore, to encounter a wide range and highly referred ‘criteria’ in DM on an SSI seemed not surprising. Parallel with Group S’s general attitudes towards human prosperity, all members of Group S thought through the criterion “Economic effects,” but only two members of Group U considered it in DM. Almost all members of Group

**Table 5** NOS understandings and NOS lenses usages relationship in DM process

Issues about NOS	U1	U2	U3	U4	U5	U6	S1	S2	S3	S4	S5	S6
NOS1 understandings	u	u	u	u	u-s	u-s	s	s	s	s	u-s	u-s
NOS1 lens usages in DM without final decision												
NOS1 lens usages in decision	u-s	u-s	u-s	u-s	u-s	u-s	s	s	s	s	s	s
NOS2 understandings	u	s	u	u	u	s	s	s	s	s	s	s
NOS2 lens usages in DM without final decision												
NOS2 lens usages in decision	u	u	u	u	u	u	s	s	s	s	s	s
NOS3 understandings	u	u	u	u	u	u	s	s	s	s	s	s
NOS3 lens usages in DM without final decision												
NOS3 lens usages in decision	u	u	u	u-s	u-s	u-s	s	s	s	s	s	s
NOS4 understandings	s	s	s	s	s	s	s	s	s	s	s	s
NOS4 lens usages in DM without final decision												
NOS4 lens usages in decision	u-s	u-s	u-s	u-s	u-s	u-s	s	s	s	s	s	s
NOS5 understandings	u	u	u	u-s	s	s	u-s	u-s	u-s	u-s	s	u-s
NOS5 lens usages in DM without final decision												
NOS5 lens usages in decision	u	u	u	u	u	u	s	s	s	s	s	s
NOS6 understandings	u	u-s	u	u	u	u-s	s	s	s	s	s	s
NOS6 lens usages in DM without final decision												
NOS6 lens usages in decision	s	s	s	u	s	s	s	s	s	s	s	s

u: Unsophisticated

u-s: Mixed

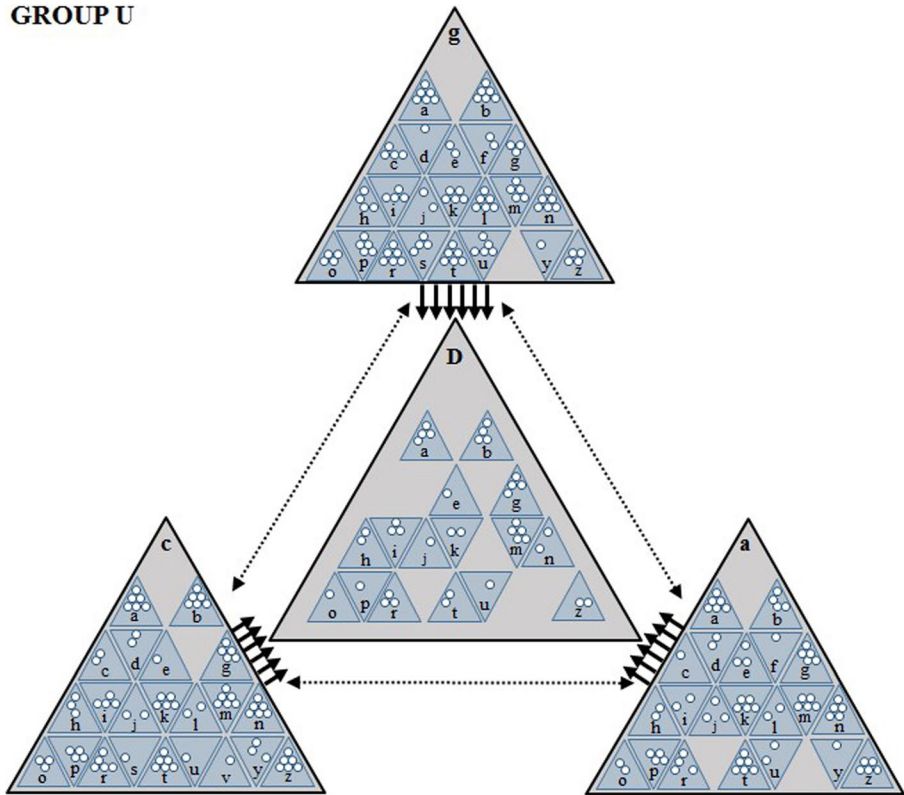
s: Sophisticated

**Table 6** Other lenses usage codes in DM process related with the artificial meat and its alternatives

Lenses	Codes
Animal rights (Moral)	Evaluations through the consideration of whether animals will be hurt or not
Environmental rights (Moral)	Evaluations through environment protection
Humanity (Moral)	Evaluations considering people's health and benefit for people through a large scale "humanity"
Information rights (Moral)	Emphasis made in terms of informing consumers correctly
Natural order (Moral)	Evaluations specifically through the alteration that ecologic or natural order can be exposed to
Curiosity	Evaluations by making emphasis on personal interest areas and curiosity
Prejudice	Judgments formed without basing on enough knowledge and hasty generalizations, e.g., artificial meat has been tested, artificial meat is unhealthy, etc
Priority	Evaluations through personal preference and priority related terms such as artificiality, naturalness, taste, and luxury
Personal experience	Evaluations made by providing examples from family, relatives, friends and personal experiences
Personal experience-lesson	Evaluations by making references to what has been learnt in class
Technology	Technological considerations with evaluations through the validity of production method/process (whether it is applicable in certain aspects or whether it is suitable in certain aspects)
Malicious use	Evaluations by considering the probability of misuse
Risk Factor	Evaluations through the consideration of whether it poses a threat on human health in the short-term and/or in the long-term, in terms of production method, nutritional value, content and being tested
Credibility	Evaluations through highlighting the competence of people or institutions on the related topic
Socio-cultural	Evaluations by drawing attention to Turkish culture, traditions, family and the structure of the society, and local diversities in Turkish culture
Socio-economic	Evaluations through purchasing power such as wealth/poverty or expensiveness/cheapness
Societal benefit	Evaluations based on needs and/or the quality of people's life at a large scale
Religious	Evaluations by highlighting religious belief
Economic	Evaluations through cost, profit-loss, financial development and the emphasis on sectors
Support science	Evaluations through the importance of scientific curiosity, the necessity of scientific development and the feasibility of scientific development in other fields
Pop culture	Evaluations by giving examples from widely known films, cartoons and alike
Legal issues	Evaluations by putting forth the necessity of a state control, legality and permit
Need for more information	Evaluations by making an emphasis on the requirement for more information

U thought about the "Legality" of the artificial meat, while only half of Group S stated "Legality" as a criterion. This situation was also concluded to be related with the differences between the groups in general approaches to society's needs. With unsophisticated NOS1 understandings, Group U generally tried to collect all the information from the texts, but they did not ask for additional research about it. In the informing part, it was stated

**GROUP U**

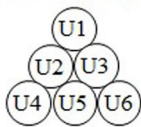


Thinking regions in decision making (DM) are  
 g: goals, c: criteria, a: alternatives, D: decision

◄—►: Interaction between thinking regions

○: Usages of other lenses

The order of lens usages of Group U members  
 for each other lens in each thinking region:



The order of involvements of thinking regions  
 of Group U members in their decision:



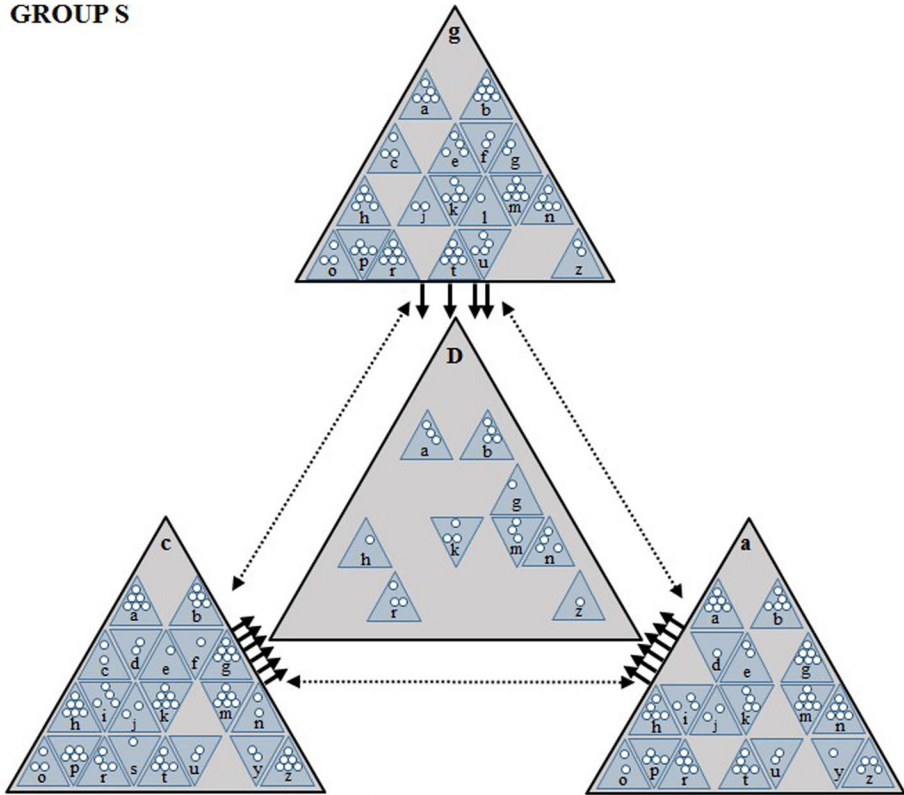
Other lenses represented with small triangles  
 in each thinking region

- |                           |                     |
|---------------------------|---------------------|
| a: Animal Rights          | m: Risk Factor      |
| b: Environmental Rights   | n: Credibility      |
| c: Humanity               | o: Socio-cultural   |
| d: Information Rights     | p: Socio-economic   |
| e: Natural order          | r: Societal benefit |
| f: Curiosity              | s: Religious        |
| g: Prejudice              | t: Economic         |
| h: Priority               | u: Support science  |
| i: Personal experience    | v: Pop culture      |
| j: P. experience (lesson) | y: Legal issues     |
| k: Technology             | z: Need more info   |
| l: Malicious use          |                     |

**Fig. 9** Overall demonstrations for other lens usages of Group U in DM

that the scientists thought that the artificial meat would not give any harm to human health and animals, and therefore unlike Group S, members of Group U did not avoid mentioning “Healthiness” and “Effects on animals” in “decision.”

**GROUP S**

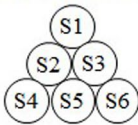


Thinking regions in decision making (DM) are g: goals, c: criteria, a: alternatives, D: decision

◄————►: Interaction between thinking regions

○: Usages of other lenses

The order of lens usages of Group S members for each other lens in each thinking region:



The order of involvements of thinking regions of Group S members in their decision:



Other lenses represented with small triangles in each thinking region

- a: Animal Rights
- b: Environmental Rights
- c: Humanity
- d: Information Rights
- e: Natural order
- f: Curiosity
- g: Prejudice
- h: Priority
- i: Personal experience
- j: P. experience (lesson)
- k: Technology
- l: Malicious use
- m: Risk Factor
- n: Credibility
- o: Socio-cultural
- p: Socio-economic
- r: Societal benefit
- s: Religious
- t: Economic
- u: Support science
- v: Pop culture
- y: Legal issues
- z: Need more info

**Fig. 10** Overall demonstrations for other lens usages of Group S in DM

At the beginning of the interview, the participants tried to load meanings to the artificial meat through the “alternatives.” However, as the DM process proceeded, they started to evaluate the effectiveness of the artificial meat by comparing it with its “alternatives.”

These findings are parallel to Piaget's Theory. According to Piaget, when people meet a new situation, they try to fix the new knowledge to their existing schema, and this helps people to improve existing schemas and to develop new schemas (Erden & Akman, 1995). In the "decision," regardless of which group they are in, all participants focused almost only on two "alternatives," one of which was "Normal meat" and the other was "Animal husbandry," which were the naturally closest alternatives to the artificial meat. Disappearance of the other alternatives in "decision" can be explained as, whether they voted "YES" or "NO," after all informing parts in the interview, the participants thought the artificial meat as a unique product.

No direct lens usages of NOS1 and NOS7 were detected, which is parallel with the studies of Zeidler et al. (2002), Walker and Zeidler (2003), and Sadler et al. (2004). However, although Bell (1999) reached some clues about the fact that some participants' understandings about NOS1 were active in DM, his findings were limited to only 1 of 4 scenarios and with 2 of 18 participants, and this did not affect the participants' decisions (Bell & Lederman, 2003). Moreover, Khishfe (2012) found a better clue for the reflection of NOS1, but the findings came from the treatment group members who were instructed about the application of NOS to DM. Moreover, with the present study, NOS3 lens usages were clearly detected in DM, and this finding is different from all six previous studies, which directly focused on NOS effect on DM about SSI. In addition to this, although NOS5 lens usages were not revealed in the decision itself and although the effectiveness of NOS5 lens was less than NOS3 and NOS4, the deeper analysis gave a clue that it was active in almost all steps of DM for all participants because it may behave as contact lenses on eyes instead of lenses used in eyeglasses. It was concluded that this situation might make it difficult to detect the usage of NOS5 lens, especially in the decision.

Furthermore, it was understood that for all participants, while NOS4 lens was highly active in DM, NOS2 lens was only active in thinking region "goals." The usages of NOS6 lens were sophisticated and very similar in Group U and Group S, although their understandings about this aspect were different from each other. Therefore, it was concluded that as the artificial meat issue was highly socioscientific, it made the participants, even the members of Group U, consider the interaction between the science behind the artificial meat and the society in which the artificial meat is used. It means that the nature of the issue in the referendum, a socioscientific issue-artificial meat, affected the usage of NOS6 lens in the DM. In DM process, in line with their sophisticated NOS understandings, Group S was not always, but mainly made sophisticated NOS lens usage in DM. In the present study, there were no perfect unsophisticated participants in terms of NOS, and therefore it was observed that Group U could make some sophisticated NOS lens usage in DM. However, in some cases, some members of Group U also had NOS lens usages different from their related NOS understandings. With the findings of the present study, it was concluded that for a person, using different NOS lenses in DM from his/her own NOS understandings can exist because the understandings of some NOS aspects can affect the usage of NOS lenses in different aspects, just in the case of Group S, having sophisticated understandings about NOS1 paralyzed the usage of NOS4 lenses or in the case of Group U, having unsophisticated understandings in other NOS aspects may paralyze the usage of NOS2 lenses. Moreover, DM process itself and the nature of the issue of DM process can affect the usage of NOS lenses in DM. With the analysis, it was understood that NOS3 and NOS4 lenses were active in thinking region "decision" for all participants.

The effectiveness of the lenses animal rights, environmental rights, humanity, information rights, curiosity, prejudice, priority, and personal experience (lesson) on DM was identified firstly with the present study, which focused on the artificial meat as a socioscientific

issue. Moreover, most of the other lenses were identified with the present study, such as natural order, personal experience, and socio-economic (Bell & Lederman, 2003; Cebesoy, 2014; Halverson et al., 2009; Lee & Grace, 2012; Sadler & Zeidler, 2004). All the participants used multiple lenses in DM, and these results are in contrast with Kortland (1996), Hogan (2002), and Liu et al. (2010) but in line with Halverson et al. (2009), Lee and Grace (2012), and Cebesoy (2014). According to Bell and Lederman (2003), Sadler and Zeidler (2004), Khishfe (2012), and Cebesoy (2014), the “decision” about socioscientific issue was affected by social considerations and/or moral considerations. In the present study, it was found that the lenses of animal rights, environmental rights, which are related with morality, and societal-benefit which is related with social considerations were used very frequently by both Group U and Group S in not only ‘decision’ but also in the whole DM process about the artificial meat. Furthermore, in the present study, Group S made less usages of other lenses, especially in “goals” and in “decision.” As stated before, the connection between the “goals” and “decision” was not as strong in Group S as in Group U. Therefore, it was seen that these findings support each other. Liu et al. (2010) reported that non-science college students or college students who had tentative beliefs about scientific knowledge tended to consider an SSI with multi-perspective.

## 11 Recommendations

Science teachers are not only ordinary citizens who have the responsibility in SSIs but also the educators who lead students to take responsibility in SSIs. Therefore, a course with explicit instruction which specifically focuses on DM process should be constructed for pre-service science teachers and in-service science teachers; in this way, not only skills about informed DM about SSIs but also skills about making better decisions will improve. Moreover, DM is affected by many epistemologies other than NOS. Explicit NOS instructions, well prepared SSI activities, and even explicit DM instructions may not be sufficient to improve informed DM skills related with SSIs if a well-prepared instruction about epistemologies is not added to them. Being informed about the epistemologies will help students to have control over their DM process more consciously and to re-organize the information when they need it in DM process as they will understand how they are informed in DM process. Furthermore, the K12 science curriculum is the “habitat” for the learning outcomes covering informed DM about SSIs as the core of this issue is dependent vitally on NOS. On the other hand, as SSIs cover many more epistemologies, supports from other disciplines such as language lessons (Turkish, English etc.), social science lessons, and information technologies lessons are also essential. Therefore, curriculum developers should make connections among disciplines with clear learning outcomes about SSIs by considering the general conditions of the classrooms. Moreover, the present study shows that there was a hidden and complex effect of the understandings about the NOS aspect “tentativeness of scientific knowledge” on DM. In the lessons of all disciplines at all levels, it would be better if the tentativeness of scientific knowledge is emphasized more with the concepts “scope and comparison” through the validity and reliability of the scientific knowledge, which helps the students understand and handle circumstances of SSIs more consciously.

In the present study, with the analyses of the responses of pre-service science teachers during a DM simulation of an SSI, the Fractal Model of DM was constructed to express the real DM process of ordinary citizens about an SSI. To better understand how the real DM



process is for a wider population, firstly, more studies about DM on SSI covering especially K12 students should be done by considering the findings of previous DM studies and the Fractal Model of DM. Moreover, not only in pre-service science education but also in K12 education and in-service science education, the DM on SSI simulations should be conducted through the Fractal Model of DM by considering the participants' true interests in that SSI. With the analysis through the Fractal Model of DM, it will be understood how sophisticated decisions about SSIs were made by a person or group of people in terms of NOS and other lenses. Furthermore, with the Fractal Model of DM, the pools of "goals," "criteria," and "alternatives" in DM processes about SSIs will be visible with the interactions among them. Therefore, it will be possible to identify particular goals, criteria, and alternatives which directly shape that "decision." In this way, the framework of a decision will be revealed, and then, making some valid inferences about the efficiency of a decision will be possible even before the application of the decision. Thus, the DM simulation about an SSI through the Fractal Model of DM will serve as a meaningful medium to discuss the decision, which is thought to be important to increase the possibility of making better decisions for further SSIs.

**Author Contributions** 1. Conception or design of the work: Author 1 & Author 2.  
2. Data collection: Author 1  
3. Data analysis and interpretation: Author 1 & Author 2  
4. Drafting the article: Author 1  
5. Critical Revision of the article: Author 2  
6. Final approval of the version to be published: Author 1 & Author 2

**Data availability** All relevant data can be provided on request by corresponding author.

**Code Availability** All relevant codes explaining the relevant data are stated in the article, and corresponding author can provide more information about codes when it is needed.

## Declarations

**Ethics Approval** This study was approved by Applied Ethics Research Center of Middle East Technical University Ankara/TURKEY. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Consent to participate** Informed consent was obtained from all individual participants in the study.

**Consent for Publication** I, Elif Ece Adal, hereby declare that I participated in the study and in the development of the manuscript titled (INVESTIGATION OF PRESERVICE SCIENCE TEACHERS' NATURE OF SCIENCE UNDERSTANDING AND DECISION MAKING ON SOCIO SCIENTIFIC ISSUE THROUGH THE FRACTAL MODEL). I have read the final version and give my consent for the article to be published in Science and Education.

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

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